CALIFORNIA LETTUCE RESEARCH BOARD
April 1, 2011 – March 31, 2012

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
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) Fertilizer technologies to improve nitrogen use efficiency; Studies were conducted to evaluate the utility of nitrification inhibitors to slow the conversion of ammonium to nitrate. This has the potential to reduce leaching because ammonium is positively charged and is held to clay and organic matter in the soil. The nitrification inhibitor, DCD, applied to crop residue delayed nitrification of N contained in the residues. DCD has the potential to reduce nitrification over at 4-6 weeks, leaving more of the N mineralized from incorporated crop residue in ammonium form, which is less susceptible to leaching during germination of the succeeding crop. Two field trials were conducted on romaine lettuce; a significant increase in yield was observed in one of the trials in the Agrotain Plus treatment (contains DCD). These results indicate that this fertilizer additive may have some limited potential to improve nitrogen use efficiency and safeguard yield of lettuce. ***2) Nitrogen uptake characteristics of spinach:*** In a survey of 11 spinach fields, we measured the uptake of nitrogen in three spinach products. Nitrogen uptake was 75, 96, and 115 lbs N/A, respectively for baby, teenage and bunch spinach. In the first two weeks of the growth cycle spinach takes up 10-15 lbs N/A, but in the final two weeks of the growth cycle it takes up 7.3 lbs N/A/day. In four fertilizer trials it was observed that first crop spinach crops with low levels of residual soil nitrate will need robust at-planting applications of N fertilizer to achieve acceptable levels of yield and quality. Spinach plantings with high residual soil nitrate can be successfully grown with lower rates of N. ***3) Impact of leaching fraction on salt and nitrate leaching:*** Applying a 50% leaching fraction reduced salt accumulation in the soil profile during the drip phase of lettuce production. The increased leaching resulted in higher marketable yields at the south county site where soil salinity levels were highest, but did not result in increased yield at the north county site. The extra water applied to leach salts also resulted in an increased loss of nitrate-N from soil. The addition of extra fertilizer N to compensate for leaching of nitrate-N did not result in increased yield at the north county site, and only slightly significant effects on yield at the south county site. The results of this study demonstrate that the best strategy to manage salts in soils with a high salinity and minimize associated nitrate leaching is to use a leaching fraction of approximately 50% and maintain soil nitrogen levels at 20 ppm nitrate-N. ***4) Impact of denitrification bed reactors to reduce the nitrate content of tile drain effluent.*** Denitrification beds reduced nitrate in tile waters by approximately 8 PPM NO_3-N per day of residence time during the irrigation season (May through October), and approximately 5 PPM during the winter. Denitrification rates were limited by cold water temperatures. The rates could be improved by additions of a more labile source of carbon, but this would incur greater costs.

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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. Nitrification inhibitor evaluations:
Nitrification inhibitors are chemicals that inhibit the mineralization of nitrate from ammonium. Nitrate is highly susceptible to leaching because the negatively charged molecule is repelled by soil binding sites forcing it to remain the in the soil water faction of the soil. Ammonium however, is positively charge and is attracted to the negative charges that occur on clay and organic matter (the cation exchange sites). Ideally, if more of the mineral nitrogen in the soil was in the ammonium form, there would be less nitrate leaching; this is the function of nitrification inhibitors. Dicyandiamide (DCD) is a nitrification inhibitor that is available for use on lettuce and other crops. We conducted trials with this material in two ways: we applied DCD at a rate equivalent to 6-8% of residue N to see if it can slow the nitrification of mineralized N, and minimize NO3-N loss during the establishment phase of the following crop. Soil incubation studies were conducted at UCD and soil NH_4-N and NO_3-N concentration were determined after 2, 4 and 6 weeks. Two field trials evaluating the impact of DCD were conducted on lettuce and weekly soil nitrate, biomass N, nitrate leaching and yield of the lettuce were evaluated.

2. Spinach N nutrition studies: plant N uptake, N fertility trials, impact of water management on N utilization: Four preplant nitrogen fertilizer trials were conducted; two trials were conducted on first crop and two on second crop spinach to determine the nitrogen uptake dynamics and fertilizer needs of the crop. A survey of 11 spinach fields was conducted to evaluate the nitrogen content of the tops and roots of spinach on several commercial fields; evapotranspiration (ET) water demand of spinach was evaluated from reference ET from CIMIS weather stations and estimates of crop coefficients developed from monitoring canopy growth and determining the evaporation loss from the soil after overhead irrigations. The amount and timing of irrigation events was monitored with a flow meter interfaced with datalogger.

3. Impact of leaching fraction on salt management and nitrate losses: Leafy green vegetables are highly sensitive to salinity in water and soil. Water salinity levels above 0.9 dS/m and soil salinity levels above 1.3 dS/m are known to reduce lettuce yield. The application of a leaching fraction is a common practice that growers use to prevent a salt buildup in the crop root zone, but additional water applied to leach salts can also leach soil nitrate. We conducted two replicated trials in commercial lettuce fields to evaluate the effect of additional leaching requirements during the post thinning stage of the crop on soil salinity, nitrate losses, plant uptake of N, and crop yield. The trials were conducted at locations with irrigation water with high salinity levels (> 1 dS/m). Irrigation treatments of different leaching fractions (0% and 50% above the crop water-use requirement) would be imposed after thinning in drip irrigated lettuce fields. Soil nitrate, crop N uptake, and concentration of salts and nitrate in leachate was monitored during the crop growth, and marketable yield, biomass, and total N uptake was evaluated.

4. Treatment of tailwater or tile drain effluent with 'denitrification beds': Nitrate loads in tile water are discharged into the drains that run through the lower Salinas Valley. High loads of nitrate commonly found in these drains exceed the regulatory limit of 10 ppm nitrate-N. The use of denitrification beds can reduce the levels of nitrate in water. In this technique, nitrate rich effluent is channeled through a source of labile carbon (straw, wood chips, etc.). Denitrification beds were constructed with two cooperating growers. The beds were designed to allow for two days residence time of the water to allow for treatment of the water. Samples of influent and effluent were collected twice weekly for NO_3-N determination, and the N removal rate was calculated.

5. Outreach/extension: We will develop a comprehensive website that will discuss all practical aspects of N loss and N management for the entire lettuce/spinach growth cycle. It would be modeled on the UCIPM year-round crop management sites in that it would start at the beginning of the crop cycle and continue through the winter fallow. There is a good deal of current information on N management of lettuce that can get this site up and running and as new information is developed it can be added.

Results

1. Nitrification inhibitor: *Laboratory Studies:* The effectiveness of DCD to retard nitrification of mineralized residue nitrogen varied between the soils tested. In the static incubation DCD application resulted in significantly higher percentage of mineral N remaining in NH_4-N form in both soils (Fig. 1). Elevated NH_4-N was maintained through 6 weeks of incubation in soil 2, whereas in soil 1 there was no evident DCD effect after 4 weeks. In soil DCD is microbially degraded, and this process was apparently more rapid in soil 1. In the column study DCD significantly retarded NO_3-N leaching in both soils during the first leaching event (after 2 weeks of incubation), consistent with the retardation of nitrification observed in the static incubation (Fig. 2). The DCD effect faded after 2 weeks in soil 1, and after 4 weeks in soil 2. Over the 6 week period (3 leaching events) DCD treatment reduced NO_3-N leaching by 12% and 30% in soil 1 and soil 2, respectively. These results suggest that the use of DCD to delay nitrification of mineralized N between the incorporation of spring crop residues and planting the succeeding crop would be site-dependent, affected by the rate of microbial degradation of the DCD, and the extent of leaching. In a best case scenario, DCD could substantially reduce nitrification over at 4-6 weeks, leaving more of the N mineralized from incorporated crop residue in NH_4-N form, less susceptible to leaching during germination of the succeeding crop.

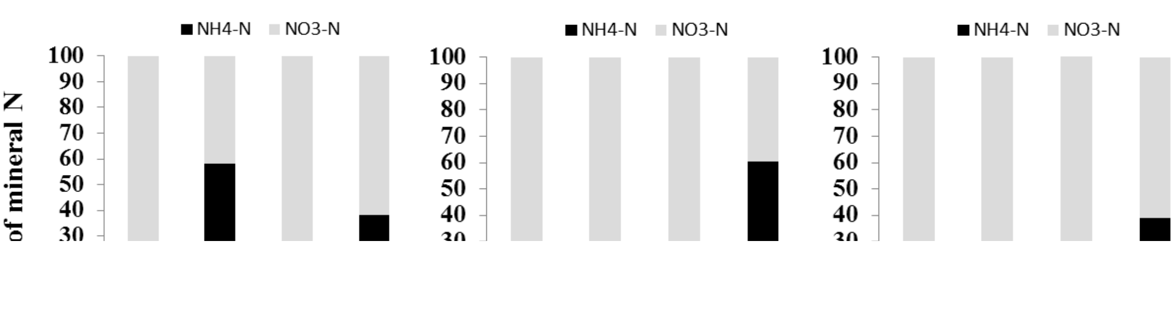


Figure 1. Effect of dicyandiamide (DCD) on rate of nitrification of mineralized residue nitrogen.

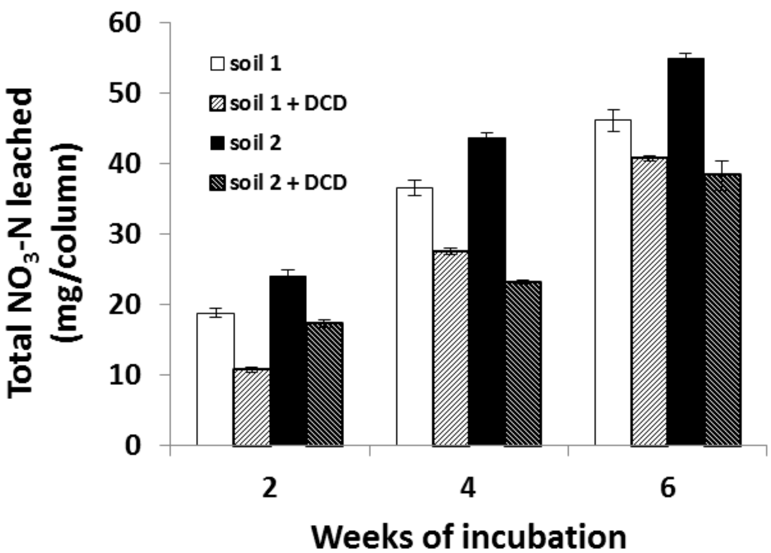


Fig. 2. Cumulative NO_3-N leaching loss (mg/column) over 6 weeks of incubation, with leaching events at 2, 4 and 6 weeks; bars indicate standard error of measurement.

Field Studies: Two trials were conducted and the key comparison is between the moderate level of applied N with and without the fertilizer additives. The moderate level of N was chosen in order to not maximize yield, but to be able to observe improvements in yield that fertilizer additives may provide. In trial number 1 few differences in soil nitrate were observed (Table 1), but an increase in fresh yield of the moderate rate of applied N was observed in the Agrotain Plus treatment over the same treatment without the additive (Table 2). In a second trial on a much lighter and more gravelly soil, no differences were observed in any of the moderate N rate treatments and those with additives. These results were not as positive as we had hoped, but the one positive result indicates that there is promise for this technology; there may be factors that affect the function of these materials that we do not yet fully understand.

Table1. Trial No. 1. Soil ammonium and nitrate levels in the soil on five evaluation dates

Treatments (lbs N over season and additives)	Ammonium-N					Nitrate-N				
	May 17	May 25	May 31	June 9	June 16	May 17	May 25	May 31	June 9	June 16
Untreated	0.6	0.5	0.7	0.5	1.0	5.5	5.0	4.0	3.2	3.2
150 (Standard N)	0.6	1.6	1.7	1.1	1.0	6.0	9.7	13.4	22.1	17.2
100 (moderate level)	0.8	1.6	1.5	1.0	1.1	5.5	9.8	18.0	16.5	9.8
100 + AgrotainPlus	0.7	2.2	1.7	0.9	1.4	4.8	7.8	10.5	14.8	22.8
100 + DCD @ 4%	0.7	1.4	1.2	1.9	1.4	5.7	6.1	12.4	19.7	7.8
100 + DCD @ 8%	0.5	2.5	2.4	1.3	0.9	5.7	11.2	8.2	11.0	15.3
Pr>F treat	0.226	0.606	0.197	<0.001	0.613	0.824	0.044	0.009	0.002	0.278
Pr>F block	0.481	0.798	0.896	0.094	0.225	0.508	0.752	0.141	0.282	0.859
LSD 0.05	NS	NS	NS	0.4	NS	NS	1.7	1.9	2.0	NS

Table 2. Trial No. 1. Yield evaluation on June 20: Fresh and dry biomass, N concentration in leaf and N uptake by crop

Treatments (lbs N over season and additives)	Yield Fresh wt. tons/A	Yield Dry biomass lbs/A	Mean head weight lbs	Biomass N concentration percent	N uptake by plant lbs N/A	N uptake lbs N/A/day
Untreated	12.8	1775	0.85	2.3	40.0	0.4
150 (Standard N)	22.7	2775	1.51	3.1	85.9	1.9
100 (moderate level)	20.1	2540	1.34	2.7	68.2	0.8
100 + AgrotainPlus	22.3	2734	1.48	2.9	78.7	1.5
100 + DCD @ 4%	20.4	2647	1.36	2.7	71.0	1.5
100 + DCD @ 8%	20.8	2629	1.39	2.9	75.8	1.7
Pr>F treat	<0.001	<0.001	<0.001	0.001	<0.001	
Pr>F block	0.576	0.131	0.579	0.053	0.765	
LSD 0.05	2.0	267	0.14	0.3	11.5	

2. Spinach N nutrition studies: plant N uptake, N fertility trials, impact of water management on N utilization

Four fertilizer trials were conducted to understand the nitrogen fertilizer uptake by spinach grown in modern high-density, 80 inch wide beds. Two trials were carried out on first crop spinach production fields, and given wet spring weather of 2011, the fields had low residual soil nitrate levels at the onset (5-10 ppm nitrate-N). Two trials were also conducted in second crop spinach fields following lettuce or cole crops with higher residual soil nitrate. Ammonium sulfate was applied at various rates at-planting. Ammonium was chosen as the source of N because it is attracted to the cation exchange sites in the soil and would be less susceptible to leaching losses during the application of germination water. In both first crop fertilizer trials the spinach responded to nitrogen up to 40 lbs N/A (Table 3). This was surprising because spinach takes up less than 20 lbs of N/A in the first two weeks of production. We did not change any of the grower's fertilizer practices beyond the at-planting applications. Even with robust amounts of supplemental fertilizer applications starting at the 1-2 true leaf stage (approximately 14-18 days after germination water), the low at-planting fertilizer treatments (0 and 20 lbs N/A) had reduced spinach yield. In the second crop spinach trials, spinach responded well to residual soil nitrate. In one trial, the grower skipped at-planting N applications. We applied the fertilizer treatments at the 1-2 true leaf stage in this trial and observed no response to fertilizer (Table 4). This trial indicated that in spite of the shallow root system, spinach is capable of absorbing sufficient quantities of residual soil nitrate-N from the soil to meet a large portion of its needs.

In general, first crop spinach crops with low levels of residual soil nitrate will need robust at-planting applications of N fertilizer to achieve acceptable levels of yield and quality. Second crop spinach can be managed with reduced fertilizer N inputs and can be successfully grown with lower rates of N. However, achieving the 1.0 requirement proposed by the CCRWQCB may only be possible for second crop spinach.

Modern clipped spinach is typically grown for 30 days and harvested mechanically. Overall it has a moderate demand for N. The overall demand for N depends on the product that is being grown: baby, teenage, and bunch spinach N uptake was 75, 96, and 115 lbs N/A, respectively in these studies (Figure 3). The demand for N by spinach can be high during specific periods during the crop cycle. In the first two weeks of growth, N uptake is low due to the small size of the crop; the average N uptake by spinach in the first two weeks of the growth cycle was 7 lbs N/A. At two weeks after planting to harvest, spinach growth and N uptake increases rapidly and averaged 4.3 lbs N/A/d. However, in the week preceding harvest, average N uptake averaged 7.3 lbs N/A/d, but can be as high as 10 lbs N/A/d. In comparison, lettuce N uptake from thinning to harvest ranges from 3.7- 4.4, but can be as high as 5 lbs N/A/d. The high-density planting on 80-inch wide beds and high N content at harvest (5.5%) explain the high N uptake rates for spinach. The amount of residue N left in the fields after harvest were 44% and 35% of total biomass N for clipped and bunch spinach, respectively. Spinach has a higher demand for potassium (K) than N, with an average K uptake total K uptake averaging 160 lbs K/A and daily uptake of 9.3 lbs K/A/d from two weeks after planting to harvest. Phosphorus (P) uptake was 12 lbs P/A which is equivalent to P taken up by mature lettuce (Figure 4).

Table 3. Trial No. 1, Gonzales. Treatment N applications and total N applications and biomass evaluations on May 2

At-planting Treatments Lbs N/A	Topdress[3] May 2 1-2 true leaf	Sprinkler[4] May 9 Mid-growth	Sprinkler[5] May 12 preharvest	Total Lbs N/A	May 2 (19 DAG)				
					Fresh (lbs/A)	Fresh (tons/A)	Dry (lbs/A)	%N	lbs N/A
0	63	38.5	32.1	133.6	2,349	1.2	237	4.4	10.6
20[1]	63	38.5	32.1	153.6	2,902	1.5	306	4.6	14.2
40[1]	63	38.5	32.1	173.6	3,226	1.6	330	5.0	16.5
80[1]	63	38.5	32.1	213.6	3,408	1.7	347	5.5	19.1
80[2] Standard	63	38.5	32.1	213.6	4,134	2.1	421	5.4	22.7
Pr>Treat					0.009	0.009	0.002	0.001	<0.001
Pr>Block					0.050	0.050	0.021	0.201	0.021
$LSD_{0.05}$					800	0.4	64	0.4	3.7

1 – ammonium sulfate applied immediately post planting; 2 – 15-8-4 applied immediately post planting;
3 – ammonium sulfate; 4 – CN9; 5 – CAN17

Table 3 (continued). Trial No. 1, Gonzales. Biomass evaluation on May 11 and yield evaluation on May 16

At-planting Treatments Lbs N/A	May 11 (19 DAG)						May 16 (33 DAG)					
	Fresh (lbs/A)	Fresh (tons/A)	Dry (lbs/A)	%N	lbs N/A	Uptake (lbs N/d)	Fresh (lbs/A)	Fresh (tons/A)	Dry (lbs/A)	%N	lbs N/A	Uptake (lbs N/d)
0	7,392	3.7	949	3.3	31	2.3	16,771	8.4	1,797	3.6	65	6.6
20[1]	9,722	4.9	1,200	3.5	42	3.1	18,869	9.4	1,852	3.9	72	5.9
40[1]	10,873	5.4	1,298	3.6	47	3.4	22,999	11.5	2,175	4.1	88	8.3
80[1]	13,401	6.7	1,556	4.6	72	5.9	25,931	13.0	2,466	4.5	110	7.6
80[2] Standard	12,943	6.5	1,552	4.2	65	4.7	25,031	12.5	2,309	4.2	98	6.5
Pr>Treat	0.004	0.004	0.002	<0.001	<0.001	NA	0.010	0.010	0.062	0.189	0.006	NA
Pr>Block	0.166	0.166	0.148	0.695	0.235	NA	0.598	0.598	0.574	0.591	0.805	NA
$LSD_{0.05}$	2,860	1.4	269	0.5	13	NA	5,221	2.6	NS	NS	23	NA

1 – Ammonium sulfate applied immediately post planting; 2 – 15-8-4 applied immediately post planting.

Table 4. Trial No. 3, Salinas. Biomass and nitrogen uptake evaluations on two dates

Topdress Treatments Lbs N/A	August 4 (19 DAG)					August 8 (23 DAG)					
	Fresh (lbs/A)	Fresh (tons/A)	Dry (lbs/A)	%N	lbs N/A	Fresh (lbs/A)	Fresh (tons/A)	Dry (lbs/A)	%N	lbs N/A	Uptake (lbs N/d)
0	4,974	2.5	385	4.95	19.1	13,101	6.6	930	5.34	49.9	7.7
25	5,273	2.6	403	5.13	20.7	14,367	7.2	996	5.53	55.3	8.6
50	5,338	2.7	414	5.20	21.5	13,434	6.7	957	5.50	52.7	7.8
75	5,315	2.7	420	5.46	22.9	14,411	7.2	1000	5.71	57.2	8.6
105 Standard	4,898	2.4	398	5.35	21.3	14,256	7.1	989	5.58	55.2	8.5
Pr>Treat	0.453	0.453	0.529	0.130	0.360	0.909	0.909	0.882	0.087	0.181	
Pr>Block	0.012	0.012	0.014	0.170	0.093	0.387	0.387	0.325	0.004	0.002	
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Table 4 (continued). Trial No. 3, Salinas. Yield and nitrogen uptake.

Topdress Treatments Lbs N/A	August 12 (27 DAG)					
	Fresh (lbs/A)	Fresh (tons/A)	Dry (lbs/A)	%N	lbs N/A	Uptake (lbs N/d)
0	26,291	13.1	1532	5.42	83.5	8.4
25	28,201	14.1	1664	5.74	95.6	10.1
50	27,135	13.6	1528	5.75	87.9	8.8
75	28,823	14.4	1564	5.86	91.7	8.6
105 Standard	28,556	14.3	1621	6.03	97.8	10.7
Pr>Treat	0.627	0.627	0.247	0.077	0.103	
Pr>Block	0.298	0.298	0.037	0.039	0.010	
$LSD_{0.05}$	NS	NS	NS	NS	NS	

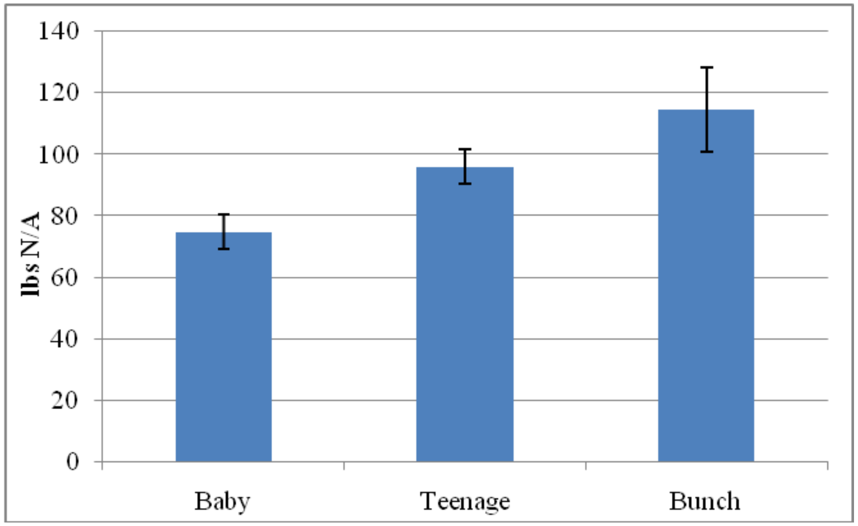


Figure 3. Nitrogen uptake by product at harvest. Error bars represent the SEM

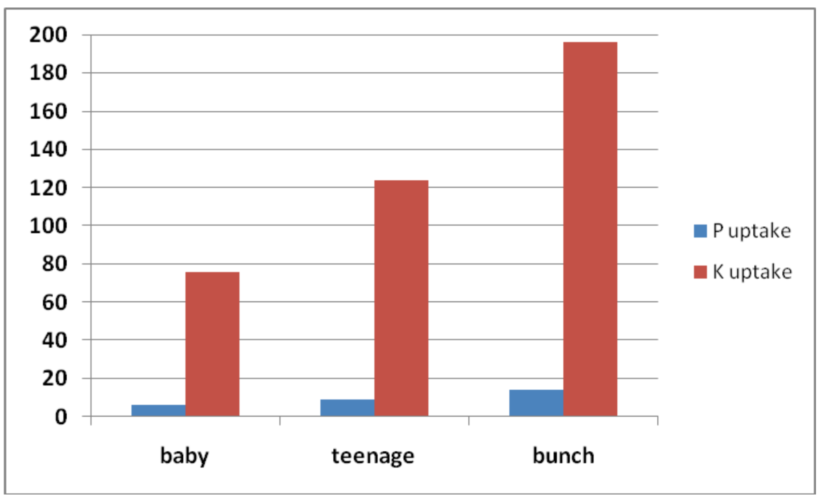


Figure 4. Phosphorus and potassium uptake at harvest of three spinach products (lbs P or K/A)

3. Impact of leaching fraction on salt management and nitrate losses

The purpose of these trials was to investigate if leaching in the early stages of the crop, such as before planting and during stand establishment is sufficient to sustain production through the remaining crop cycle. We conducted 2 replicated trials in commercial lettuce fields to evaluate the effect of additional leaching requirements during the post thinning stage of the crop on soil salinity, nitrate losses, plant uptake of N, and crop yield. Trial 1 was conducted in north-Monterey County and was planted with iceberg lettuce on 40 inch-wide beds on June 14, 2011. Trial 2 was conducted in south Monterey county and seeded with romaine lettuce on 80 inch-wide beds on August 10, 2011. Salinity of the irrigation water averaged 1.2 and 0.9 dS/m at Trials 1 and 2 respectively. Irrigation treatments of 100% and 150% of crop ET were imposed after thinning in drip irrigated lettuce fields to create leaching fractions of 0% and 50% (Table 5). High and low rates of nitrogen fertilizer (Table 6) were applied to the irrigation treatments to determine if additional N fertilizer was needed to sustain production under higher leaching fractions. Salinity levels in the soil profile were evaluated before pre-plant irrigation, after emergence, and at crop maturity. Pre-plant, germination, and post thinning applied water volumes were measured using flow meters. Soil nitrate, crop N uptake, and concentration of salts and nitrate in leachate were monitored during the crop cycle. Marketable yield, biomass, and total N uptake were evaluated at crop maturity.

Results

A leaching fraction greater than 150% of crop ET during the drip phase of the lettuce crops increased estimated cumulative losses of salt and nitrate-N compared to 100% of crop ET leaching fraction at both trials (Figs. 5-8). Additionally, residual nitrate concentrations in the soil profile after harvest were lowest under the 150% ET treatment at both trials, presumably due to the effect of leaching (Figs. 9-10). However, in neither trial were soil nitrate levels at levels (< 20 ppm NO3-N) that would be expected to cause yield loss. Highest nitrate-N concentrations at the 3 foot depth were measured after harvest (Figs. 11-12). Salinity concentrations measured in the upper 2 feet of the soil profile were highest in the 100% ET treatments in both trials after harvest (Figs 13-16), indicating that without a leaching fraction soil salinity levels increased significantly. Generally additional applied nitrogen fertilizer did not increase soil salinity levels (Table 9), with the exception of a significant effect on SAR at the south county trial.

Marketable and biomass yields were highest under the 150% crop ET treatment at the south county trial (Table 8). The irrigation treatments had no effect on yields at the north county trial (Table 7). Increasing the fertilizer N rate during the drip phase of the crop did not increase yields at either trial, and caused a slight but statistically significant marketable yield loss at the south county trial (Table 8), where soil NO3-N concentrations were greater than 40 ppm in the 100% ET, high N treatment. Yields at the south county trial appeared to have been suppressed by accumulation of salts in the upper profile (Fig. 16). Salinity levels of the soil profile after harvest were highest under the 100% ET treatment (Fig. 15).

Applying a 50% leaching fraction reduced salt accumulation in the soil profile during the drip phase of lettuce production. The increased leaching resulted in higher marketable yields at the south county site where soil salinity levels were highest, but did not result in increased yield at the north county site. The extra water applied to leach salts also resulted in an increased loss of nitrate-N from soil. The addition of extra fertilizer N to compensate for leaching of nitrate-N did not result in increased yield at the north county site, and only slightly significant effects on yield at the south county site. The results of this study demonstrate that the best strategy to manage salts in soils with a high salinity and minimize associated nitrate leaching is to use a leaching fraction of approximately 50% and maintain soil nitrogen levels at 20 ppm Nitrate-N.

Table 5. Summary of irrigation water volumes applied at 2011 lettuce trials.

	Applied Water		
Treatment	sprinkler	drip	total
	------- inches -------		
North County Trial			
Grower standard	5.3	4.2	9.5
100% ET	5.3	3.1	8.4
150% ET	5.3	4.5	9.7
South County Trial			
Grower standard	8.4	5.3	13.7
100% ET	8.4	4.7	13.0
150% ET	8.4	6.6	15.0

Table 6. Summary of fertilizer N applied at 2011 lettuce trials.

	Applied N fertilizer		
Treatment	pre-drip	drip	total
	------- lbs N/acre -------		
North County Trial			
Grower standard	100	64	164
Low N	100	0	100
High N	100	80	180
South County Trial			
Grower standard	134	20	154
Low N	134	19	153
High N	134	71	205

Table 7. Irrigation and nitrogen management treatment effects on iceberg yield at trial 1 (North County)

Treatment	Plant weight	Trimmed Plant weight	Trim/bulk ratio	Biomass Yield	Marketable yield	Dry mater content	Nitrogen content of dry tissue	Crop N uptake	
	lb/plant			tons/acre		%		lb N/acre	lb N/1000 plants
Grower Standard	1.57	0.71	0.43	22.90	10.45	4.63	3.96	82.00	2.82
100% ET low N	1.52	0.70	0.44	22.35	10.38	4.23	3.97	72.80	2.49
150% ET low N	1.54	0.70	0.43	22.58	10.22	4.30	3.80	72.03	2.47
100% ET High N	1.54	0.67	0.42	22.48	9.74	4.34	4.06	76.88	2.64
150% ET High N	1.56	0.69	0.42	22.05	9.83	4.84	3.94	83.23	2.94
$LSD_{0.05}$ [z]	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation Treatment									
100% ET	1.53	0.68	0.43	22.41	10.06	4.28	4.01	74.84	2.57
150% ET	1.55	0.69	0.43	22.31	10.02	4.57	3.87	77.63	2.70
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS
N fertilizer Treatment									
Low N	1.53	0.70	0.43	22.46	10.30	4.26	3.88	72.41	2.48
High N	1.55	0.68	0.42	22.26	9.79	4.59	4.00	80.05	2.79
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	0.11	NS	NS

[z] Fisher's protected least significant difference, multi-comparison test at $p < 0.05$ level

NS means are not statistically different at the $p < 0.05$ level

Table 8. Irrigation and nitrogen management treatment effects on romaine yield at trial 2 (South County)

Treatment	Plant weight	Trimmed Plant weight	Trim/bulk ratio	Biomass Yield	Marketable yield	Dry mater content	Nitrogen content of dry tissue	Crop N uptake	
	lb/plant			tons/acre		%		lb N/acre	lb N/1000 plants
Grower Standard	1.77	1.61	0.91	31.3	28.4	4.70	4.18	122.3	3.46
100% ET low N	1.60	1.47	0.92	28.8	26.3	5.28	3.99	119.4	3.32
150% ET low N	1.77	1.62	0.92	32.1	29.4	4.57	4.22	122.7	3.39
100% ET High N	1.52	1.38	0.91	27.6	24.9	5.10	4.14	115.9	3.20
150% ET High N	1.75	1.60	0.91	32.2	29.4	4.79	4.26	131.0	3.57
$LSD_{0.05}$ [z]	0.08	0.08	NS	1.2	1.1	0.40	NS	7.9	NS
Irrigation Treatment									
100% ET	1.56	1.42	0.91	28.2	25.6	5.19	4.07	117.7	3.26
150% ET	1.76	1.61	0.91	32.2	29.4	4.68	4.24	126.9	3.48
$LSD_{0.05}$	0.14	0.11	NS	1.6	1.3	0.37	NS	8.0	NS
N fertilizer Treatment									
Low N	1.69	1.54	0.92	30.5	27.8	4.92	4.10	121.1	3.35
High N	1.64	1.49	0.91	29.9	27.2	4.94	4.20	123.5	3.38
$LSD_{0.05}$	NS	0.05	NS	NS	0.5	NS	NS	NS	NS

[z] Fisher's protected least significant difference, multi-comparison test at $p < 0.05$ level

NS means are not statistically different at the $p < 0.05$ level

Table 9. Irrigation and N fertilizer treatment effects on soil salinity evaluated after harvest (0 to 3 foot depth).

Treatment Factor	EC	SAR	Ca	Na	Cl
	------------ p-value -----------				
North County Trial					
Irrigation	0.02	NS	0.01	0.03	0.03
N fertilizer	NS	NS	NS	NS	NS
South County Trial					
Irrigation	0.06	NS	0.09	NS	0.01
N fertilizer	NS	0.05	NS	NS	NS

NS not statistically significant at $p < 0.1$ level

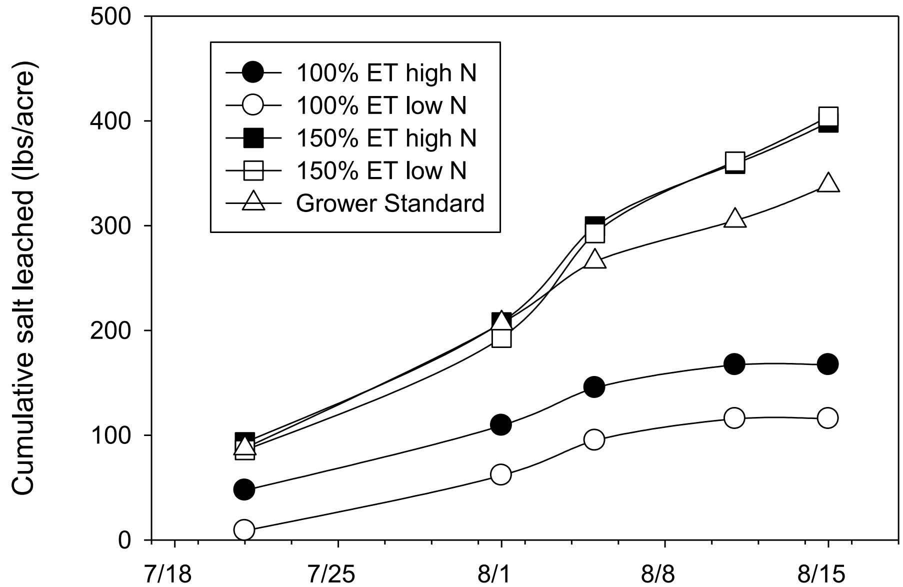


Figure 5. Water and N fertilizer treatment effects on estimated cumulative salt leached in iceberg lettuce crop, post thinning (north county trial [1]).

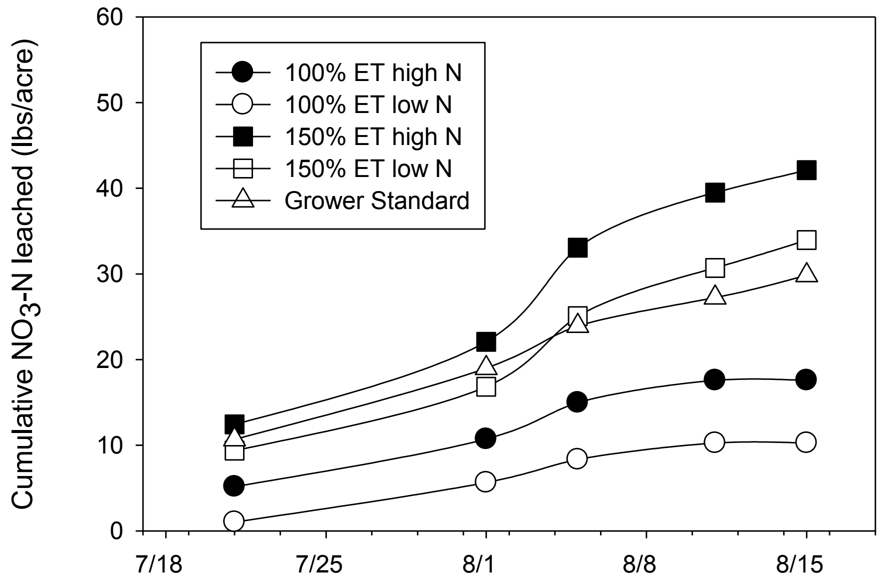


Figure 6. Water and N fertilizer treatment effects on estimated cumulative nitrate leached in iceberg lettuce, post thinning (north county trial [1]).

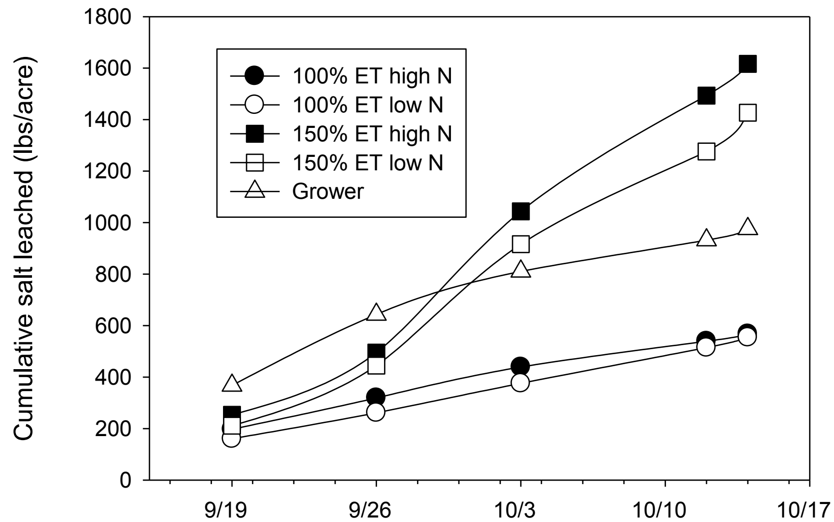


Figure 7. Water and N fertilizer treatment effects on estimated cumulative salt leached in romaine lettuce, post thinning (south county trial).

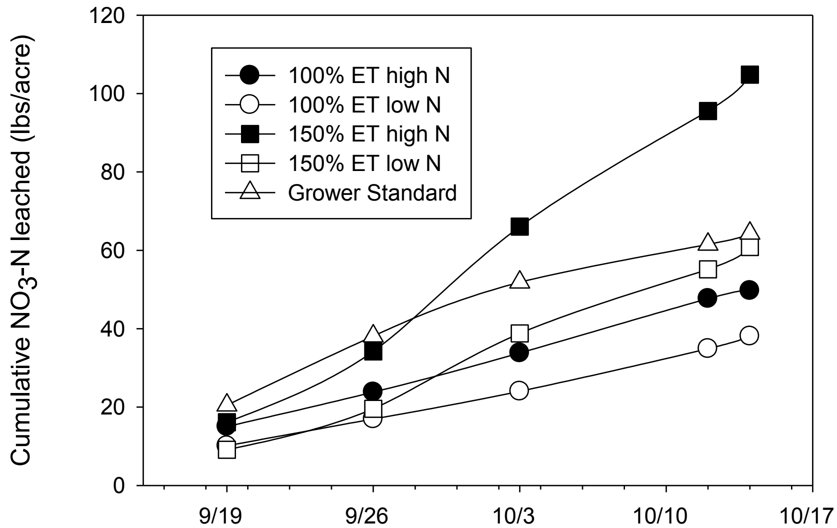


Figure 8. Water and N fertilizer treatment effects on estimated cumulative nitrate leached in romaine lettuce, post thinning (south county trial).

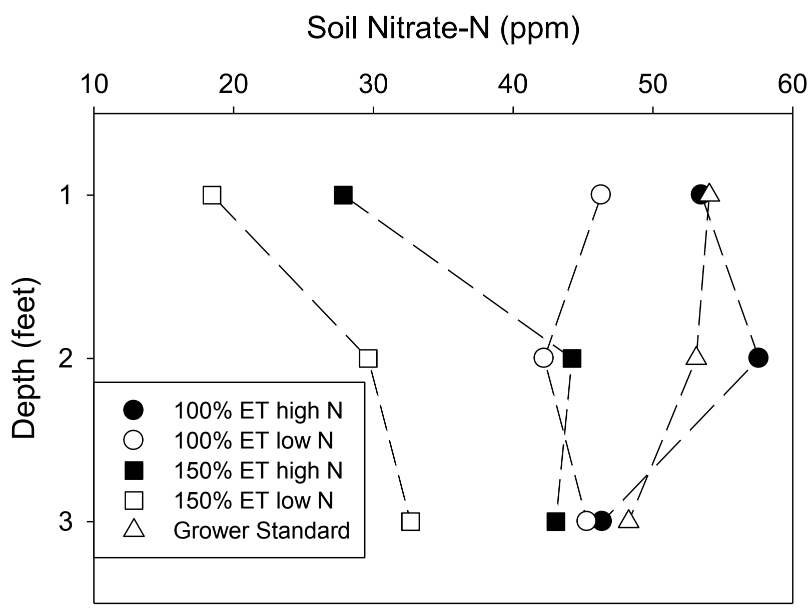


Figure 9. Water and N fertilizer treatment effects on soil nitrate distribution after harvest of iceberg lettuce (north county trial [1]).

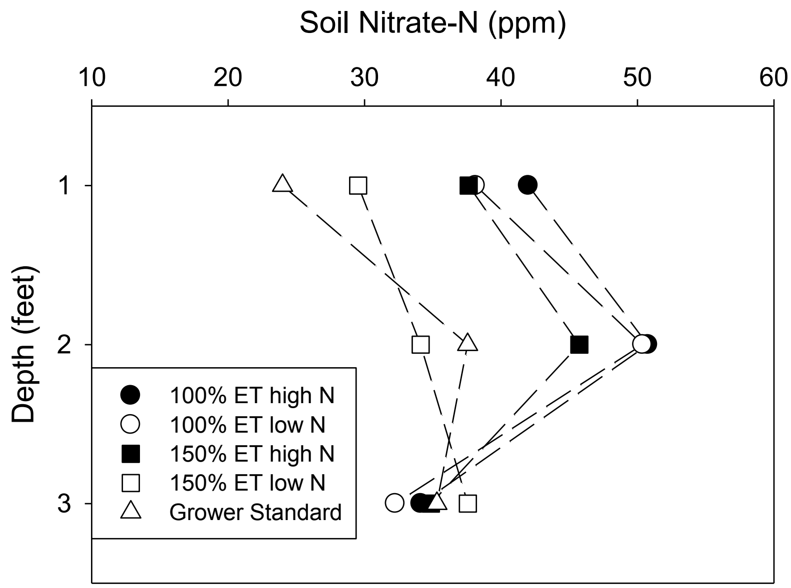


Figure 10. Water and N fertilizer treatment effects on soil nitrate distribution after harvest of romaine lettuce (south county trial [2]).

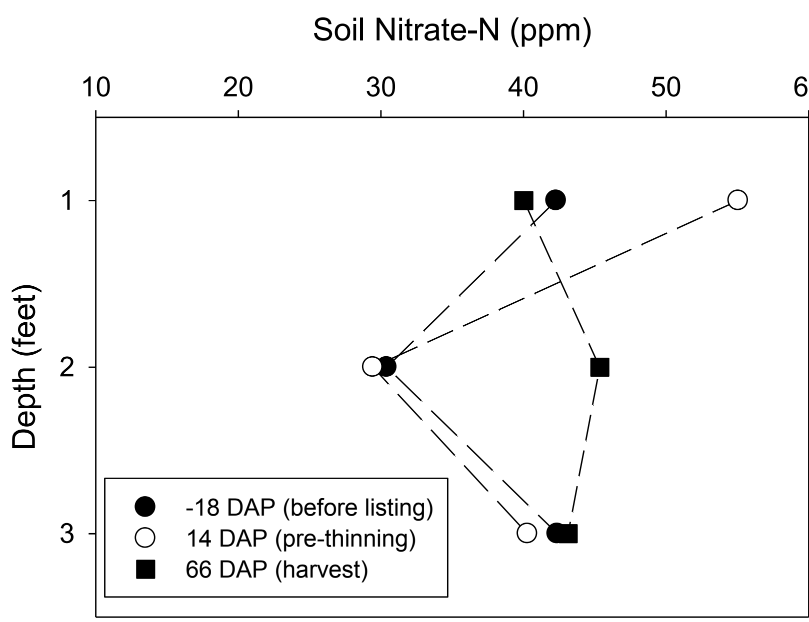


Figure 11. Soil nitrate distribution before planting, after N fertilizer sidedress, and after harvest in iceberg lettuce (north county trial [1]).

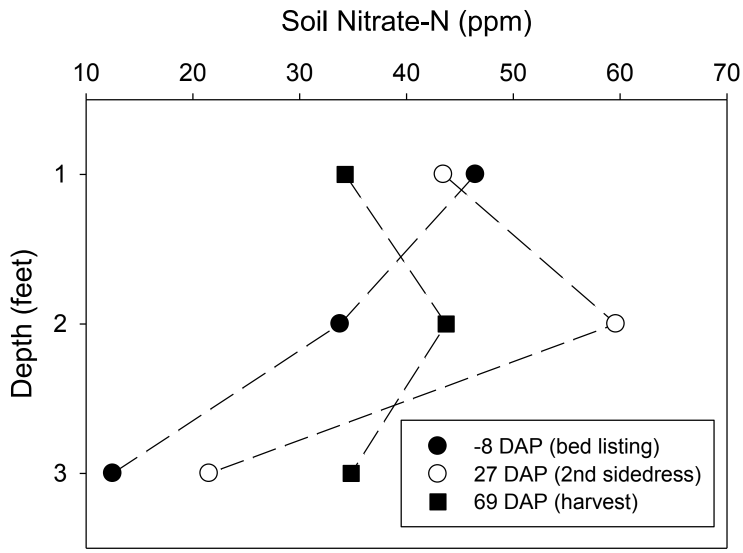


Figure 12. Soil nitrate distribution before planting, after N fertilizer sidedress, and after harvest in romaine lettuce (south county trial [2]).

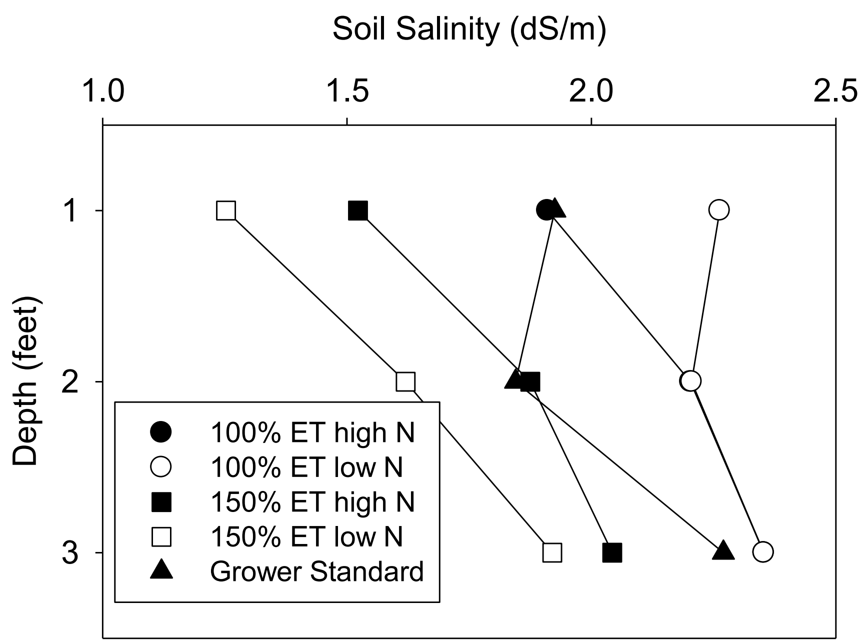


Figure 13. Irrigation and N fertilizer treatment effects on soil salinity measured after harvest in iceberg (north county trial [1]).

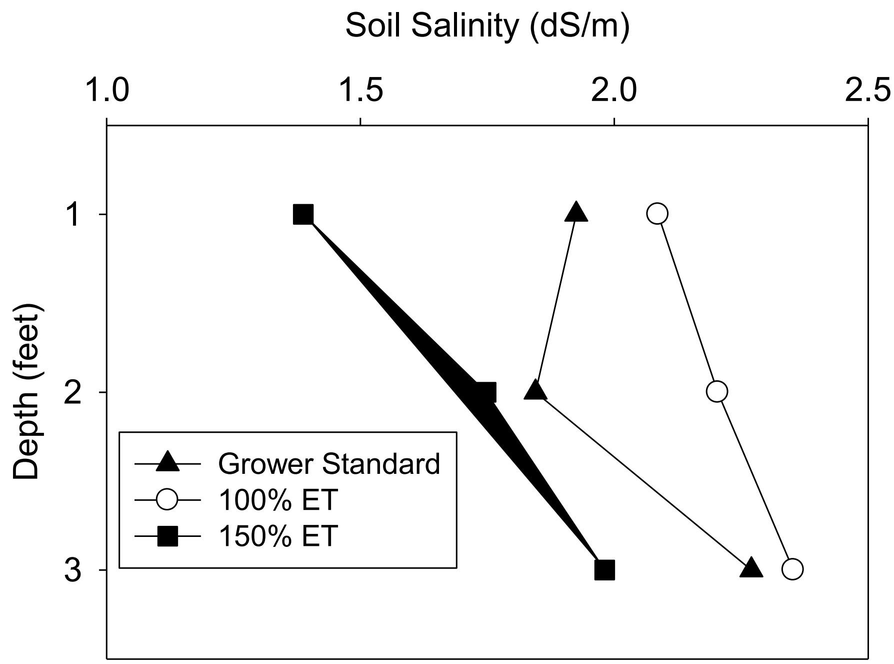


Figure 14. Irrigation treatment effects on soil salinity measured after harvest in iceberg (north county trial [1]).

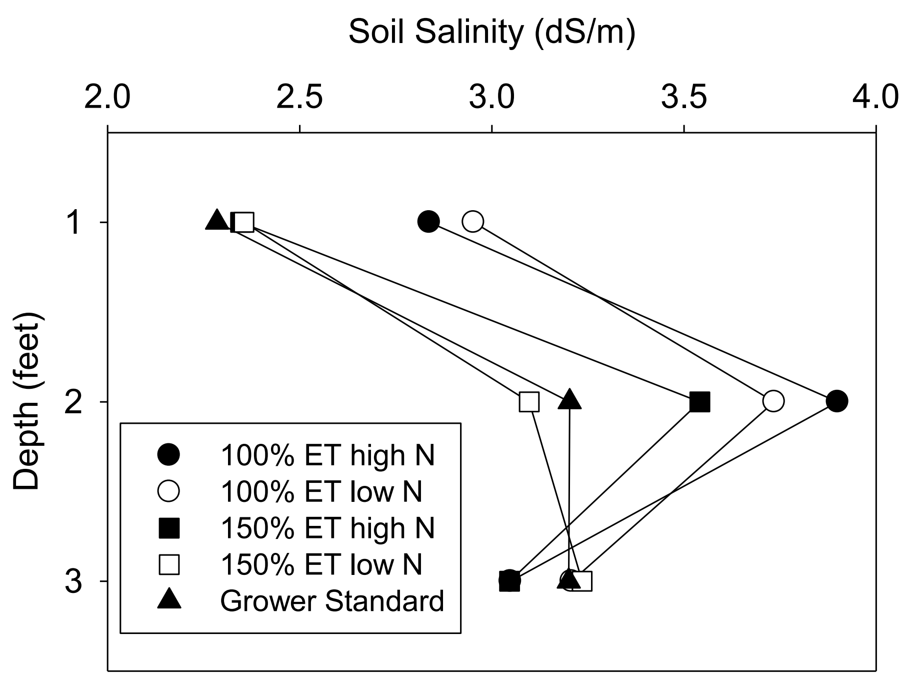


Figure 15. Irrigation and N fertilizer treatment effects on soil salinity measured after harvest in romaine (south county trial [2]).

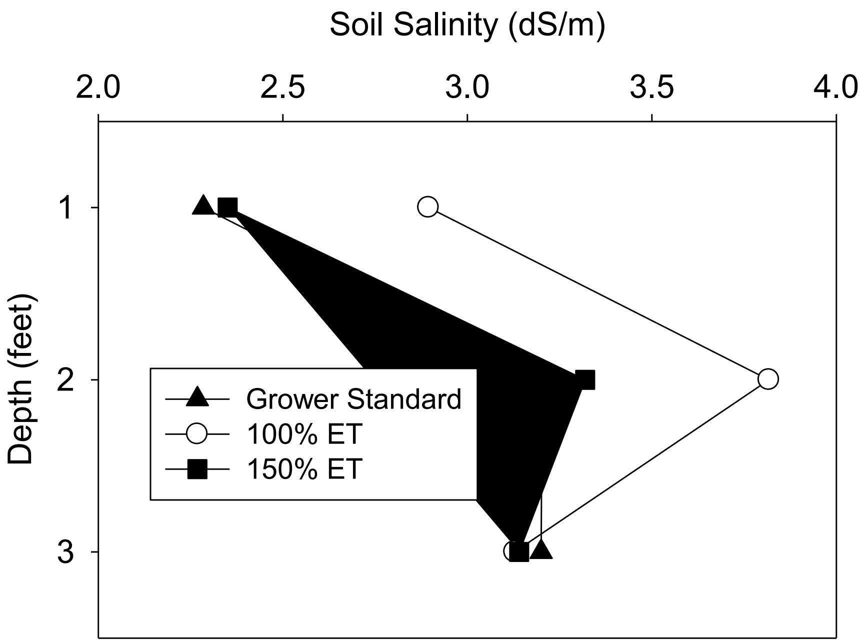


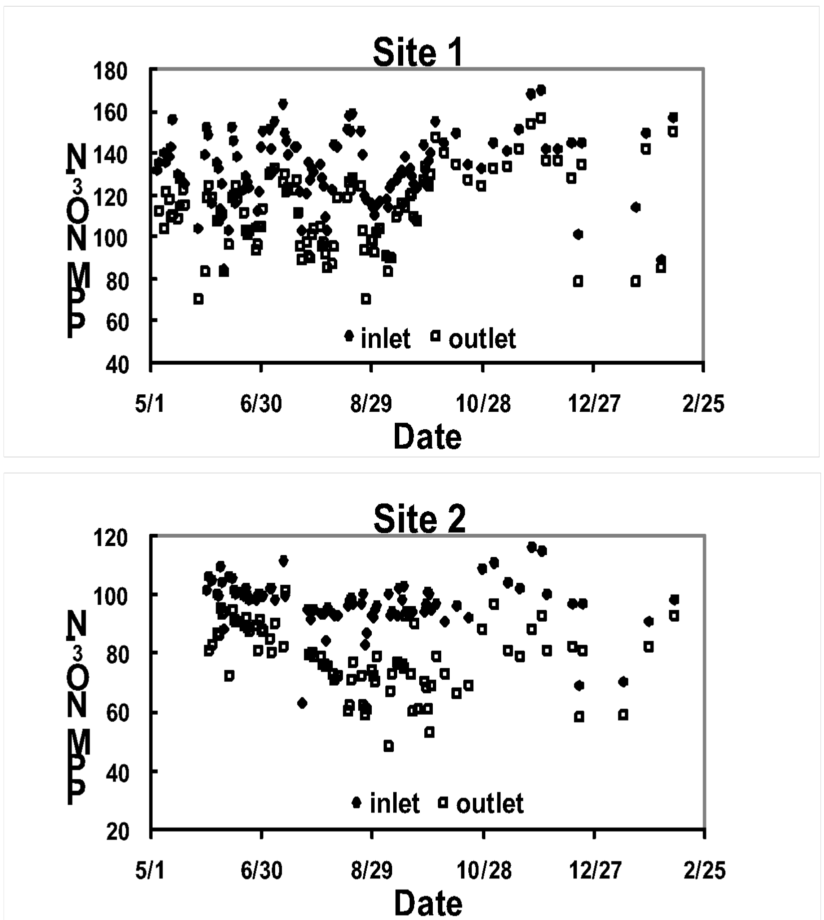
Figure 16. Irrigation treatment effects on soil salinity measured after harvest in romaine (south county trial [2]).

4. Treatment of tailwater or tile drain effluent with 'denitrification beds': Denitrification bioreactors (DBRs) were constructed on two Salinas Valley farms to treat tile drain effluent. The concept behind bioreactors is to utilize anaerobic bacteria to convert nitrate-nitrogen (NO_3-N) in agricultural wastewater into gaseous N_2; this is done by providing an anaerobic environment, and labile carbon to support bacterial growth and function. Pits of 930 and 450 ft^3 volume were dug at sites 1 and 2, respectively, lined with plastic, and filled with chipped construction wood waste (individual pieces 1-3 inches long) obtained from the Monterey Regional Waste Management District. Water from tile drain sumps was continuously pumped through the DBRs at a rate to give an average hydraulic residence time of approximately 2 days. Inflow and outflow from the DBRs were continuously sampled, and NO_3-N and dissolved organic carbon (DOC) was measured in composite samples 3-5 times a week during the production season and once a week during the winter.

Denitrification began within days of the initial filling of the DBRs (Fig. 17) Across sites, denitrification rates averaged approximately 8 PPM NO_3-N per day of residence time during the irrigation season (May through October), and approximately 5 PPM during the winter. The wood chip medium did not supply enough microbially available carbon to maximize denitrification rates. Injection of soluble carbon from molasses (site 1) or ground straw (site 2) increased denitrification by approximately 30%. Another limitation was the temperature of the tile drain water, which averaged only about 61 and 54 ^oF during the summer and winter, respectively; as a biological reaction, denitrification rate is strongly influenced by temperature.

The denitrification rates achieved in the DBRs were substantially higher than those typical of other biologically-based treatment options (vegetated ditches, treatment wetlands, etc.), which in general have been reported to reduce NO3-N concentration by no more than 1-2 PPM per day of residence time. Even using the DBR approach, the high tile drain NO_3-N concentration (an average of approximately 130 and 100 PPM at sites 1 and 2, respectively) would require extended hydraulic residence time for NO_3-N removal to meet the environmental benchmark of 10 PPM. For this technology to be a practical water treatment option it would have to be used in conjunction with improved N fertilization practices that reduced the NO_3-N concentration in tile drain effluent. Both DBRs will continue to be operated through 2012. Additionally, a third bioreactor will be constructed to treat surface runoff on a farm with elevated irrigation water NO_3-N concentration.

Figure 17. Inlet and outlet nitrate levels at sites 1 and 2



5. Outreach/extension: The CropManage website (https://ucanr.org/cropmanage/login/) has been established are provides growers an opportunity for growers to input soil nitrate and irrigation information about specific production blocks. The computer model provides information on nitrogen and irrigation management. This site will be supplemented with crop production information in the future to provide a complete service to the growers in irrigation and nutrient management.