CALIFORNIA LETTUCE RESEARCH BOARD
April 1, 2010 – March 31, 2011

Title: Evaluation and demonstration of best management irrigation and nutrient management practices (BMP) to safeguard water quality

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

SUMMARY

Water quality regulations proposed by the Central Coast Regional Water Quality Control Board (CCRWQCB) will likely require agriculture to reduce discharges of nitrate-nitrogen (NO_3-N) to surface and ground water. Monitoring carried out by the Cooperative Monitoring Program (CMP) of surface waters throughout the coastal lettuce production region have indicated that nutrient loads are commonly out of the acceptable range. To comply with proposed water quality regulations, growers on the Central Coast are in need of assistance in implementing practices that reduce losses of nitrate-N from vegetable fields. Research has shown the close connection of irrigation practices to nitrogen fertilizer use efficiency. Given the availability of tools and information for effectively managing applied nitrogen and irrigation water, it is important that ways of incorporating this knowledge into grower practice be explored.

The research reported here was comprised of three components: 1) outreach and demonstration trials; 2) evaluations of nitrate leaching and phosphorus losses from organic production; and 3) replicated nitrogen and water management evaluation in head and leaf lettuce. In the outreach and demonstration trials, we worked with cooperating growers and demonstrated the utility of accounting for residual soil nitrate in making fertilizer application decisions. We reduced nitrogen applications by 32% and in four of five trials did not reduce the yield of lettuce as measured by commercial harvests. The reduction in applied fertilizer did not reduce nitrogen uptake by the crop. In the evaluations of organic lettuce production, two of the fields that were monitored had low levels of nitrate leaching, but one had elevated levels of nitrate leaching indicating that organic production can have a range of nitrate loss due to leaching. In the replicated nitrogen and irrigation trials, three irrigation and nitrogen regimes were imposed: 1) grower's strategy for managing nitrogen fertilizer and scheduling irrigations; 2) utilized the nitrate quick test to guide nitrogen fertilizer applications and water was applied between 125% and 150% of crop ET and the irrigation interval was 6 to 7 days; and 3) utilized the nitrate quick test to guide nitrogen fertilizer applications and water was applied water at 100% of crop ET and the irrigation interval was 4 to 5 days. Fertilizer N inputs were reduced by 127 and 59 lbs N/A in the head and romaine trials, respectively in the 4 & 7 day treatments relative to the grower treatment. Less water was applied to the 4-day treatment and less water and nitrate was leached in this treatment in both trials. Marketable yield and N uptake were not different among treatments in either trial. Nitrogen fertilization did not affect post harvest lettuce quality or intensity of browning of tissue.

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Objectives: To evaluate and demonstrate nitrogen and irrigation management in commercial lettuce production

PROCEDURES AND RESULTS:

Outreach and demonstration trials: We worked closely with growers managing irrigation and nutrient application on 6 commercial lettuce production fields. Strips, the width of a harvest machine (6 to 12 rows wide), were established in growers fields. In the strip nitrogen was monitored on a weekly basis, and if residual soil nitrate levels were high enough, fertilizer application was either skipped or reduced. Flow meters were installed to evaluate amounts of irrigation water applied to the fields. Growers were emailed the results of the soil and water evaluations on a weekly basis to provide the information that we used to base our fertilizer decisions. The treatments were evaluated for the following: soil mineral nitrogen (weekly), and biomass N (3×per crop), yield and quality evaluations. Commercial yields were obtained by obtaining box counts from the harvest crew.

Organic Production Evaluations

Fertilizer management practices, crop nutrient status and the potential for environmental nutrient loss was evaluated in three organic lettuce fields. All nutrient inputs were quantified (cover crop N content, compost or preplant fertilizer N and P, and any sidedress N application). Soil mineral N concentration was monitored on a weekly basis, and crop N uptake every other week. Soil NO_3-N concentrations in leachate were measured by vacuum lysimeters for each irrigation event; soil moisture and irrigation volume was measured to allow the calculation of nitrate leaching loss. Phosphorus levels in the three soils were measured. Runoff from the soils was simulated by applying water to flats of soil and measuring the phosphate content of the water to determine the potential for phosphorus loss in surface runoff.

Commercial BMP Evaluation – Conventional Production: Two trials evaluating the impact of irrigation management on nitrogen fertility were conducted in a commercial lettuce production field. Lettuce was germinated with overhead sprinklers, and subsequently irrigated with surface drip. Three irrigation/nitrogen treatments were established post thinning during the drip phase of the crop (Table 1): Treatment 1 was the grower's strategy for managing nitrogen fertilizer and scheduling irrigations. Treatment 2 utilized the nitrate quick test to guide nitrogen fertilizer applications and water was applied between 125% and 150% of crop ET and the irrigation interval was 6 to 7 days. Treatment 3 utilized the nitrate quick test to guide nitrogen fertilizer applications and water was applied water at 100% of crop ET and the irrigation interval was 4 to 5 days. The irrigation intervals of treatments 2 and 3 were adjusted for crop stage, soil type, weather conditions and pesticide spray events.

Table 1. Irrigation/nitrogen management treatments.

Treatment	Nitrogen management	Irrigation Management
1	Grower Standard	Grower Standard
2	Nitrate quick test[1]	5-7 day irrigation intervals[2]
3	Nitrate quick test[1]	4-5 day irrigation intervals[2]

[1] nitrogen will be applied based on the use of the nitrate quick test using 20 ppm of nitrate-N as the threshold for fertilizer application

[2] irrigation amount based on evapotranspiration data and soil water holding capacity.

Treatments were replicated four times in a randomized complete block design and individual plots were approximately 100 feet in length and 4 beds in width. The center 2 beds were used for harvest and plant evaluations. The irrigation treatments were accomplished using a manifold plumbed into the growers mainline. Applied water in each treatment was monitored with flow meters. Fertilizer and irrigation decisions were carried out in close consultation with the grower. The treatments were evaluated for the following: soil mineral nitrogen (weekly), leaf tissue nitrate-N and total N (3×per crop), nitrate leaching with lysimeters (at each irrigation event), soil moisture tension using watermarks sensors, volumetric soil moisture using neutron probe (at each irrigation event), yield and quality evaluations. The effects of irrigation and nitrogen management on postharvest lettuce quality were evaluated in several ways. At harvest, total N, NO_3-N and dry matter concentration of head tissue was determined. Samples of midrib tissue were analyzed for phenylalanine ammonia lyase (PAL) activity; elevated PAL activity can enhance the production of phenolic compounds responsible for browning in lightly processed lettuce.

Results

Outreach and demonstration trials: Average applied nitrogen fertilizer rates in the grower standard and BMP managed strips was 221 and 149 lb N/A, respectively which is a 72 lb N/acre (32.1%) reduction (Table 2a). Nitrogen uptake in the total crop biomass at harvest in the standard and BMP treatments was 107 and 110 lb N/A, respectively; although there was some variability in the uptake of some fields, the increased nitrogen fertilizer in the standard treatment did not result in greater nitrogen uptake by the crop. There was lower nitrate in the soil over the growing season in the BMP strips, but were still above the level considered adequate for optimal growth (20 ppm nitrate-N). Seasonal applied water at the 6 trials ranged from 5.1 to 21.4 inches (Table 3). Average seasonal crop ET was 6.8 inches. The lowest soil nitrate levels were measured at sites where water applications were highest. Total biomass evaluations did not detect a difference in yield between the grower standard and BMP treatments. However, average commercial yields of the BMP treatments were 97% of the yield of the grower standard Table 2b). Commercial yields did not differ at some sites, but were most affected at site no. 4 where, due to logistical issues related to the furrow irrigation, we were not able to apply a late season fertilizer application to the BMP treatment and suffered yield loss accordingly.

Organic Evaluations: We monitored soil nitrogen and phosphorus characteristics at three organically managed blocks from Salinas to San Juan Bautista. The blocks varied widely in soil type, irrigation efficiency, water drainage through the soil and estimates of leached nitrogen. Site no. 1 had coarse textured soil with high initial background nitrate levels. A great deal of nitrate was leached in the germination phase of the growth cycle which ultimately led to high overall nitrate losses at this site (Table 4a). The other two sites had more moderate levels of nitrate in the soil throughout the growing cycle, and low nitrate leaching losses over the growing cycle. Soil phosphorus levels at all three sites were high and estimates of phosphate-phosphorus in surface water runoff were all above currently proposed TMDL levels (Table 4b).

Replicated Irrigation and Nutrient Management Trials: The 4-day irrigation interval required less water than either the 7 day and grower treatments in both the head and romaine trials while maintaining similar soil moisture tensions (Tables 5 & 6; Figures 1 & 2). Use of the nitrate quick test in the 4 day and 7 day treatments allowed a reduction of sidedress N relative to the grower standard of 127 and 59 lb/acre in the head and romaine trials, respectively. Estimated post-thinning drainage was several times higher for the grower and 7-day interval treatments compared to the 4-day interval in both trials. Additionally, the least amount of N was leached under the 4-day interval treatment at both sites. Residual soil nitrate after harvest was highest at the 2 and 3 foot depths under the grower standard treatment which had received the highest fertilizer N rate and 140% of crop ET in the head lettuce trial (Figure 3). Residual soil nitrate after harvest was highest at the 1 foot depth under the 7-day treatment which received 140% of crop ET in the romaine trial. Marketable yield and uptake of N were not statistically different among treatments at either trial (Table 7). However, the biomass yield, trimmed and untrimmed head weights and plant population were statistically different in the romaine trial (Table 8). Since the 4 day and 7 day treatments received the same N input, the lower mean head weight and total biomass in the 4 day treatment may have been due to the lower soil moisture level in the last week before harvest.

Nitrogen fertilization and irrigation management had no consistent effect on postharvest lettuce quality (Table 9). In the iceberg trial, the grower treatment had somewhat greater PAL activity after 3 days of storage than the BMP treatment utilizing a 7 day irrigation interval, but that difference was not evidenced by more browning at later evaluation dates. In fact, after 3 and 9 days of storage the browning intensity was greatest in the BMP treatment utilizing the 7 day irrigation interval. No treatment differences in either PAL activity or tissue browning intensity were observed in the romaine trial. Visual evaluation of the romaine lettuce also showed no treatment effects (Fig. 4).

Table 2a. Characteristics of demonstration strips, fertilizer applications, soil nitrate, crop nitrogen uptake and yield evaluations

Trial	Crop Bed width (seedlines)	Grower	BMP	BMP Nitrogen Reduction Lbs N/A (%)	Grower	BMP	Grower	BMP
		Total Applied Nitrogen (lbs N/A)			Biomass N Lbs N/A		Mean seasonal soil nitrate ppm N03-N	
1	Head 40"/2	192.5	135.2	57.3 (29.8)	112	111	49.4	33.5
2	Head 40"/2	165.2	165.2	0.0 (0.0)	89	97	23.9	23.6
3	Head 80"/5	302.5	160.5	142.0 (46.9)	121	128	31.0	22.4
4	Head 40"/2	148.3	63.5	84.8 (57.2)	134	138	46.5	27.2
5	Romaine 80"/6	293.3	229.1	64.2 (21.9)	107	105	63.3	55.6
6	Head 40"/2	228.3	144.3	84.0 (36.8)	80	79	12.5	14.8
Average		221.7	149.6	72.1 (32.1)	107	110	37.8	29.5

Table 2b. Soil characteristics, irrigation system and yield evaluations

Trial	Soil	Grower	BMP	BMP relative yield (% of grower)	Grower	BMP	BMP relative yield (% of grower)
		Total harvest biomass (tons/A)			Commercial harvest (boxes/A)[1]		
1	sandy loam & silty clay	31.5	31.9	101.2	1112	1136	102.2
2	clay loam	27.5	29.1	106.0	1163	1075	92.4
3	clay loam	29.2	31.8	109.0	947	1054	111.3
4	silty clay	38.7	41.9	108.3	1179	1004	85.2
5	clay loam	36.1	34.3	94.9	712	703	98.7
6	clay	21.7	22.0	101.3	NA[2]	NA[2]	NA[2]
Average		30.8	31.8	103.5	1023	994	97

1 - Total box counts for head lettuce include jumbo 24's, 24's, and 30's; Romaine = 36 hearts/box
2 – Bulk lettuce harvest and data not available

Table 3. Estimated crop ET and applied water at commercial organic and conventional lettuce sites.

site code	production method	Irrigation method	Lettuce type	Crop ET	Applied Water: establishment	Applied Water: post-establishment	Applied Water: total	Applied Water: % of ETc
				------------------- inches	---------------------			
O1	organic	sprinkler	romaine	8.6	5.9	9.5	15.4	179
O2	organic	sprinkler/drip	romaine	7.3	4.4	5.9	10.4	142
O3	organic	sprinkler	leaf baby	4.8	3.4	3.5	6.9	145
C1	conventional	sprinkler/drip	head	5.4	2.1	3.0	5.1	94
C2	conventional	drip	head	5.5	4.1	5.2	9.3	169
C3	conventional	sprinkler/drip	head	8.8	6.6	10.8	17.4	198
C4	conventional	sprinkler/furrow	head	8.5	7.1	14.3	21.4	252
C5	conventional	sprinkler	romaine	7.1	4.2	7.7	11.9	167
C6	conventional	sprinkler	head	5.7	--	10.6	--	>187
AVG	organic			6.9	4.6	6.3	10.9	155
	conventional			6.8	4.8	8.6	13.0	178

Table 4a. Organic evaluations: Characteristics of organic sites and evaluations of soil and lysimeter NO_3-N and N losses

Trial	Lettuce type & bed width	Soil Type	Total N Applied Lbs/A	Soil NO_3-N ppm mean and range	Lysimeter NO_3-N ppm mean and range	Total drainage inches	N leaching loss Lbs N/A
1	Romaine 80”	loam	125.2[1]	19.8 (6.0-35.7)	135.2 (45.7-250.5)	5.3	180.9
2	Romaine 40”	silt loam	172.2[2]	18.2 (11.3-24.6)	23.7 (5.1-49.2)	2.8	15.9
3	Baby leaf 80”	silty clay loam	80.0[3]	20.9 (14.6-30.6)	22.6 (6.8-31.6)	3.8	19.2

Nitrogen fertilizer applied to each trial:
1 – preplant and sidedress: 52.0 lbs N/A dry; total; 73.2 lbs N/A liquid; total = 125.2 lbs N/A.
2 – preplant and sidedress: 120 lbs N/A compost; 48 lbs N/A dry; 4.2 lbs N/A liquid; total = 172.2.
3 – preplant: 80 lbs N/A dry; total = 80.0 lbs N/A.

Table 4b. Organic evaluations: Soil phosphorus, phosphate in runoff and yield and biomass N

Trial	Soil phosphorus (bicarbonate) ppm	Phosphate in runoff ppm	Yield Fresh T/A	Biomass N at harvest Lbs N/A
1	113.2	0.45	23.7	93.4
2	77.4	0.39	14.4	77.2
3	78.0	0.33	8.9	39.3

Table 5. Head lettuce. Applied water, applied fertilizer N, average nitrate concentration in soil and leachate, and estimated leaching losses of nitrate-N

Treatment	Applied water: Post thinning		Applied water: Total	Post-thinning drainage	Applied N	Average soil nitrate-N	Average nitrate-N in leachate	Estimated leaching losses
	inches	% ETc	----- inches -----		lb/acre	--------- ppm --------		lb/acre
4-day	5.5	101	9.1	0.7	127	26.0	21.0	4.6
7-day	7.7	142	11.3	2.2	127	21.4	18.9	4.7
grower	7.3	134	10.9	2.1	253	44.6	44.5	30.2

Table 6. Romaine lettuce. Applied water, applied fertilizer N, average nitrate concentration in soil and leachate, and estimated leaching losses of nitrate-N

Treatment	Applied water: Post thinning		Applied water: Total	Post-thinning drainage	Applied N	Average soil nitrate-N	Average nitrate-N in leachate	Estimated leaching losses
	inches	% ETc	----- inches -----		lb/acre	--------- ppm --------		lb/acre
4-day	3.5	103	7.4	0.32	130	28.9	46.9	5.8
7-day	4.7	140	8.6	1.42	130	26.1	61.1	21.7
grower	4.6	137	8.5	1.26	189	47.9	36.2	10.5

Table 7. Head lettuce. Head weight, plant population, yield, and crop uptake of N

Treatment	Head Weight: Untrimmed	Head Weight: Trimmed	Plant Population: Marketable	Plant Population: Diseased	Yield: Marketable	Yield: Biomass	Crop N uptake: Total	Crop N uptake: Harvested
	------- lb/head --------		----- plants/acre ----		------------------- lbs/acre -----------------			
4-day	2.493	1.72	39685	883	68350	101080	108	73
7-day	2.483	1.68	41156	441	69363	103339	116	78
grower	2.546	1.72	40241	343	69023	103231	129	86
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns	ns

^{ns} means are not statistically different at $p < 0.05$ level

Table 8. Romaine lettuce. Head weight, plant population, yield, and crop uptake of N

Treatment	Head Weight: Untrimmed	Head Weight: Trimmed	Plant population: Marketable	Plant population: Diseased	Yield: Marketable	Yield: Biomass	Crop N uptake: Total	Crop N uptake: Harvested
	------- lb/head --------		----- plants/acre ----		------------------- lbs/acre -----------------			
4-day	1.627	0.45	34640	5200	15664	64832	129	31
7-day	1.829	0.51	32539	6688	16542	71775	135	31
grower	1.743	0.48	35809	4971	17265	71065	129	31
$LSD_{0.05}$	0.11	0.07	2265	ns	ns	4407	ns	ns

^{ns} means are not statistically different at $p < 0.05$ level

Table 9. Effect of N fertilization and irrigation practices on phenylalanine ammonia lyase (PAL) activity (µmol cinnamic acid h^{-1} g^{-1}) and browning intensity (absorbance at 320 nm) of minimally processed lettuce.

Trial	Measurement	Storage duration (days)	Treatment		
			Grower	4 day	7 day
Iceberg	PAL activity	0	0.03a*	0.04a	0.02a
		3	0.06b	0.04ab	0.03a
		6	0.03a	0.03a	0.03a
		9	0.03a	0.03a	0.03a
Romaine		0	0.03a	0.07a	0.05a
		3	0.15a	0.15a	0.14a
		6	0.09a	0.08a	0.09a
		9	0.04a	0.06a	0.05a
Iceberg	Browning intensity	0	0.27a	0.27a	0.29a
		3	0.38a	0.45ab	0.49b
		6	0.54a	0.67a	0.68a
		9	0.63a	0.70ab	0.81b
Romaine		0	0.40a	0.38a	0.34a
		3	0.42a	0.46a	0.43a
		6	0.47a	0.52a	0.48a
		9	0.56a	0.59a	0.60a

* within rows, means followed by the same letter not significantly different at $p = 0.05$, by Tukey's mean separation test.

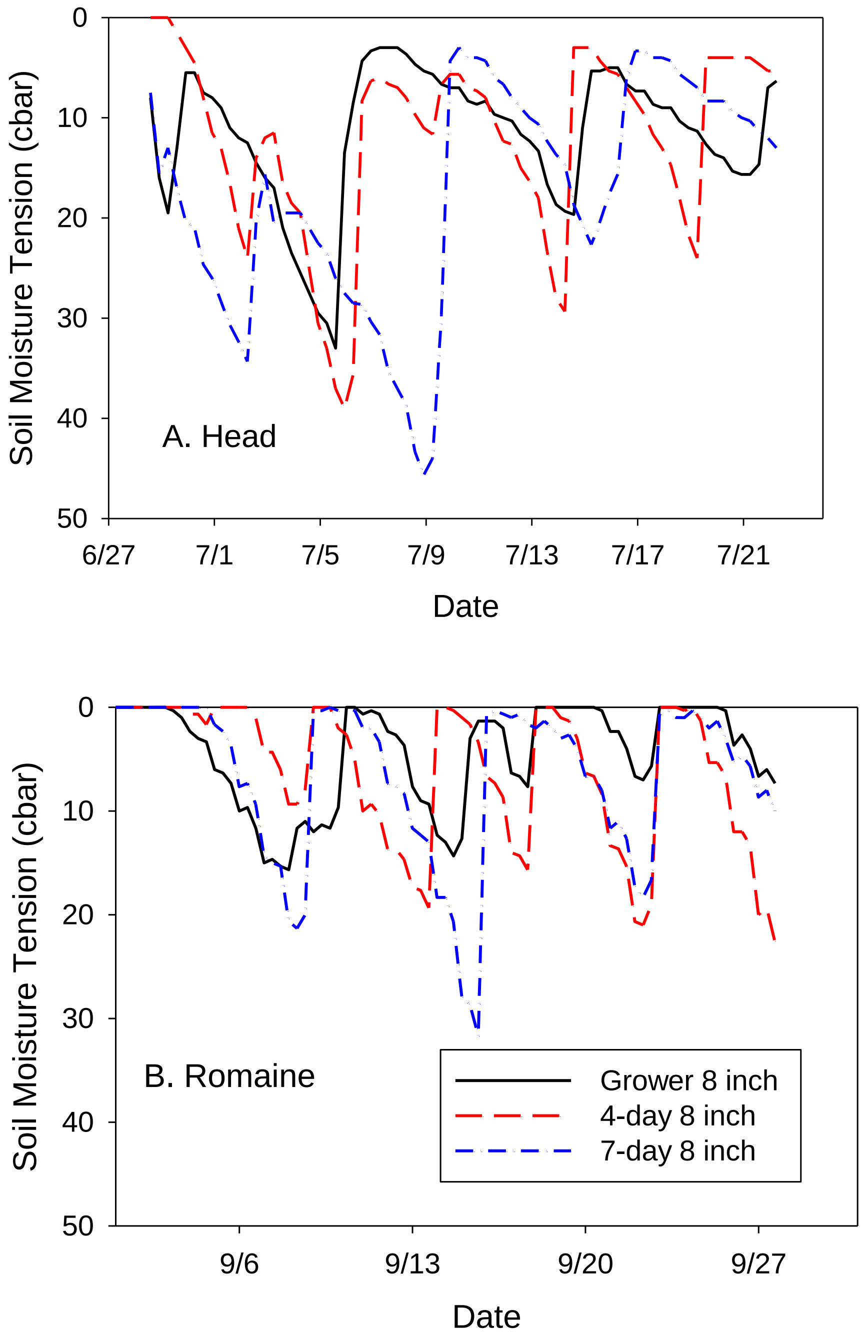

Figure. 1. Soil moisture tension at 8 inch depth for head and romaine.

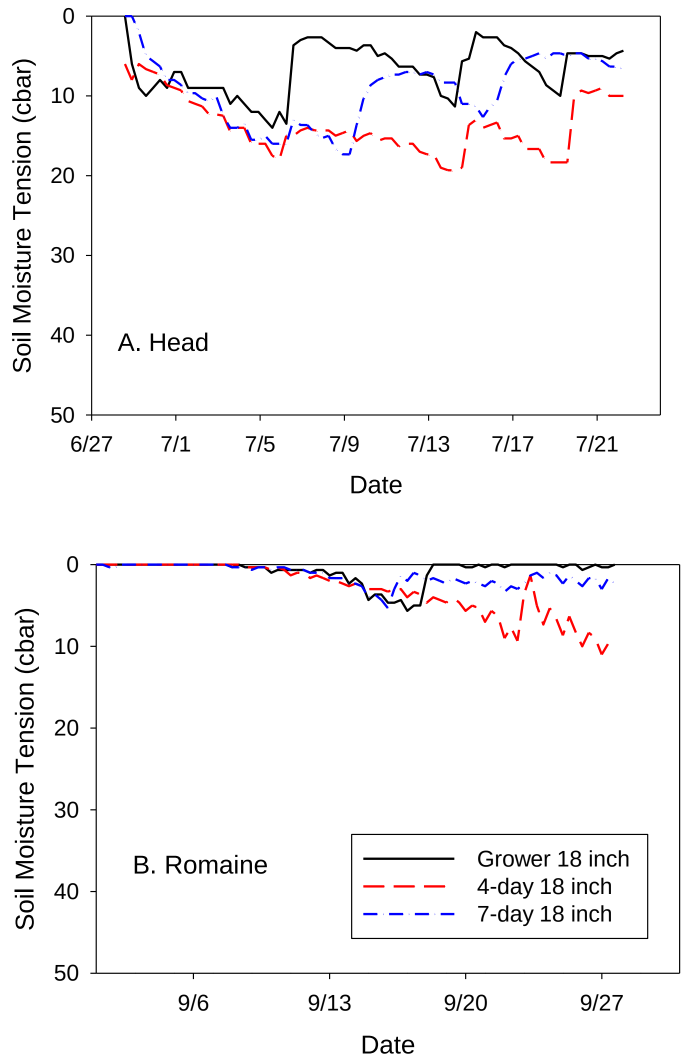

Figure. 2. Soil moisture tension at 18 inch depth for head and romaine.

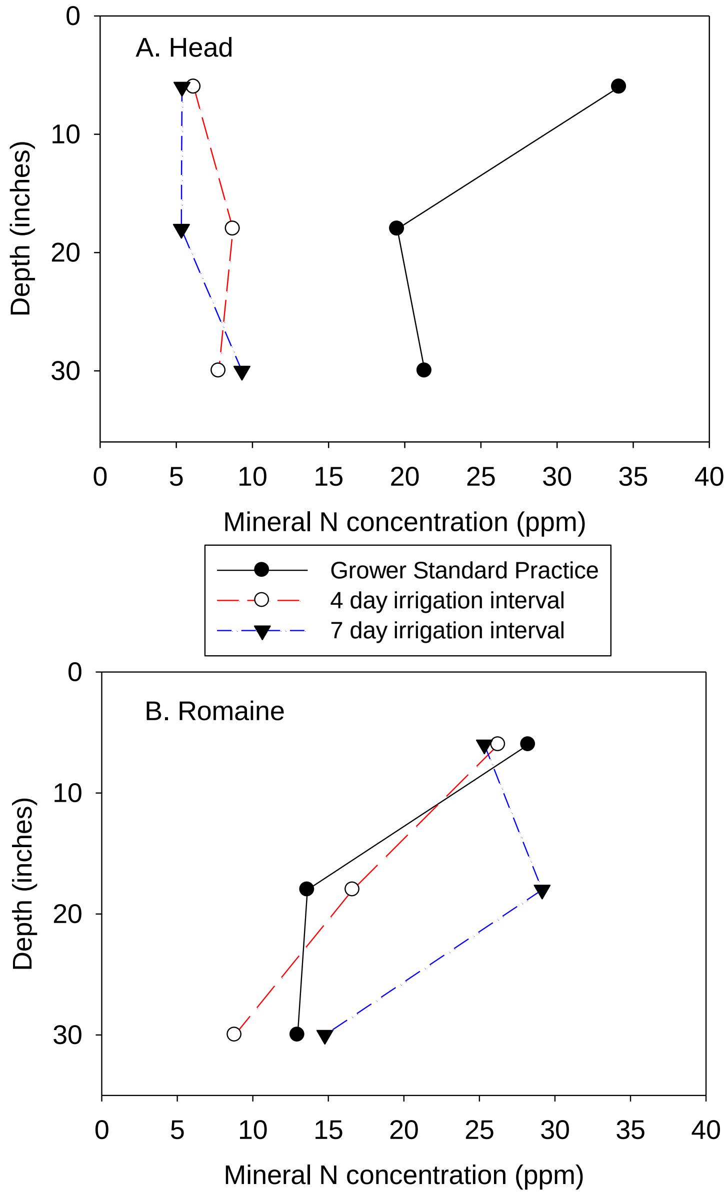

Figure. 3. Post-harvest mineral N in soil profile for head and romaine heart.

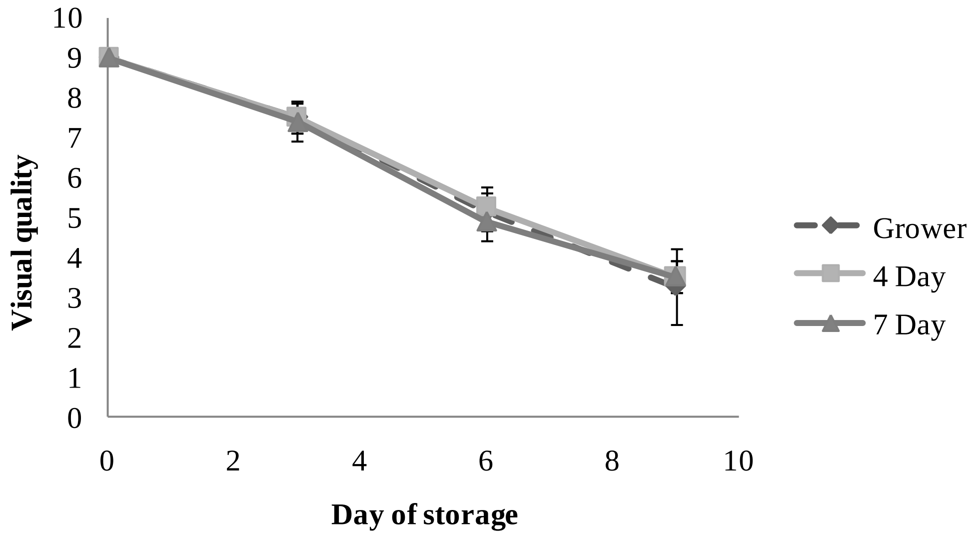

Fig. 4. Visual quality of minimally processed romaine lettuce stored at 5 ^{o}C. Each data point is the average of 4 replications; bars indicate standard deviation.