Leaching fraction effects on salt management and nitrate losses in commercial lettuce production

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The Salinas Valley is fortunate to have an ample supply of ground water available for irrigating crops, but as water is applied to fields, it may be adding something that can be detrimental to crop production: salt. Of course, all salts to some degree are needed for plant nutrition, especially calcium, magnesium, potassium, and sulfate, but too much of any salt can slow plant growth. The main effect of excessive salt in soil is that plants have difficulty extracting moisture; growth slows, and yields decrease. In addition, a high concentration of some ions such as sodium and chloride can cause toxicity when absorbed into plant cells.

Previous research has demonstrated that salinity levels greater than 1 deciSiemen per meter (dS/m) in irrigation water can significantly affect yields of lettuce and other leafy greens. Similarly, when soil salinity levels build up to values greater than 2.5 dS/m, yield of lettuce is impacted. A common practice to minimize salt effects on crop growth is to leach the soil profile so that salts move below the root zone. This practice is traditionally done during pre-irrigation and during germination, when more water is applied than is lost by evaporation from the soil surface.

Because many growers have transitioned from using overhead sprinklers to using surface drip for production of lettuce, less leaching may occur during the post-thinning stage of the crop. This is because less water may be applied under drip compared to sprinklers, and because drip tape is positioned to distribute moisture between the rows of plants, forcing salts to accumulate in the plant rows. Applying extra water during the drip phase of the crop to minimize salt accumulation in the root zone could lead to a significant loss of nitrate-N during the period when the crop has the greatest nitrogen demand. In this situation, a higher N fertilizer rate may be needed to compensate for N losses associated with applying extra water for salt control.

To understand the balance between N fertilizer requirement and leaching fraction during the drip phase of lettuce production, we conducted replicated irrigation trials in commercial fields. Trials were designed to investigate if leaching in the early stages of the crop, such as before planting and during stand establishment was sufficient to sustain production through the remaining crop cycle, and to determine if extra N fertilizer is needed when a leaching fraction is applied during the drip phase of the crop. Irrigation treatments of 100% and 150% of crop evapotranspiration (ET) were imposed after thinning in drip-irrigated lettuce fields to create leaching fractions of 0% and 50% (Table 1). High and low rates of nitrogen fertilizer (Table 2) were applied to the irrigation treatments to determine if additional N fertilizer was needed to sustain production under higher leaching fractions.

We conducted trials in regions representing different growing environments and water sources. 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. A blend of recycled, ground, and surfaced water was used to irrigate Trial 1 and only ground water was used for irrigating Trial 2. Salinity levels in the soil profile were evaluated before pre-plant irrigation, after emergence, and at crop maturity. Irrigations were scheduled following the growers' standard practices. Pre-plant, germination, and post thinning applied water volumes were measured using flow meters (Table 1). Fertilizer N rates differed by more than 50 lbs N/acre between the high and low N treatments at each trial site during the drip phase of the crop (Table 2). Soil nitrate, crop N uptake, and concentration of salts and nitrate in leachate were monitored during the crop cycle. Suction lysimeter tubes were used to collect leachate during each drip irrigation event. Marketable yield, biomass, and total N uptake were evaluated at crop maturity.

Results

Leaching fraction and N management effects on yield Leaching fraction had varying effects on yield for the 2 field trials. The irrigation treatments had no effect on yield (Table 3) at the north county trial (Trial 1) ; however, biomass and marketable yields were lower than the industry average at this trial and crop ET was also low. At the south county trial (Trial 2), marketable and biomass yields were highest under the 150% crop ET treatment (Table 4). 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 Trial 2 (Table 4), where soil NO_3-N concentrations were greater than 40 ppm in the 100% ET, high N treatment.

Irrigation treatment effects on soil salinity Salinity levels of the soil profile after harvest were highest under the 100% ET treatment for both trials (Figs. 1 and 2).). Soil salinity levels increased with depth, demonstrating that salts were leached from the surface during the drip phase of the crop (Figs. 1 and 2). The lowest salinity levels at the 1 foot depth were measured under the 150% ET treatment at both trials. Bulk salinity (EC), calcium, sodium, and chloride levels in the 0 to 3 foot depths were statistically lowest in the 150% ET treatment at harvest (data not presented).

Salinity effects on lettuce production. The buildup of soil salinity appeared to impact lettuce yield at Trial 2 (south county trial). Yields were lowest for the 100% ET treatment where soil salinity levels at the 0 to 1 foot depth were greater than 2.5 dS/m (Fig. 2). In contrast, at the north county trial, where yield was not affected by the irrigation treatments, soil salinity was less than 2.5 dS/m at the 1 foot depth for all treatments.

Irrigation treatment effects on leaching of nitrate and salts A leaching fraction greater than 150% of crop ET during the drip phase of the lettuce crops increased estimated losses of salt and nitrate-N compared to the 100% of crop ET treatment at both trials (Figs. 3-6).   Nitrate-N losses were estimated to range from 10 to 40 lbs/acre and 40 to 100 lbs/acre for Trials 1 and 2, respectively. The highest N losses due to leaching occurred in the 150% ET, high N treatment for both trials (Figs. 3 and 4).   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. 7 and 8). However, in neither trial were soil nitrate levels at levels (< 20 ppm NO_3-N) that would be expected to cause yield loss. The total salt estimated to have been leached ranged from 100 to 400 lb/acre and 400 to 1600 lb/acre at Trials 1 and 2, respectively (Figs. 5 and 6). The greatest amount of salt was leached under the 150% ET treatments for both trials. Also, salinity concentration measured in the upper 2 feet of the soil profile was lowest in the 150% ET treatment at both trials after harvest (Figs. 9 and 10), indicating that without a substantial leaching fraction soil salinity levels increased significantly.

Conclusions

The results of these field trials demonstrated that applying a 50% leaching fraction (150% of crop ET) reduced salt accumulation in the soil profile and increased yield during the drip phase of lettuce production under conditions where soil or water salinity was moderately high.   Extra water applied to leach salts also resulted in an increased loss of nitrate-N from the soil profile. Additional fertilizer N to compensate for leaching of nitrate-N was not necessary to maintain yields, presumably because nitrate levels were substantially above 20 ppm nitrate-N in the top foot of soil.   The results also demonstrated that the best strategy to manage salts in soils with high salinity and minimize associated nitrate leaching is to use a leaching fraction of approximately 50% and maintain nitrate-N levels above 20 ppm in the top 1 foot layer of soil. The quick nitrate test is a useful tool for growers to assess whether additional fertilizer N is required to maintain an adequate level of mineral N in the soil.

Acknowledgements
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Table 1. Summary of irrigation water volumes applied at 2011 lettuce trials. Trial 1 was conducted in north county and Trial 2 was conducted in South County.

	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 2. 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 3. 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 4. 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

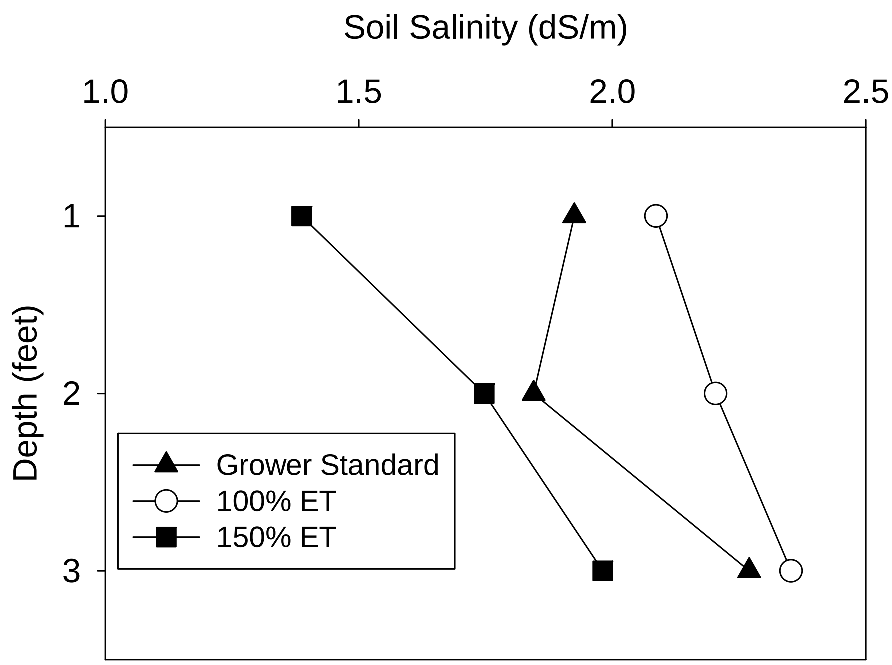

Figure 1. Irrigation treatment effects on soil salinity measured after harvest in iceberg (north county trial [1]). Means for the 100% and 150% ET treatments represent the average of the high and low N treatments.

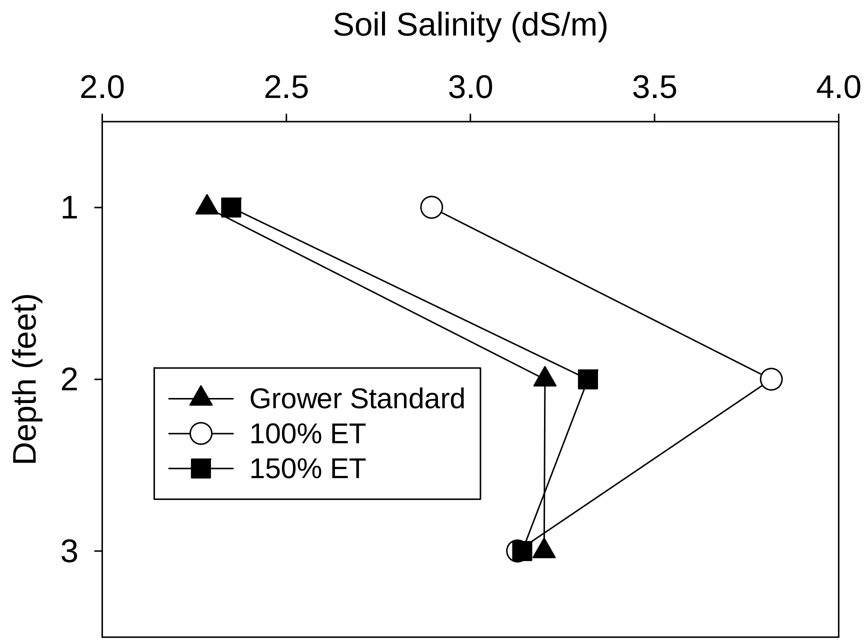

Figure 2. Irrigation treatment effects on soil salinity measured after harvest in romaine (south county trial [2]). Means for the 100% and 150% ET treatments represent the average of the high and low N treatments.

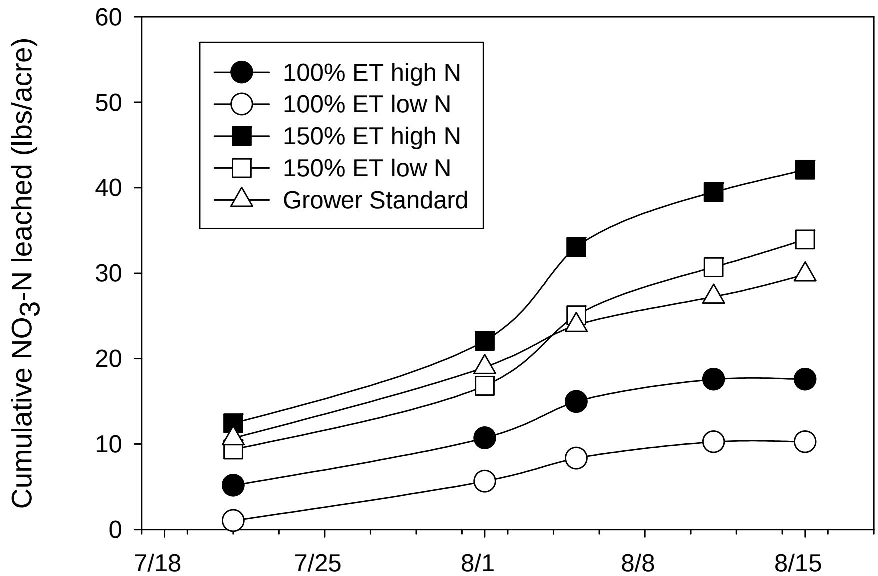

Figure 3. Water and N fertilizer treatment effects on cumulative nitrate leached in iceberg lettuce, post thinning (north county trial [1]).

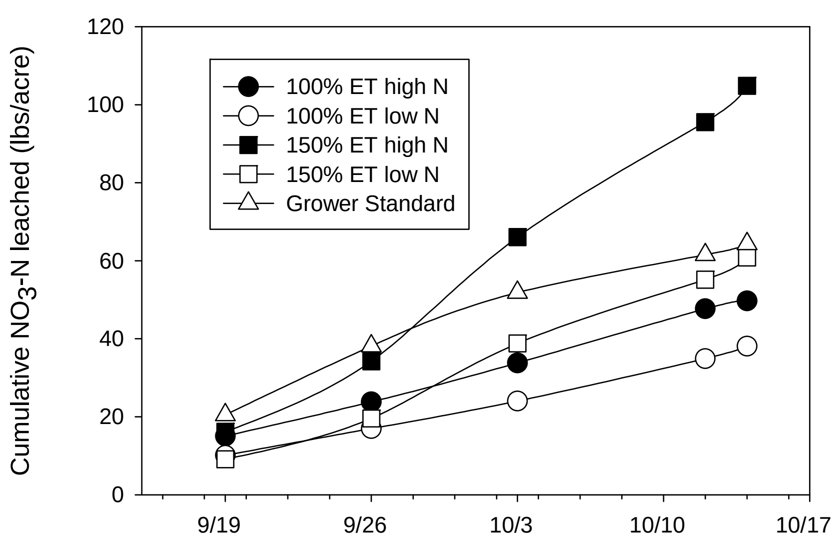

Figure 4. Water and N fertilizer treatment effects on cumulative nitrate leached in romaine lettuce, post thinning (south county trial [2]).

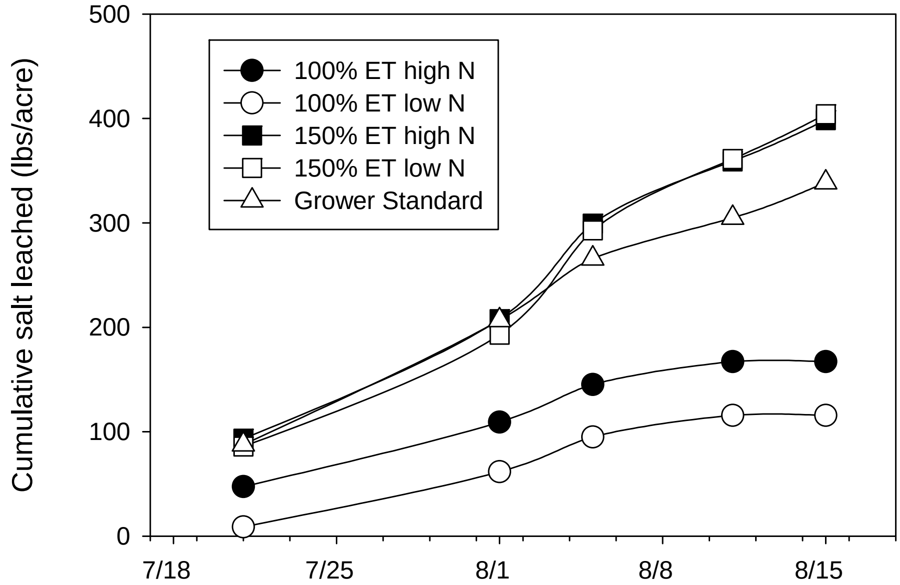

Figure 5. Water and N fertilizer treatment effects on cumulative salt leached in iceberg lettuce crop, post thinning (north county trial [1]).

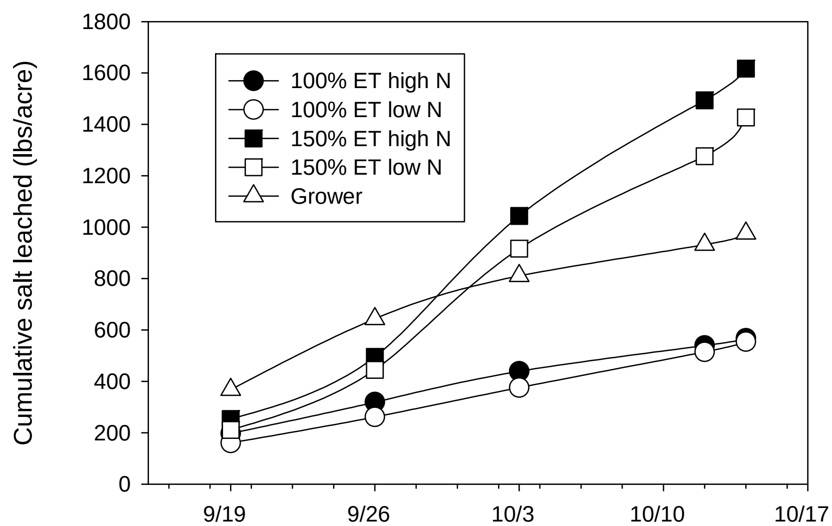

Figure 6. Water and N fertilizer treatment effects on cumulative salt leached in romaine lettuce, post thinning (south county trial [2]).

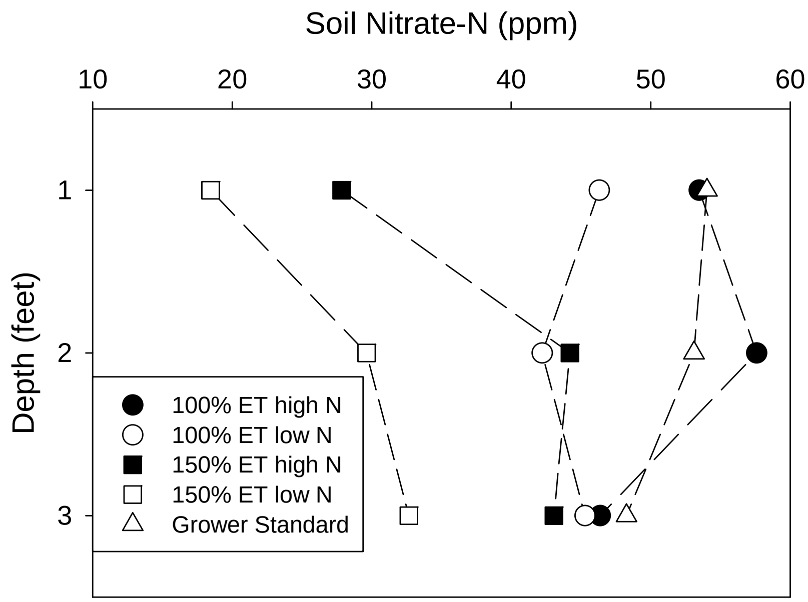

Figure 7. Water and N fertilizer treatment effects on soil nitrate distribution after harvest of iceberg lettuce (north county trial [1]).

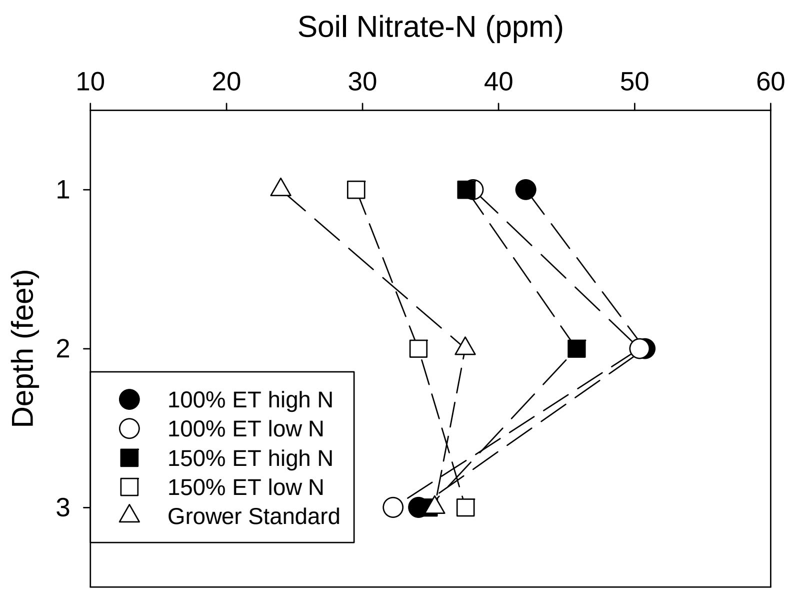

Figure 8. Water and N fertilizer treatment effects on soil nitrate distribution after harvest of romaine lettuce (south county trial [2]).

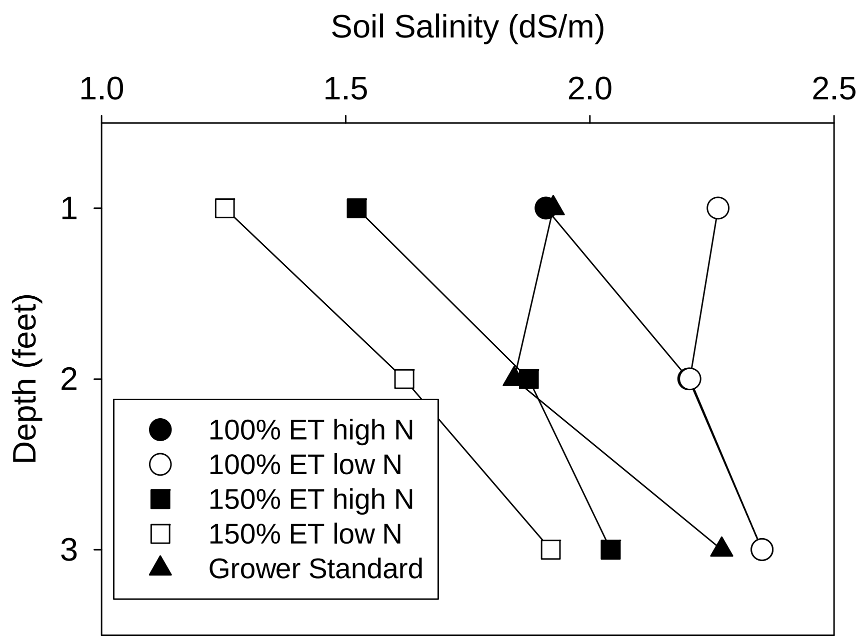

Figure 9. Irrigation and N fertilizer treatment effects on soil salinity measured after harvest in iceberg (north county trial [1]).

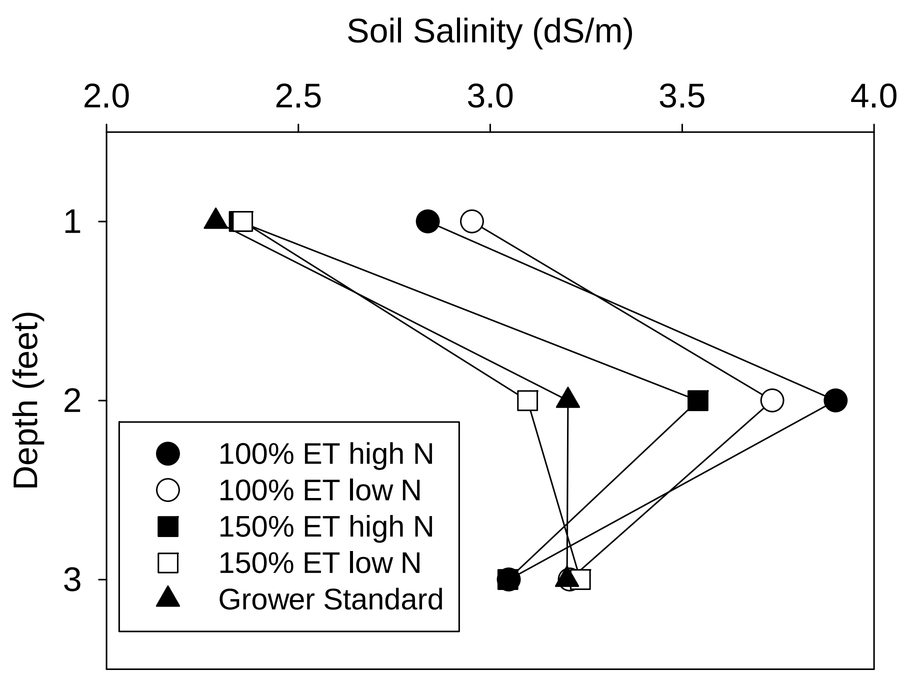

Figure 10. Irrigation and N fertilizer treatment effects on soil salinity measured after harvest in romaine (south county trial [2]).