CALIFORNIA LETTUCE RESEARCH BOARD

Title: Project title: Evaluation of best management irrigation and nutrient best management practices (BMP) and treatment of nitrate in tile and surface water to safeguard water quality

Project Investigators: Richard Smith, and Mike Cahn, UCCE, Monterey County
Tim Hartz, University of California, Davis

SUMMARY

The new regulations passed by the Central Coast Regional Water Quality Control Board are compelling growers to evaluate nitrogen fertilizer applications to leafy vegetables and explore strategies make nitrogen applications more efficient. This project evaluated aspects of nitrogen use efficiency and management as well as techniques to reduce nitrate loss from production fields:

1. Treatment of tile drain and surface water to remove nitrate with denitrification bed reactor and nitrate selective resins: These results indicated that bioreactors can provide stable nitrate reduction of tile drain water over multiple years. Preliminary economic analysis suggested that bioreactor construction and operating costs to be between $1.50-2.50 per pound of NO_3-N denitrified, depending on the assumptions made about performance.

2. Document 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: The results of the 2 field trials demonstrated that ambient N in irrigation water has fertilizer value for shallow rooted vegetable crops such as lettuce, even when the N concentration in the water was low (< 20 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. Also, the volume of water applied affected the recovery rate of N, suggesting that all water applied containing N had fertilizer value to the crop.

3. Nitrogen credit for mineralization of nitrogen from prior crop: Net N mineralization from residue was rapid in the initial 2 weeks of incubation, averaging 44% of initial residue total N content. After 8 weeks of incubation an average of 65% of initial residue total N content had been mineralized, ranging across soils from 80% for spinach to only 52% for head lettuce.

4. Evaluation of fertilizer technology to improve nitrogen use efficiency: The controlled release fertilizer, D45 and the nitrification inhibitor, Super U (urea + DCD) gave improved yields over the standard treatment in one trial on spinach. The method of application of the fertilizer technology materials affect their efficacy.

5. ***Provide direct assistance to leafy green growers on improving irrigation and N fertilizer management:*** After 2 years of development, we formally announce the availability of this web-based tool to the vegetable growing community and offer trainings on using the software in March 2013. Funding from the CLGRB was used to provide direct assistance to at least 5 growers to implement the use of the quick nitrate test and weather based irrigation scheduling.

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Title: Evaluation of best management irrigation and nutrient management practices (BMP) and treatment of nitrate in tile water to safeguard water quality

Project Investigators: Richard Smith, and Mike Cahn, UCCE, Monterey County
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Objectives: To evaluate and demonstrate nitrogen and irrigation management in commercial lettuce production

PROCEDURES AND RESULTS:

Evaluations to improve nitrogen use efficiency:

1. Treatment of tile drain and surface water to remove nitrate with denitrification bed reactor and nitrate selective resins

Reduction in NO_3-N loss in surface runoff and tile drain effluent from lettuce fields may be possible through modification of irrigation and fertilization practices. However, consistent compliance with the 10 PPM NO_3-N regulatory target for surface water listed in the Ag Order will not be possible by modification of production practices alone. Additionally, the ongoing Federal Total Maximum Daily Load (TMDL) process for the Salinas, Pajaro and Santa Maria Rivers may require even more stringent NO_3-N standards, and will introduce numerical standards for PO_4-P as well. Even if ideal production practices are used, some remediation technique will be needed to even approach these concentration-based standards.

2013 evaluations included operation and sampling at all three bioreactor sites. Samples were collected once per week during the winter (tile drain sites only) and twice per week during the production season (all sites). At the tile drain bioreactors all samples were analyzed for NO_3-N, with periodic analysis for NO_2-N and dissolved organic carbon (DOC). At the surface runoff bioreactor all samples were analyzed for NO_3-N and PO_4-P, with periodic analysis for NO_2-N, DOC and sediment content. Work on the anion resin approach depended on whether the consultant succeeds in his goal of installing a prototype system on a tile-drained Salinas Valley farm by the summer of 2013. He did not get his unit installed in time for evaluations during this work cycle.

2. Document 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

Field trials (spring and summer crops) were conducted on the USDA Spence research facility near Salinas in 2013 to address objective 2. 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. 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). Water-powered proportional injectors were used to enrich all drip applied water to the target concentrations of treatments. 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

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 ET treatments. In both trials soil samples were 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 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. The 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. N recovery from irrigation water N was 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 was calculated by comparing the uptake of N to the total amount of N applied to the crop through the irrigation water.

3. Nitrogen credit for mineralization of nitrogen from prior crop

A second year of studies on the mineralization of nitrogen from incorporated crop residues was conducted on coastal district soil types and three residue types: lettuce (head and romaine), cole crops (broccoli and cauliflower) and spinach. Fresh residues was collected from fields during harvest and will be chopped and mixed with 500 grams of soil that was wetted to field capacity (10-20 cbars) and incubated at 70 F for 8 weeks. Soil samples were collected at two week intervals and total mineral nitrogen (nitrate and ammonium) was extracted from the soil. The quantity of tissue included in incubation chamber was calculated to provide 150-200 ppm of N in order to be able to effectively measure an elevation in the level of background mineralization from soil organic matter. An unamended sample of each soil was included in the incubations to provide a measure of background levels of nitrate mineralization.

4. Evaluation of fertilizer technology to improve nitrogen use efficiency

The fertilizer technologies, nitrification inhibitors and controlled release fertilizers, were evaluated on lettuce and spinach. The lettuce trial was conducted at the USDA Spence Research Station. A cereal cover crop was grown and removed to draw down residual soil N. The D45 treatments were applied to the top shaped beds on June 11; the beds were mulched with a power mulcher to incorporate the material on the same day. The romaine variety Green Forest was seeded on June 12 and 1.0 lb a.i./A of Kerb and the anti-crustant 7-7-0-7 was applied at the rate of 35 gallons/A (25 lbs N/A) were applied on June 13. The first water was applied on June 14. Each plot was 2 40-inch beds wide by 150 feet long and replicated 4 times in a RCBD. The soil type was Chualar loam. The field was sprinkler irrigated until thinning and then was irrigated with drip for the rest of the growth cycle. First and second sidedress of the liquid fertilizer treatments were injected into the drip irrigation system by use of a multi-port manifold with backflow prevention valves which fed two inch layflat that provided water and fertilizer for each treatment (Table 1). Injector ports in each layflat were used to inject the appropriate rate of UAN 32 liquid fertilizer. Battery powered pumps were used to inject fertilizer/nitrification inhibitors mixtures into the layflat and injections were made during the middle third of irrigation events. Irrigation levels were managed at 152% of ET. Treatments were evaluated for soil nitrate weekly, and total nitrogen content at harvest. Nitrate leaching was conducted in each plot by sampling down to three feet at the beginning of the cropping season to establish the baseline levels and at the end of the cropping season.

The treatments include an untreated control and a standard N treatment (155 lbs N/A). In addition there is a moderate N treatment (105 lbs N/A). This moderate N treatment is designed to not supply sufficient N to maximize yield; the fertilizer technology treatments are applied at the moderate N level to evaluate if they are capable of boosting the yield of lettuce by increasing the NUE of applied N. Fertilizer technology materials evaluated include nitrification inhibitors (Agrotain Plus and nitrapyrin) and controlled release fertilizers (D45 and NSure). Lettuce was grown with each of these treatments and evaluated for N uptake and yield.

Spinach evaluations were conducted with cooperating growers on commercial spinach production fields. Two trials were conducted south of Castroville and one in King City. Each plot was one 80-inch bed wide by 15 feet long with four replications and laid out in a randomized complete block design. The following fertilizer technologies were tested: nitrapyrin (Instinct – Dow AgroSciences), D45 (Agrium), N-Sure (Tessenderlo Kerley), Super U (Koch Industries). The material were applied at planting. Soil nitrate levels were measured weekly and total biomass N and yield were measured at the end of the growth cycle by conducing evaluations of 0.5 m2 areas in each plot.

Location	**Planting date**	**Variety**	**Soil type**	**Harvest date**
Castroville1	April 12	Violin	Clear lake clay	May 15
Castroville 2	May 6	Missouri	Diablo clay	June 5
King City	Sept 12	Silver Whale	Cropley silty clay	October 27

5. *Provide direct assistance to leafy green growers on improving irrigation and N fertilizer management*

After 2 years of development, we formally announced the availability of this web-based tool to the vegetable growing community and offer trainings on using the software in 2013. Funding from the CLGRB was used to provide direct assistance to at least 5 growers to implement the use of the quick nitrate test and weather based irrigation scheduling. CropManage was used to facilitate timely recommendations on the irrigation volumes and fertilizer N rates to growers and provide a means to maintain and share records of demonstration fields. In addition, we conducted 3 strip trials comparing yield under the grower standard irrigation or nitrogen fertilizer practice with the CropManage recommended practices. Strips of each treatment would be the width of a harvester so that they can be commercially evaluated.

RESULTS

1. Treatment of tile drain and surface water to remove nitrate

The three denitrification bioreactors built in previous years were operated throughout the 2013 production season. The bioreactors treating tile drain effluent (sites 1 and 2) showed summer denitrification rates of approximately 8-9 PPM NO_3-N reduction per day of residence time, similar to rates observed in 2011 and 2012 (Fig. 1). Winter denitrification rates averaged approximately 5 PPM NO_3-N per day of residence time during 2011-12 and 2012-13; lower winter rates were undoubtedly due to lower water temperature. The site 3 bioreactor (treating surface runoff) averaged about 10 PPM NO_3-N reduction per day of residence time, again similar to that documented in 2012 after the initial 'break-in' period when the higher carbon availability of fresh wood chips gave higher denitrification rates.

In bioreactor research conducted throughout the world, wood chip bioreactors have been shown to be carbon-limited (the rate of denitrification being limited by the microbial availability of carbon). To test whether our bioreactors were carbon-limited, we injected methanol (a soluble, easily degradable carbon source widely used in municipal water treatment) into the bioreactors at site 1 and 2 during alternate months in 2013. The injection of approximately 20 PPM C from methanol increased denitrification by more than 40% at both sites, confirming carbon limitation. PO_4-P concentration in surface runoff was relatively high at site 3, typically ranging between 0.4-0.8 PPM. Alum (aluminum sulfate) pre-treatment reduced PO_4-P by > 50%. With or without alum pre-treatment, PO_4-P was further reduced in the bioreactor, presumably due to denitrifying bacteria assimilating PO_4-P into their biomass. The PO_4-P concentration in tile drain effluent at sites 1 and 2 was much lower than surface runoff, typically ranging between 0.05-0.3 PPM (frequently above an environmentally desirable level of <0.1 PPM). Bioreactor treatment alone (no alum pretreatment) reduced PO_4-P by > 50% on average.

These results indicated that bioreactors can provide stable performance over multiple years. Preliminary economic analysis suggested that bioreactor construction and operating costs to be between $1.50-2.50 per pound of NO_3-N denitrified, depending on the assumptions made about performance, land value, system longevity, etc. Given the carbon limitation of wood chip bioreactors, and the relatively high NO_3-N load in tile drain and runoff water, the physical footprint of a bioreactor would have to be relatively large to denitrify a substantial portion of wastewater NO_3-N. Also, wastewater NO_3-N concentration at any site can vary widely over time, meaning that a bioreactor of a fixed size would be unable to achieve a consistent degree of remediation. If it could be done economically, soluble C augmentation could reduce the required size of a bioreactor, and allow adjustment for changing wastewater NO_3-N concentration. To that end we constructed six laboratory-scale wood chip bioreactors at UC Davis continued to study soluble C enrichment.

NO_3-N solution was continuously injected into three of the laboratory bioreactors, while the other three reactors received the same NO_3-N solution plus varying concentrations of methanol equivalent to 40-100 PPM carbon. After several days equilibration at each C concentration, effluent samples were measured daily for NO_3-N concentration. C enrichment became increasingly efficient as the C injection rate increased (Fig. 2), reaching a ratio of approximately1.3 mg C per mg NO_3-N denitrified. This increasing efficiency with increasing C enrichment rate has profound economic implications, and suggests that a small bioreactor using C enrichment may be both more practical and more economical than a large reactor operated without C enrichment. We are currently investigating the use of industrial grade glycerin as a C enrichment material. Glycerin is a byproduct of biodiesel refining, and may be a more economical C source than methanol; it is also non-flammable, and therefore has fewer safety issues for on-farm storage. Glycerin enrichment will be tested at the Site 1 bioreactor in summer, 2014.

The use of anion resins for removal of NO_3-N from tile drain water was investigated. We assisted Paul Wegner, a private consultant, on a project to develop a prototype resin treatment system. This system has only recently been installed on a commercial farm in the Salinas Valley, and no performance data is yet available. In laboratory tests at UC Davis, nitrate-selective anion resins from several companies were evaluated and shown to efficiently remove NO_3-N from water with a typical tile drain anion composition. However, in initial tests we were unable to develop a resin regeneration process of sufficient efficiency to make it a practical means of NO_3-N remediation. Given the promise shown by the laboratory bioreactor C enrichment study we terminated the laboratory resin evaluation.

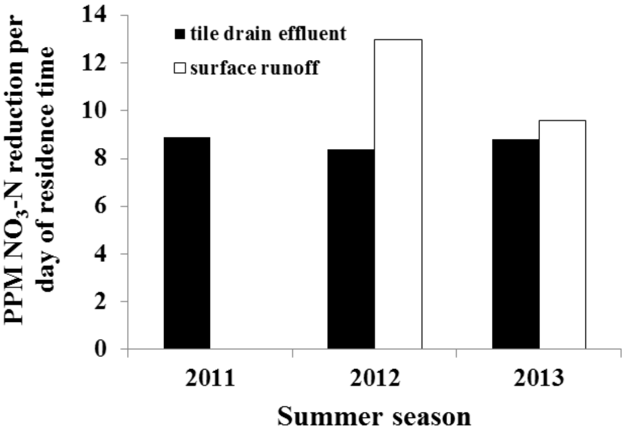

Fig. 1. Mean reduction in NO_3-N concentration per day of bioreactor residence time; values for tile drain effluent are averaged across sites 1 and 2.

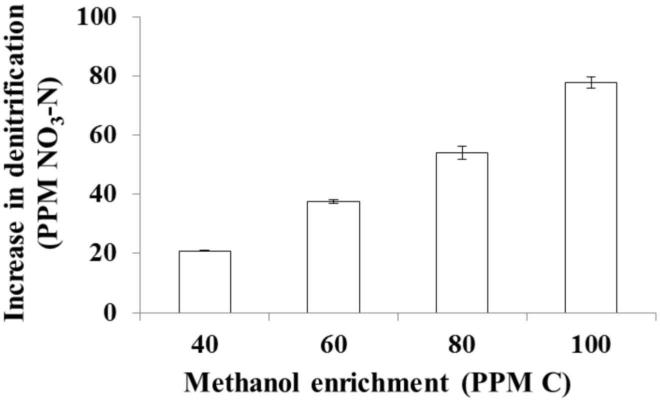

Fig. 2. Effect of methanol enrichment on denitrification in laboratory bioreactors; bars indicate standard error of measurement.

2. Document 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

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 1 and 2, Figs. 1 and 2), 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 1 and 2), indicating that the fall crop was taking up N but was growing 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, demonstrating 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. 1-2. Although the N rate of the fertigation treatments were higher than the N rates of the water treatments, the data from all 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 N 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 (Fig. 3). Crop recovery of N from the water treatments averaged 86% during the summer and 41% 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 (Fig. 4).

The concentration of ambient N in the irrigation water had minimal effects on the residual N levels in the soil after harvest of the summer trial (Table 3). Also the volume of water applied did not affect soil nitrate concentration in the soil measured after harvest of the summer trial (Table 4). Similar results were measured for the fall harvested trial. However, significant differences in soil mineral N concentration were measured among treatments in the 0-1 foot layer 2 weeks before harvest of the fall trial. Irrigation water treatments with higher concentrations of ambient N resulted in higher soil N levels (Table 5).

The results of the 2 field trials demonstrated that ambient N in irrigation water has fertilizer value for shallow rooted vegetable crops such as lettuce, even when the N concentration in the water was low (< 20 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. Also, the volume of water applied did the affect the recovery rate of N, suggesting that all water applied containing N had 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 (eg. furrow), recovery of N would be less than was reported in these trials. The 2nd year of trials will allow us to evaluate if giving full fertilizer credit to the N in the irrigation water can reliably reduce fertilizer N rates without affecting yield.

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

Irrigation water treatments	Applied N Irrigation water	 Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N upake
	--- 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

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

	Applied N					
Irrigation water treatments	Irrigation water	Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N upake
	-------- 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

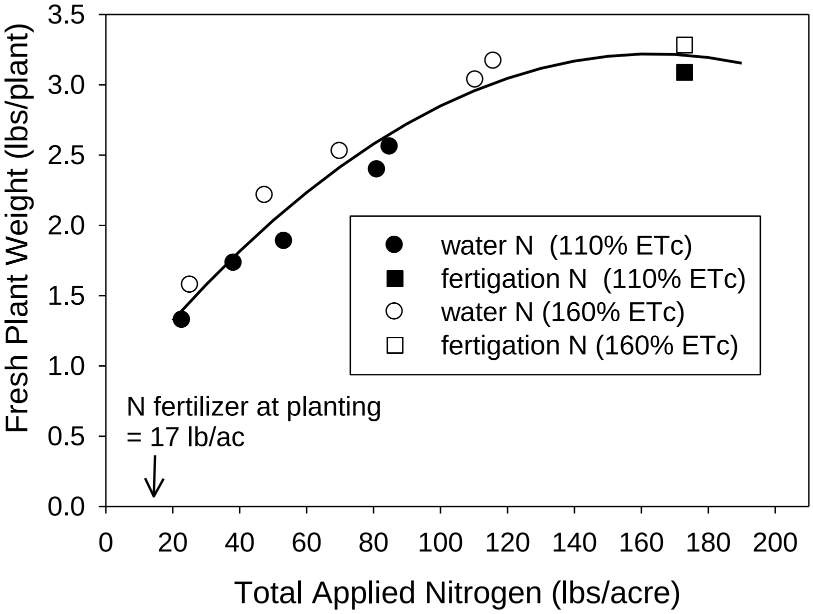

Figure 1A. Effect of applied nitrogen on fresh weight of plants (trial 1, summer harvest).

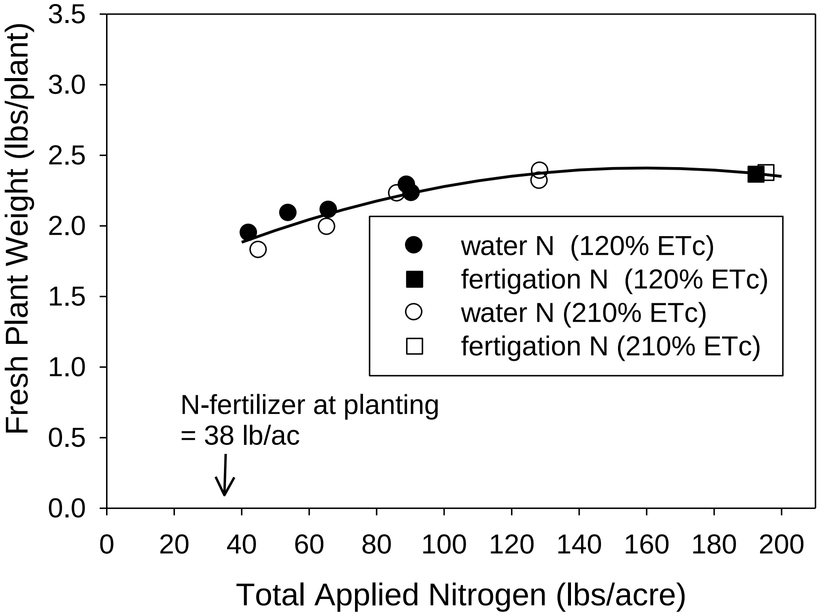

Figure 1B. Effect of applied nitrogen on fresh weight of plants (trial 2, fall harvest).

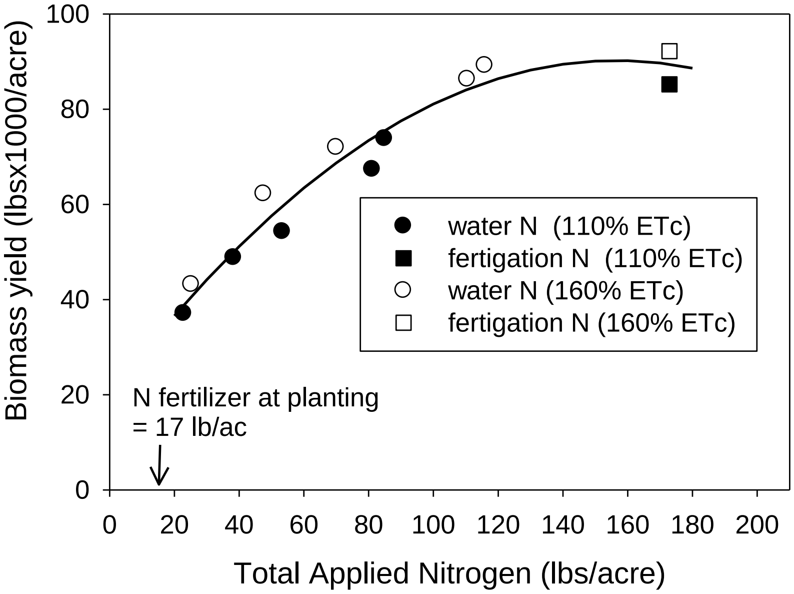

Figure 2A. Effect of applied nitrogen on biomass yield (trial 1, summer harvest).

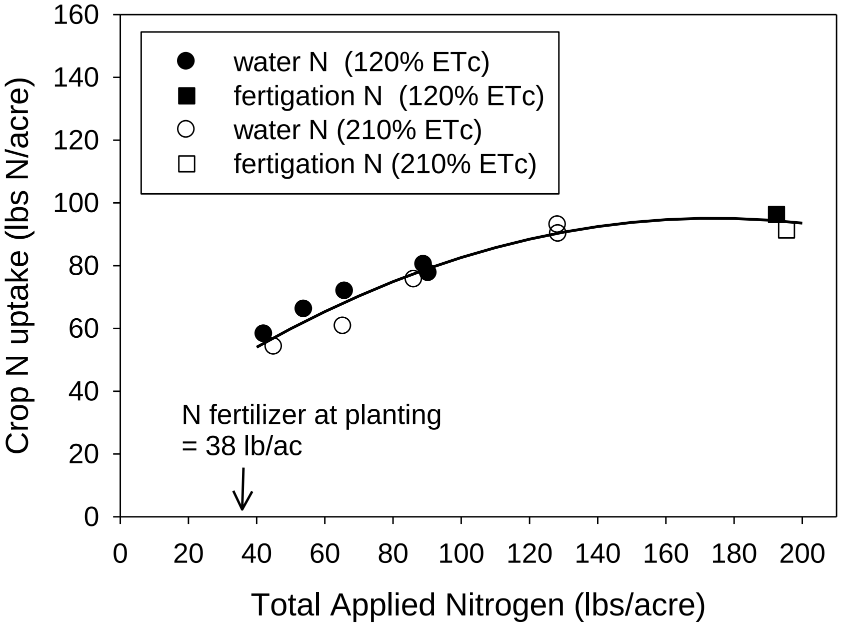

Figure 2B. Effect of applied nitrogen on biomass yield (trial 2, fall harvest).

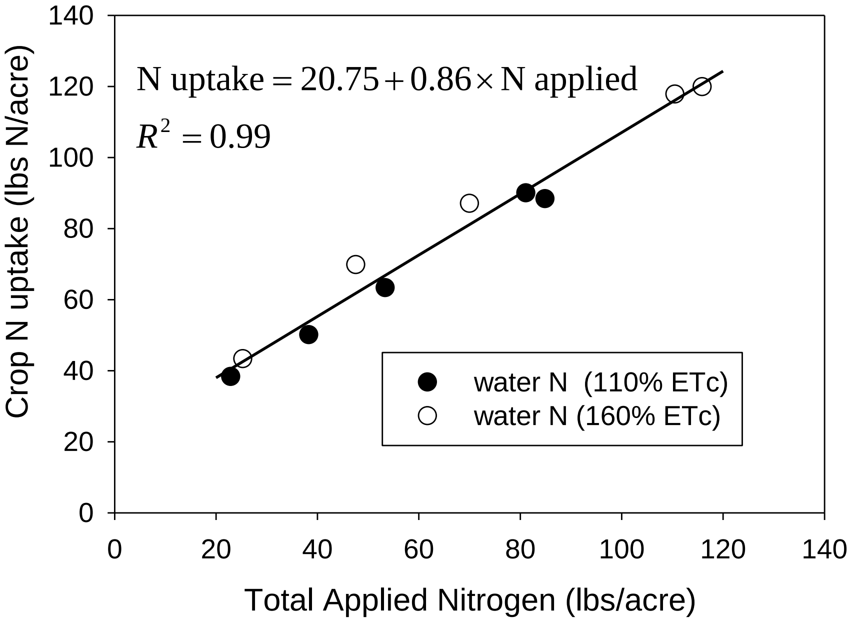

Figure 3A. Effect of applied nitrogen in water treatments on crop N uptake (trial 1, summer harvest).

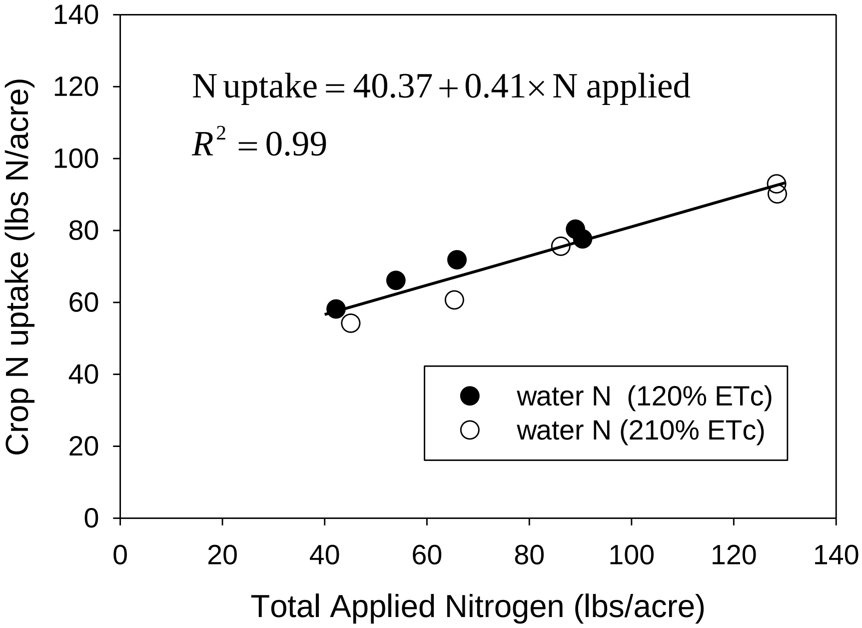

Figure 3B. Effect of applied nitrogen in water treatments on crop N uptake (trial 2, fall harvest).

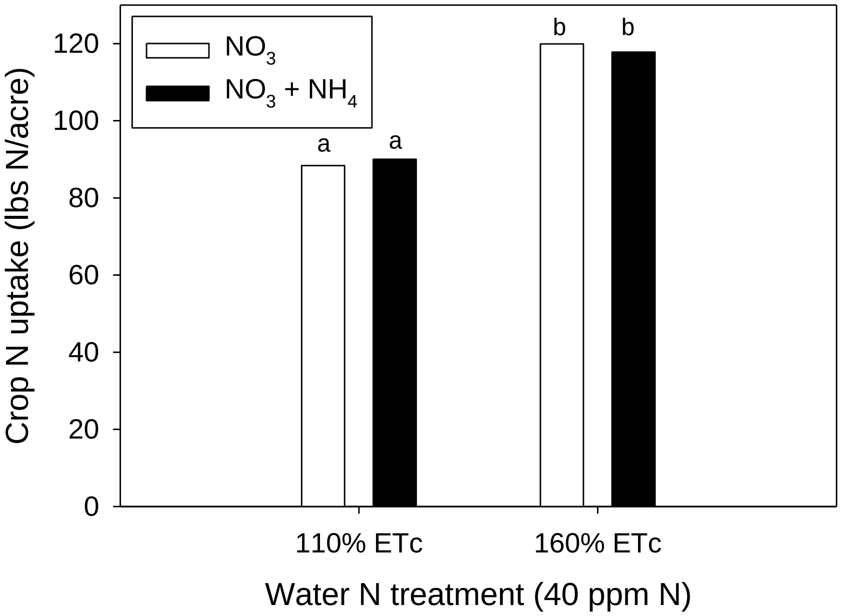

Figure 4A. Effect of 40 ppm NO_3-N and NO_3+NH_4-N water treatments on crop N uptake (trial 1, summer harvest).

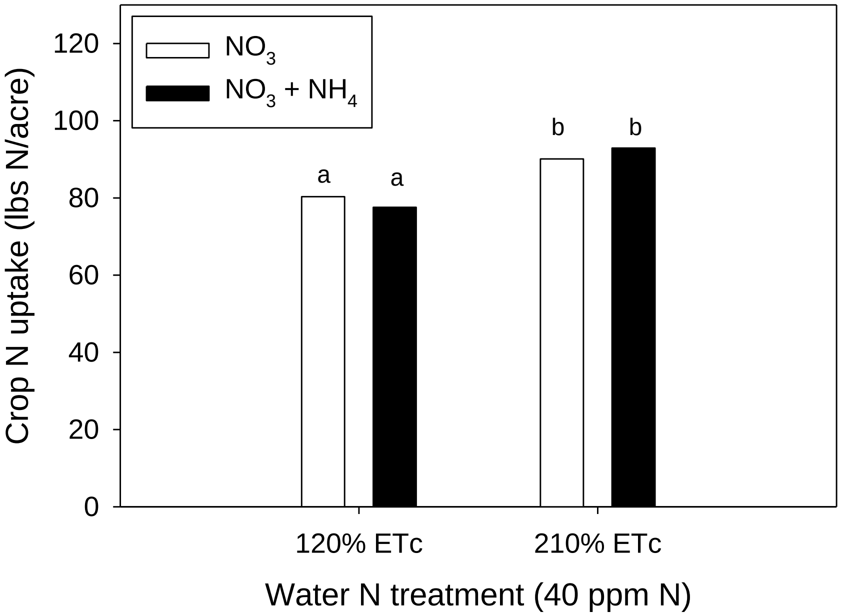

Figure 4B. Effect of 40 ppm NO_3-N and NO_3+NH_4-N water treatments on crop N uptake (trial 2, fall harvest).

Table 3. Soil mineral N of ambient N treatments after harvest of the summer trial.

#	Nitrogen Treatment	depth	NO_3-N	NH_4-N	Total N
		feet	----------	ppm	-----------
1	Unfertilized Control	1	1.2	8.4	9.6
		2	0.9	6.0	6.9
		3	0.8	3.9	4.7
2	Fertilized standard (172 lbs N/A)	1	1.0	3.0	3.9
		2	0.7	2.5	3.2
		3	0.7	3.2	3.9
3	10 PPM NO3-N	1	1.1	3.5	4.6
		2	0.8	1.9	2.7
		3	0.7	2.1	2.8
4	20 PPM NO3-N	1	1.0	4.0	5.0
		2	0.8	3.7	4.5
		3	0.7	3.2	4.0
5	40 PPM NO3-N	1	1.0	2.9	3.9
		2	0.7	1.9	2.6
		3	0.7	1.6	2.4
6	40 PPM N (Ammonium + nitrate)	1	1.0	4.4	5.3
		2	0.8	4.2	5.0
		3	0.7	2.4	3.1

Table 4. Soil mineral N of water volume treatments after harvest of the summer trial.

Irrigation Treatment	depth	NO3-N	NH4-N	Total N
		----------	ppm	-----------
110% of Crop ET	1	1.1	5.8	6.8
	2	0.8	4.5	5.3
	3	0.7	3.1	3.8
160% of Crop ET	1	1.0	2.9	4.0
	2	0.7	2.2	2.9
	3	0.7	2.4	3.1

Table 5. Average soil mineral N values for the 0 to 1 foot depth of the ambient N treatments of the fall harvested trial, sampled on October 17, 2014.

#	Treatment Description	NO_3-N	Mineral-N NO_3-N+NH_4-N
		-------- ppm	--------
1	Unfertilized control (2 PPM NO3-N)	4.5	5.5
2	Standard Fertilizer (150 lb N/Acre)	17.3	18.3
3	12 PPM NO_3-N in irrigation water	8.7	9.7
4	22 PPM NO_3-N in irrigation water	5.1	6.1
5	42 PPM NO_3-N in irrigation water	12.0	13.0
6	42 PPM N (NO_3+NH_4)	12.0	13.3
$LSD_{0.05}$		6.8	6.8

3. Nitrogen credit for mineralization of nitrogen from prior crop

Soil was collected from two Salinas Valley vegetable fields (a sandy loam and a clay), air-dried and screened through ¼" mesh. Crop residue from Salinas Valley fields was collected from one field of each of these crops: broccoli, cauliflower, celery, head lettuce, romaine, and spinach. Residues were collected around 1 August, transported to UC Davis and kept refrigerated at 5 C until 6 August. On that day residue was finely chopped, and a subsample of each residue was oven-dried to determine dry matter percentage. The broccoli residue was split into leaf and stem portions. Fresh chopped residue was mixed with both soils at a rate estimated to add approximately 100 PPM N to the dry soil. The soils were then wetted to equal 50% water filled pore space (including the water content of the residue), approximating field capacity moisture content. The soil/residue blends, and unamended soils, were placed in sealed plastic containers and incubated at a constant 20^o C (68^o F) for 8 weeks; there were 4 replicate containers per soil/residue blend. After 2, 4, 6 and 8 weeks of incubation a subsample was removed from each container, extracted with 2N KCl, and analyzed for mineral N content (NH_4-N and NO_3-N). The increase in mineral N in residue-amended soil, minus the increase in unamended soil, was assumed to represent net N mineralization from the residue. Dry residue tissue was analyzed for total N content, and the net N mineralization was calculated as a percentage of initial residue total N content.

Net N mineralization from residue was rapid in the initial 2 weeks of incubation, averaging 44% of initial residue total N content. Some of these residues contained a substantial amount of mineral N initially (predominately NO_3-N, Table 1), so an average of only 31% of organic N was mineralized over that period. The rate of continuing net N mineralization slowed after 2 weeks (Fig. 1). After 8 weeks of incubation an average of 65% of initial residue total N content had been mineralized, ranging across soils from 80% for spinach to only 52% for head lettuce. Soil type had minimal effect on residue N mineralization.

The practical implication of these data is that vegetable crop residue will typically be of sufficiently high N concentration to exhibit rapid N mineralization after soil incorporation, and that this rapid mineralization phase is of short duration (2-4 weeks). Thereafter, N mineralization continues, but at a much slower pace, and the additional contribution to the N supply of the subsequent crop will be modest. Since the period between residue incorporation and in-season N fertilization of the subsequent crop is usually more than 4 weeks, soil NO_3-N analysis prior to in-season fertilization will measure most of the net N contribution of prior crop residue.

Table 1.Crop residue N content and net N mineralization after 8 weeks of incubation at 68 F.

Residue type	Total N concentration (% of dry matter)	% of initial N content in mineral form	Net N mineralization after 8 weeks (% of initial total N content) sandy loam soil	clay soil
broccoli leaf	4.0	23	63	66
broccoli stem	3.4	31	66	63
cauliflower	2.9	7	68	77
celery	2.9	21	68	61
head lettuce	3.2	8	52	51
romaine	3.4	26	57	56
spinach	6.2	20	82	78
average			65	65

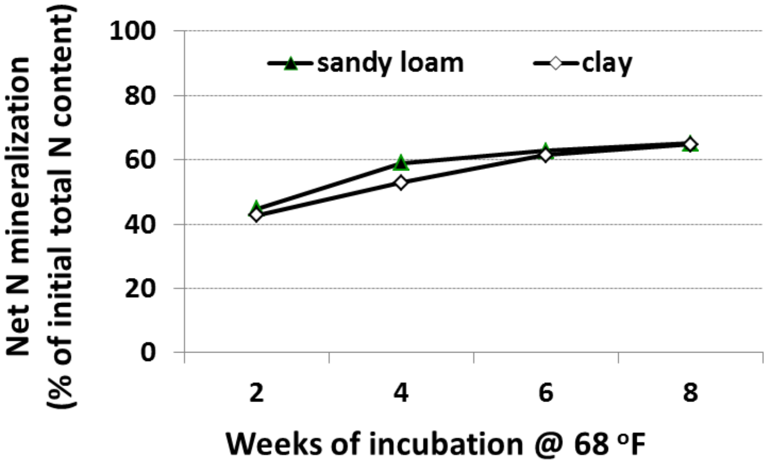

Fig. 1. Effect of soil type and length of incubation on net N mineralization, averaged across residue types.

4. Evaluation of fertilizer technology to improve nitrogen use efficiency

Lettuce Evaluation: Table 1 shows the nitrogen technology materials and rates of each applied in this trial. A suboptimal nitrogen rate (105 lbs N/A) was used to see if the nitrogen technology materials could provide a boost in yield. Unfortunately, in 2013 the difference between the suboptimal and optimal (155 lbs N/A) was not a large as we have observed in the past which made it difficult to observe any yield boost from the nitrogen technology materials. Irrigation water was applied at 152% more than crop demand (ET) in order to purposely test whether the various fertilizer technologies were capable of reducing nitrate leaching by reducing the pool of nitrate in the soil. Soil nitrate levels were 6.37 ppm NO_3-N in the trial area early in the crop cycle (June 20). The one foot soil nitrate values on July 19, 26 and August 7 have a great deal of variability (Table 2) making it difficult to observe differences among treatments. The D45 and ESN treatments had high nitrate on July 19, 26 and August 7 evaluations dates, probably due to the way the prills were applied and mulched throughout the bed making it difficult to avoid hitting them while soil sampling. By August 15 (2 days after harvest) the soil nitrate values had declined to low levels in all treatments. A similar trend is observed in the soil ammonium levels especially in the D45 and ESN treatments (Table 3). There was a large response to applied N in the trial (Table 4). The standard treatment gave the highest yield followed by the nitrapyrin @ 0.5 lb a.i./A applied with 155 lbs N/A and NSure @ 105 lbs N/A. There were no statistically significant differences in yield or mean head weight between the standard, moderate, NSure and nitrapyrin treatments (Table 4). There was greater N uptake in the standard and nitrapyrin @ 155 lbs N/A treatments over the moderate treatment. There was a trend of increased N uptake in the Agrotain Plus, NSure and nitrapyrin @ 105 lbs N/A treatments over the moderate treatment and it may be that N uptake was the most sensitive measure to detect differences between treatments in this trial. D45 and ESN did not perform well in this trial which may indicate that the application method was not appropriate for this material. The soil samples take to three feet deep at the end of the crop cycle indicate that D45 did not reduce nitrate leaching to three feet in the soil (Figure 1). Nitrapyrin had lower soil nitrate levels deeper in the soil profile, giving some evidence that perhaps this material reduced nitrate leaching to deeper in the soil profile. The bottom line is that the application method of the D45 and the nitrapyrin may not have been appropriate for the optimal functioning of these materials. D45 incorporated into the bed with the bed mulcher may not distribute the material thoroughly into the bed. By the same token, injection of nitrapyrin with the drip water has not been tested with this material. These preliminary results indicate that it may not be efficacious.

Spinach Evaluations: The same materials tested in the lettuce were tested on spinach. These materials were compared with a standard application of ammonium sulfate. Three trials were conducted on commercial farms (north and south county) and each material was applied as 2-3 rates (Tables 5,6 &7). The goal was to examine the efficacy of these materials for use on spinach which is a fast growing crop grown on high-density beds that is sensitive to nitrogen (N) deficiency. In general, the results were inconsistent in 2013; D45 and Super U applied at 120 lbs N/A gave yields equal to the standard treatment of 160 lbs N/A in one trial (Table 5) but not in the other two trials (Tables 6, 7 & 8). There were indications that some materials maintained greater levels of available ammonium and/or nitrate in the soil over the course of the growing season. Bottom line is that NSure had low yields in each trial; D45 and Super U gave improved yields over the standard treatment in one trial. Nitrapyrin in these trials did not give improved yields over the standard and the method of application of this material (sprayed onto the soil surface following spreading ammonium sulfate on the soil, and followed by mulching) may dilute this material too much and may not be the best application method. Also power incorporation of D45 prills into the beds may have the potential to break the plastic coating thereby destroying the ability of the material to control the release of N.

Table 1. Lettuce Trial. Application timing, dates and rates (lbs N/A)

Material	Preplant Lbs N/A June 11	Anticrustant 7-7-0-7 June 12	First fertigation July 10	Second fertigation July 22	Total N/A	Mode of action by the fertilizer additive
Untreated	0	25	0	0	25	---
155 (Standard)[1]	0	25	65	65	155	---
105 (Moderate)[1]	0	25	40	40	105	---
Agrotain Plus[2]	0	25	40	40	105	Urease inhibitor and nitrification inhibitor (dicyandiamide DCD)
N-Sure (50:50)[3]	0	25	40	40	105	urea triazone
Nitrapyrin 0.25 lb ai[4]	0	25	40	40	105	nitrification inhibitor (Nitrapyrin®)
Nitrapyrin 0.50 lb ai[4]	0	25	40	40	105	nitrification inhibitor (Nitrapyrin®)
Nitrapyrin 0.25 lb ai[4]	0	25	65	65	155	nitrification inhibitor (Nitrapyrin®)
Nitrapyrin 0.50 lb ai[4]	0	25	65	65	155	nitrification inhibitor (Nitrapyrin®)
D45[5]	80	25	0	0	105	polyurethane coated urea
D45[5]	130	25	0	0	155	polyurethane coated urea
ESN[5]	130	25	0	0	155	polyurethane coated urea

1 – UAN 32 applied by drip injection; 2 – mixed with UAN 32 at the rate equivalent to 15 lbs/ton UAN 32 and applied by drip injection in both fertigations; 3 – applied as 50% UAN 32 and 50% as N-Sure (28%N, 10.7 lbs/gallon, 3.0 lbs N/gallon); 4 – nitrapyrin mixed at the rates shown with UAN 32 and applied by drip irrigation; 5 – Polyurethane coated urea (44% N), spread on bedtop and mulched into the top 3” of the soil of the bedtop on June 11

Table 2. Lettuce Trial. Soil nitrate-N levels over the course of the crop cycle

Material	Total N/A	June 20	July 19	July 26	Aug 7	Aug 15
Untreated	25	6.39	23.38	10.78	19.43	0.99
155 (Standard)[1]	155	6.39	16.27	14.57	44.30	3.82
105 (Moderate)[1]	105	6.39	23.71	12.17	47.01	2.25
Agrotain Plus[2]	105	6.39	24.17	12.27	36.59	2.79
N-Sure (50:50)[3]	105	6.39	24.35	12.06	58.21	2.30
Nitrapyrin 0.25 lb ai[4]	105	6.39	27.13	14.54	36.06	5.40
Nitrapyrin 0.50 lb ai[4]	105	6.39	23.45	14.01	36.15	1.43
Nitrapyrin 0.25 lb ai[4]	155	6.39	16.23	12.53	22.15	2.05
Nitrapyrin 0.50 lb ai[4]	155	6.39	31.43	15.58	31.01	1.95
D45[5]	105	6.39	52.73	33.66	86.65	3.82
D45[5]	155	6.39	39.33	37.11	50.26	6.14
ESN[5]	155	6.39	61.45	51.12	64.71	1.77
Pr>F treat		NA				0.0263
LSD 0.05		NA				2.9693

Table 3. Lettuce Trial. Soil ammonium-N levels over the course of the crop cycle

Material	Total N/A	June 20	July 19	July 26	Aug 7	Aug 15
Untreated	25	1.02	1.17	0.74	1.02	0.55
155 (Standard)[1]	155	1.02	1.56	1.34	3.14	0.61
105 (Moderate)[1]	105	1.02	1.40	1.36	1.22	0.52
Agrotain Plus[2]	105	1.02	2.19	1.98	2.57	0.92
N-Sure (50:50)[3]	105	1.02	1.97	1.28	2.15	0.72
Nitrapyrin 0.25 lb ai[4]	105	1.02	1.46	0.82	1.04	0.60
Nitrapyrin 0.50 lb ai[4]	105	1.02	1.25	1.33	1.29	0.83
Nitrapyrin 0.25 lb ai[4]	155	1.02	2.09	1.70	1.57	1.04
Nitrapyrin 0.50 lb ai[4]	155	1.02	2.56	2.36	2.69	0.82
D45[5]	105	1.02	7.78	4.45	9.03	0.96
D45[5]	155	1.02	8.60	5.36	8.16	1.74
ESN[5]	155	1.02	11.96	7.38	9.63	1.13
Pr>F treat		NA				0.0322
LSD 0.05		NA				0.6426

Table 4. Lettuce Trial. Yield and biomass N evaluation on August 13

Material	Total N/A	Yield Fresh tons/A	Yield Fresh lbs/A	Yield Dry lbs/A	Mean Head lbs	Biomass N	N Uptake lbs N/A
Untreated	25	14.6	29,280.3	2,103.1	0.9	1.6	34.4
155 (Standard)[1]	155	33.3	66,591.8	3,611.0	2.1	2.7	96.4
105 (Moderate)[1]	105	30.3	60,619.4	3,423.4	1.9	2.3	79.1
Agrotain Plus[2]	105	30.6	61,103.9	3,646.7	1.9	2.3	84.2
N-Sure (50:50)[3]	105	32.1	64,113.5	3,715.4	2.0	2.3	85.6
Nitrapyrin 0.25 lb ai[4]	105	30.7	61,320.0	3,504.3	2.0	2.4	85.4
Nitrapyrin 0.50 lb ai[4]	105	29.1	58,150.1	3,217.5	1.9	2.6	83.4
Nitrapyrin 0.25 lb ai[4]	155	31.9	63,890.2	3,580.7	2.0	2.7	94.9
Nitrapyrin 0.50 lb ai[4]	155	32.1	64,185.6	3,525.6	2.0	2.8	97.6
D45[5]	105	20.2	40,346.3	2,714.2	1.3	2.0	54.8
D45[5]	155	19.5	39,024.3	2,496.6	1.2	2.0	50.7
ESN[5]	155	20.4	40,771.3	2,601.3	1.3	2.1	54.5
Pr>F treat		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
LSD 0.05		4.3	8,554.2	427.8	0.3	0.2	13.7

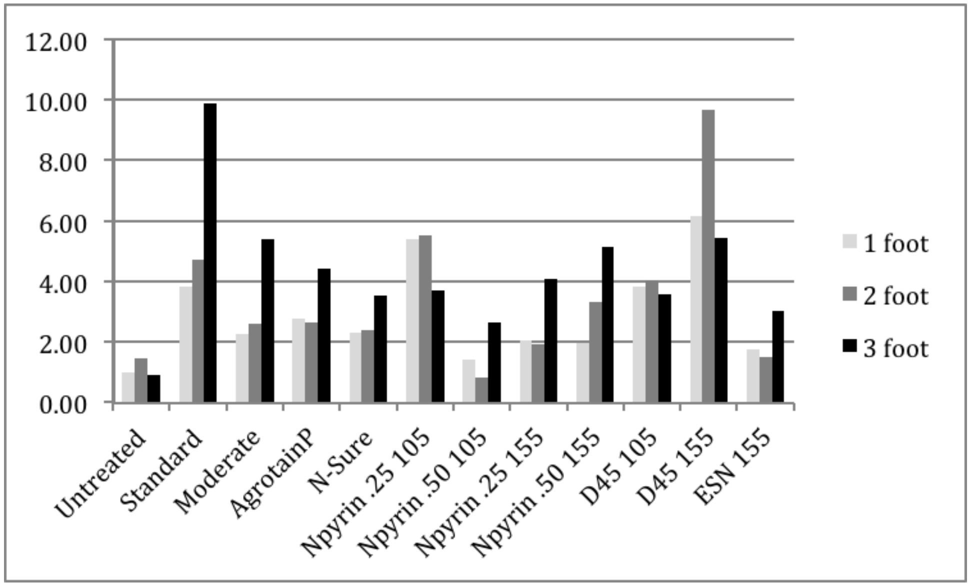

Figure 1. Lettuce Trial. Nitrate-N in the various fertilizer treatments at three depths at the end of the crop cycle

Table 5. Spinach Trials. Yield, percent N, N uptake in biomass and soil mineral nitrogen.

At-planting lbs N/A	Top dress lbs N/A	Total lbs N/A	Fresh (tons/A)	%N	lbs N/A	NH_4-N (mg/kg soil)					NO_3-N (mg/kg soil)				
						April 12	April 25	May 2	May 7	May 15	April 12	April 25	May 2	May 7	May 15
80 Ammonium sulfate +Nitrapyrin 0.50 ai/A	0	80	10.6	5.4	70.8	0.6	7.9	3.7	1.7	3.0	34.7	14.8	25.0	12.3	5.2
120 Ammonium sulfate +Nitrapyrin 0.50 ai/A	0	120	10.1	5.7	72.1	0.6	4.0	2.0	1.4	5.0	34.7	18.9	23.6	17.5	18.6
160 Ammonium sulfate +Nitrapyrin 0.50 ai/A	0	160	10.2	5.7	75.8	0.6	4.0	3.1	1.6	7.3	34.7	16.5	27.4	18.9	16.8
80 NSure (50:50[1])	0	80	8.0	4.8	51.6	0.6	1.9	1.4	1.7	2.1	34.7	12.9	19.3	12.5	1.7
120 NSure (50:50[1])	0	120	8.8	5.0	60.2	0.6	2.9	1.4	1.7	3.7	34.7	20.2	27.9	19.3	4.6
160 NSure (50:50[1])	0	160	10.2	5.1	67.1	0.6	1.6	1.4	1.6	1.6	34.7	22.1	28.7	22.8	3.0
80 Super U[2]	0	80	9.4	5.1	62.8	0.6	1.4	1.0	0.8	2.9	34.7	18.8	26.2	20.7	4.5
120 Super U[2]	0	120	10.6	5.4	72.2	0.6	3.8	3.0	2.8	1.6	34.7	28.9	44.9	47.4	17.4
160 Super U[2]	0	160	11.3	5.6	81.2	0.6	18.6	1.7	10.2	1.9	34.7	40.1	45.0	68.2	42.2
80 Ammonium sulfate	0	80	10.4	5.3	68.7	0.6	5.3	3.1	1.3	4.4	34.7	17.1	25.2	14.0	8.5
80 Ammonium sulfate	40AS	120	9.7	5.3	64.2	0.6	2.8	1.7	0.9	6.0	34.7	14.8	19.0	13.3	7.7
80 Ammonium sulfate	80AS	160	10.8	5.6	76.8	0.6	11.0	1.8	2.7	6.9	34.7	17.7	21.6	13.9	12.6
Untreated	0	0	5.2	4.2	32.8	0.6	2.0	1.3	0.9	1.6	34.7	6.6	8.5	5.6	0.5
Pr>F treat			<0.0001	<0.0001	<0.0001	NA	0.0366	0.2723	0.0058	0.049	NA	<0.0001	<0 .0001	<0 .0001	0.0002
LSD 0.05			1.2	0.3	8.0	NA	9.3	NA	3.9	4.1	NA	8.2	5.9	16.4	13.8

1 – 50% of the N was applied as UAN 32 and 50% as N-Sure (28%N, 10.7 lbs/gallon, 3.0 lbs N/gallon); 2 – Super U® (urease inhibitor + DCD impregnated on urea prill)

Table 6. Spinach Trials. Yield, percent N, N uptake in biomass and soil mineral nitrogen.

At-planting lbs N/A	Topdress lbs N/A	Total lbs N/A	Fresh tons/A	%N	lbs N/A	NH_4-N (mg/kg soil)					NO_3-N (mg/kg soil)				
						May 6	May 16	May 22	May 28	June 5	May 6	May 16	May 22	May 28	June 5
80 Ammonium sulfate +Nitrapyrin 0.50 ai/A[1]	0	80	8.4	4.9	54.2	1.3	13.0	2.0	4.3	1.3	26.9	18.2	17.8	13.9	5.5
120 Ammonium sulfate +Nitrapyrin 0.50 ai/A[1]	0	120	10.4	5.7	73.3	1.3	16.3	4.5	14.1	2.6	26.9	22.4	21.0	26.5	10.6
160 Ammonium sulfate +Nitrapyrin 0.50 ai/A[1]	0	160	11.2	5.8	79.8	1.3	13.7	3.2	7.4	6.3	26.9	26.9	23.1	25.1	25.3
80 NSure (50:50[2])	0	80	7.0	4.4	43.3	1.3	1.3	2.9	1.6	1.6	26.9	14.3	21.9	13.6	4.4
120 NSure (50:50[2])	0	120	8.3	4.6	50.6	1.3	1.8	1.1	1.8	0.9	26.9	21.4	24.8	16.2	3.5
160 NSure (50:50[2])	0	160	10.6	5.2	68.6	1.3	2.1	1.0	3.3	0.9	26.9	30.6	29.5	21.2	3.2
80 Super U[3]	0	80	10.4	5.4	69.0	1.3	2.8	0.9	1.7	0.9	26.9	26.2	33.2	15.2	4.0
120 Super U[3]	0	120	12.5	5.8	82.0	1.3	11.0	1.5	1.5	0.7	26.9	42.1	47.7	30.4	11.0
160 Super U[3]	0	160	12.4	6.0	89.3	1.3	15.0	10.2	2.8	1.3	26.9	44.1	76.5	51.4	38.0
80 D45[4]	0	80	10.6	5.1	66.6	1.3	5.2	1.7	1.8	1.3	26.9	26.5	26.1	19.4	3.0
120 D45[4]	0	120	13.4	5.8	93.6	1.3	5.6	2.6	2.3	1.3	26.9	39.5	44.8	38.5	7.9
160 D45[4]	0	160	12.8	6.1	93.4	1.3	3.7	1.0	2.5	1.9	26.9	33.8	39.5	33.3	14.9
80 Ammonium sulfate	0	80	9.5	5.1	62.2	1.3	13.9	1.6	2.5	1.2	26.9	28.3	21.3	27.0	4.4
80 Ammonium sulfate	40AS	120	10.3	5.5	69.9	1.3	17.6	1.7	4.3	8.5	26.9	28.6	21.1	34.8	14.0
80 Ammonium sulfate	80AS	160	12.2	5.7	81.4	1.3	8.7	1.7	23.3	6.0	26.9	26.2	24.0	25.8	8.9
Untreated	0	0	3.4	3.9	22.2	1.3	1.9	1.0	1.6	0.8	26.9	11.5	14.2	8.7	3.3
Pr>F treat			<0.0001	<0.0001	<0.0001	NA	0.0004	0.0010	0.0093	0.055	NA	<.0001	<.0001	<.0001	<.0001
LSD 0.05			2.2	0.5	16.1	NA	8.3	3.4	10.3	NA	NA	10.3	10.1	12.2	10.1

1 – granular ammonium sulfate was spread and nitrapyrin was sprayed over the top; 2 – 50% of the N was applied as UAN 32 and 50% as N-Sure (28%N, 10.7 lbs/gallon, 3.0 lbs N/gallon); 3 – Super U® (urease inhibitor + DCD impregnated on urea prill); 4 – Duration 45 (Polyurethane coated urea (44% N)).

Table 7. Spinach Trials. Yield, percent N, N uptake in biomass and soil mineral nitrogen.

At-planting lbs N/A	Total lbs N/A	Fresh (lbs/A)	Fresh (tons/A)	%N	lbs N/A	NH4-N (mg/kg soil)			NO3-N (mg/kg soil)		
						Sept 9	Sept 26	Oct 11	Sept 9	Sept 26	Oct 11
Ammonium Sulfate +Nitrapyrin 0.50 ai/A[1]	120	11889.0	5.9	5.9	57.4	1.38	25.6	4.7	13.75	18.2	14.4
Ammonium Sulfate +Nitrapyrin 0.50 ai/A[1]	160	12687.3	6.3	6.1	63.3	1.38	32.7	2.5	13.75	20.7	22.9
NSure (50:50[2])	120	6519.4	3.3	5.2	30.4	1.38	2.0	2.1	13.75	6.2	8.7
NSure (50:50[2])	160	7926.0	4.0	5.2	37.0	1.38	1.6	2.5	13.75	9.3	9.6
Super U[3]	120	8373.5	4.2	5.5	40.0	1.38	1.3	1.9	13.75	8.8	9.0
Super U[3]	160	7959.8	4.0	5.4	37.8	1.38	2.3	2.2	13.75	15.4	11.0
Duration 45[4]	120	9305.2	4.7	5.6	43.8	1.38	2.0	2.2	13.75	16.0	8.5
Duration 45[4]	160	10536.3	5.3	5.7	49.9	1.38	1.4	2.4	13.75	15.7	10.7
Ammonium Sulfate	120	11257.7	5.6	5.7	52.9	1.38	3.1	2.0	13.75	12.9	9.2
Ammonium Sulfate	160	13060.2	6.5	6.0	61.2	1.38	9.0	2.2	13.75	20.4	12.1
Untreated	0	6874.5	3.4	5.3	31.7	1.38	1.1	2.0	13.75	7.3	7.3
Pr>F treat		<.0001	<.0001	<.0001	<.0001	NA	<.0001	0.2599	NA	0.0027	0.0082
LSD 0.05		1835.4	0.9	0.2	8.1	NA	6.2	NA	NA	7.4	6.8

1 – ammonium sulfate was spread and nitrapyrin was sprayed over the top; 2 – 50:50 v/v mixture of NSure and UAN32; 3 – Super U® (urease inhibitor + DCD impregnated on urea prill); 4 – Duration 45 (Polyurethane coated urea (44% N)).

Table 8. Spinach Trials. Summary and comparison table of the yields of the three trials

At-planting lbs N/A	Total lbs N/A	Castroville #1 Tons/A	Castroville #2 Tons/A	King City Tons/A	Overall Yield Tons/A	Overall Yield by Material
Ammonium sulfate +Nitrapyrin 0.50 ai/A	80	10.56	8.37	---	9.46	
Ammonium sulfate +Nitrapyrin 0.50 ai/A	120	10.07	10.39	5.95	8.80	
Ammonium sulfate +Nitrapyrin 0.50 ai/A	160	10.24	11.23	6.35	9.27	9.17
NSure (50:50)	80	8.02	6.96	---	7.49	
NSure (50:50)	120	8.82	8.29	3.26	6.79	
NSure (50:50)	160	10.20	10.58	3.97	8.25	7.45
Super U	80	9.37	10.45	---	9.91	
Super U	120	10.63	12.51	4.19	9.11	
Super U	160	11.33	12.38	3.98	9.23	9.42
D45	80	---	10.57	---	10.57	
D45	120	---	13.40	4.66	9.03	
D45	160	---	12.82	5.27	9.05	9.56
Ammonium Sulfate	80	10.37	9.50	---	9.94	
Ammonium Sulfate	120	9.75	10.29	5.64	8.56	
Ammonium Sulfate – Standard	160	10.85	12.22	6.54	9.87	9.45
Untreated	0	5.21	3.36	3.44	4.00	4.19

5. Provide direct assistance to leafy green growers on improving irrigation and N fertilizer management

We have refined several key tools to help growers better manage water and nitrogen fertilizer in leafy green production during the past 5 years. These include the quick nitrate test for timely determination of the mineral N status of the soil and weather-based irrigation scheduling for matching irrigation applications with the crop evapotranspiration demand. Additionally, we have developed an innovative online software application that recommends irrigation schedules tailored to specific water and nitrogen needs of romaine and iceberg lettuce through funding from the CDFA fertilizer research and education program. The software, referred to as CropManage (Cahn et al., 2011), is hosted and serviced on the UCANR communications server in Davis. This application automates retrieval of reference evapotranspiration data from CIMIS weather stations and spatial CIMIS, and estimates water needs of lettuce. The application also facilitates use of the quick nitrate test by quickly converting the strip test value to a soil-based value and developing a recommended fertilizer N rate based on the N uptake pattern of lettuce. Both irrigation and N fertilizer recommendations are formulated for a portfolio of fields by integrating soil, plant, and irrigation system information. The tool is accessible from a range of internet portals including smart phone, tablet, laptop, and desktop computer. It is designed to be convenient and easy to use so that growers can determine irrigation schedules in a timely manner and maintain and share records of their water applications for multiple fields and farms.

After 2 years of development, we formally announce the availability of this web-based tool to the vegetable growing community and offer trainings on using the software in March 2013. Funding from the CLGRB was used to provide direct assistance to at least 5 growers to implement the use of the quick nitrate test and weather based irrigation scheduling. In addition, we conducted 3 strip trials comparing yield under the grower standard irrigation or nitrogen fertilizer practice with the CropManage recommended practices. Strips of each treatment were the width of a harvester so that they can be commercially evaluated. Results of the 2013 trials are presented in Table 1 with the results of 2012 trials, which were partially funded through a CDFA-FREP grant. During the 2 years of trials fertilizer N was reduced by average of 57 lbs N/acre (33% reduction), with no significant yield loss. Final soil nitrate concentration was also significantly reduced, which would help prevent loading of nitrate to ground water during winter storm events or when the soil is pre-irrigated for a subsequent crop.

Table 1. Summary of N management strip trials comparing grower practice to CropManage recommendations.

Strip Trial #	Management treatment	Applied water (post-thinning)	Fertilizer N	Final soil nitrate-N	Marketable Yield	Yield difference between treatments
		inches	lbs/acre	ppm NO_3-N	lbs/acre	%
	---------------------- iceberg cored 9/5/12 --------------------------					
1	Grower	9.8	183	--	64307	
	CropManage	9.8	143	17.7	65713	2.2
	---------------------- romaine cored 10/17/12 ----------------------					
2	Grower	4.9	211	95.2	19114	
	CropManage	4.9	149	71.4	18760	-1.9
	---------------------- romaine cored 10/20/12 ----------------------					
3	Grower	4.9	177	26.3	17935	
	CropManage	3.8	177	26.3	18389	2.5
	---------------------- romaine cored 9/24/13 -----------------------					
4	Grower	7.6	263	87.5	15946	
	CropManage	7.6	162	22.5	15644	-1.9
	---------------------- romaine cored 9/19/13 -----------------------					
5	Grower	4.1	96	41.7	24903	
	CropManage	4.1	71	41.7	27035	8.6
	---------------------- iceberg cartons 10/18/13 ----------------------					
6	Grower	3.9	124	62.5	32765	
	CropManage	4.3	62	21.0	38434	17.3
	----------------------------- Average ---------------------------------					
	Grower	4.4[x]	175[y]	71.7[y]	29162	
	CropManage	4.0	118	34.9	30662	4.5

[x] Average of trials 3 and 6

[y] Average of trials 1,2,4,5,and 6