Drip irrigation management for optimizing N fertilizer use, yield, and quality of lettuce.

Michael Cahn, Richard Smith, Tim Hartz, Barry Farrara, Tom Bottoms, Tom Lockhart, and Marita Cantwell

Introduction

A key to optimizing yield and quality in lettuce and minimizing nitrate leaching is to match applications of fertilizer and water with the crop needs. The nitrate quick test, used with an understanding of the N uptake pattern of lettuce, can be valuable for determining an appropriate amount of N fertilizer for pre-plant and post-thinning applications. The combined use of CIMIS evapotranspiration (ET) data and soil moisture monitoring can also guide irrigations so that lettuce growth is optimal and nitrate leaching is minimized.

Lettuce, like many cool season vegetables, is sensitive to modest deficits in soil moisture. Growth usually slows when soil water tensions are above 30 to 40 centibars (cbars). A recent survey of grower practices confirmed that many managers irrigate lettuce at intervals of 6 to 8 days during the drip phase of the crop and in amounts that are often 50% greater than the ET requirement of the crop (150% of crop ET). While an 8-day irrigation interval may be appropriate just after thinning, when plants are small, larger plants would require more frequent irrigations to keep up with the ET demand of the crop. By applying water in excess of the ET requirement of the crop, growers can maintain growth at these longer intervals, but risk leaching nitrate below the root-zone.

We conducted trials in commercial lettuce fields to evaluate if using the quick nitrate test to guide fertilizer applications and applying water at intervals of 4 to 5 days in amounts equal to the ET requirement of the crop could minimize nitrate leaching while maintaining yield and quality.

Procedures

Two trials evaluating the effects of irrigation and nitrogen management on lettuce production were conducted in commercial iceberg and romaine lettuce fields. The iceberg trial was planted May 20, 2010 on a loam soil, and the romaine trial was planted July 27, 2010, on a fine sandy loam soil. Lettuce was germinated with overhead sprinklers, and irrigated with surface drip after thinning and cultivation. Three irrigation/nitrogen treatments were compared during the drip phase of the crop (Table 1): Treatment 1 was the grower's standard strategy for irrigation and fertilizer N applications. Treatment 2 utilized the nitrate quick test to guide nitrogen fertilizer applications, and water was applied at intervals of 4 to 5 days in amounts averaging 100% of crop ET. Treatment 3 also utilized the nitrate quick test to guide nitrogen fertilizer applications, but the crop was irrigated every 6 to 8 days in amounts averaging 140% of crop ET. Although some adjustments in the irrigation of the 4 and 7-day interval treatments were made to accommodate weather conditions and field operations, the average intervals closely approximated the treatment schedule.

Table 1. Irrigation/nitrogen management treatments.

Treatment	Nitrogen management	Irrigation Interval	Irrigation volume
Grower	Grower Standard	Grower Standard	Grower Standard
4-day	Nitrate quick test[1]	4-5 day irrigation intervals	100 % crop ET
7-day	Nitrate quick test[1]	6-8 day irrigation intervals	140% crop ET

[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.

Treatments were replicated four times in a randomized complete block design and individual plots were greater than 100 feet in length and 4 beds in width. The center 2 beds were used for harvest and plant evaluations. Irrigation treatments were accomplished using a manifold plumbed into the grower's mainline. Applied water of each treatment was monitored with flow meters. Fertilizer and irrigation decisions were carried out in close consultation with the grower to fit in with other field operations. All fertilizer applications conducted post-thinning were applied through the drip system at the iceberg trial. One side-dress application of N was made using a tractor in the grower treatment in the romaine trial. All subsequent fertilizer inputs were applied through the drip system.

Treatments were evaluated for soil mineral nitrogen in the top foot of soil at weekly intervals and leaf tissue nitrate-N and total N at 3 stages of development. Leachate was sampled with lysimeters after each irrigation event and analyzed for nitrate-N concentration. Soil moisture tension was monitored with watermark granular matrix sensors at 8 and 18 inch depths in 3 of the 4 replications. The iceberg field was harvested for cartons and the romaine field was harvested for hearts. Plant population, head weight, biomass, and marketable yield were evaluated at harvest. The effect of irrigation and nitrogen management on postharvest lettuce quality was 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

The 4-day irrigation interval required less water than the 7-day and grower treatments in both the iceberg and romaine trials and maintained similar soil moisture tensions (Tables 2 and 3; Fig. 1). Applied water volumes for the 4-day irrigation interval were approximately 100% of crop ET for both trials, and approximately 140% of crop ET for the 7-day irrigation interval treatment. The applied water for grower standard practice averaged 135% of crop ET for both trials (Tables 2 and 3). The grower irrigation interval averaged 7.5 days for the iceberg trial and 4.5 days for the romaine trial.

Accounting for residual soil nitrate with the quick nitrate test, fertilizer N inputs were reduced by 127 and 59 lb N/acre in the iceberg and romaine trials, respectively, in the 4- and 7-day treatments relative to the grower standard (Tables 2 and 3, Figs. 2 and 3). Despite the reduction in fertilizer N, nitrate-N levels were maintained greater than 20 ppm in the top foot of soil until harvest in 4- and 7-day treatments. In both trials, the grower fertilizer practice resulted in soil nitrate-N concentrations greater than 40 ppm after the first post-thinning application (approximately 30 days after planting). The grower treatment had the highest concentration of nitrate in leachate samples collected in the iceberg trial (Table 2) and lowest concentration in leachate collected in the romaine trial (Table 3). The load of nitrate lost by leaching is assumed equal to the nitrate-N concentration in the leachate multiplied by the volume of drainage below the root zone of the crop. Estimated post-thinning drainage was several times higher for the grower and 7-day interval treatments compared to the 4-day interval for both trials. The lower amount of drainage resulted in the least amount of N leached under the 4-day interval treatment at both sites (Tables 2 and 3).

The combination of applying water equal to crop ET and using the quick nitrate test to guide fertilizer applications resulted in less risk for nitrate leaching after harvest. In the iceberg trial, the grower standard practice had the highest residual soil nitrate concentrations at all depths in comparison to the 4- and 7-day interval treatments which utilized the soil nitrate quick test to reduce N fertilizer inputs (Fig. 4). This residual soil nitrate can be lost by leaching during pre-irrigations for a subsequent crop or during fall and winter rain events.

In the romaine trial, residual soil nitrate was lower than in the iceberg trial. The 7-day treatment which received 140% of crop ET and had the most drainage, also had the highest concentration of nitrate was at the 2 and 3 foot depthsr (Table 3, Fig. 4). In both trials, the pattern of residual soil nitrate measured after harvest corresponded with the estimated loads of N lost by leaching for the various irrigation/nitrogen treatments.

Marketable yields and uptake of N were not statistically different among treatments at either trial (Tables 4 and 5). However, biomass yield, trimmed and untrimmed head weights and plant population were statistically different in the romaine trial. Head weights and biomass yield were highest for the 7-day treatment and the plant population was highest in the grower treatment at the romaine trial.

Nitrogen fertilization and irrigation management had no consistent effect on postharvest lettuce quality (Table 6). In the iceberg trial, the grower treatment had somewhat greater PAL activity after 3 days of storage than the 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 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. 5).

Discussion and Conclusions

Results of the 2 trials demonstrated that using the quick nitrate test with careful water management could minimize potential leaching losses of N during the crop cycle and also lower the residual level of nitrate in the soil after harvest. By shortening the irrigation interval to 4 or 5 days during the drip phase, lettuce could be irrigated at 100% of crop ET without causing excessive water stress or drainage that can carry nitrate below the root zone of the crop.

The grower treatment in the iceberg trial resulted in the highest loss of N by leaching and the most residual nitrate in the soil profile due to applying more N than was taken up by the crop, and by applying water equal to 134% of crop ET at intervals averaging 7.5 days. In contrast the grower treatment in the romaine trial resulted in relatively minimal leaching losses of nitrate-N and lower residual N levels in the soil profile compared to the 7-day treatment. In this case, the grower's irrigation interval averaged 4.5 days, almost equal to the 4.4 day interval used in the 4-day treatment. Though the grower treatment at the romaine trial also equaled 137% of crop ET, by irrigating at short intervals, the volumes of water applied for an individual irrigation were less than in the iceberg trial, thereby reducing the volume of water that percolated below the root zone (Table 2).

Although marketable yields and post harvest quality were not statistically different among treatments at both trials, the biomass yield and head weights were statistically lowest in the 4-day treatment at the romaine trial. Since similar rates of N fertilizer were applied for the 4 and 7-day treatments, one would assume that the reduced water application in the 4-day treatment resulted in lower weight heads and reduced biomass. However, we measured higher soil moisture contents in the 4-day interval than in the 7-day interval treatment at the 8 inch depth until a few days before harvest. Nevertheless, the results demonstrate that some yield risk may be associated with cutting the corners too close on water applications. For crops such as lettuce which are sensitive to moisture and N deficits, balancing irrigation and N applications to minimize nitrate leaching and maintain yields will certainly require growers to use all their tools in their tool box. Based on the results of these and previous trials, our recommendations for drip irrigated lettuce are:

For nitrogen--

1. Use the quick N test to monitor the level of mineral nitrogen in the top foot of soil, especially before planting and after thinning.
2. Avoid applying large applications of N fertilizer (> 40 lb N/acre) in a single application.
3. Match fertilizer applications with crop uptake requirements. In other words, minimal amounts of N should be applied during the first 30 days of the crop because uptake is low. Crop N uptake after thinning averages 4.5 lbs of N/acre per day during late spring and summer.

For water—

1. Use ET data and monitor soil moisture to match water applications with crop requirements.
2. Consider shortening irrigation intervals during the last 3 to 4 weeks of the crop to avoid having to apply extra water to maintain adequate soil moisture.
3. Avoid heavy irrigations that coincide with N fertilizer applications.

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Table 2. Iceberg lettuce. Applied water, applied fertilizer N, average nitrate concentration in soil and leachate, and estimated leaching losses of nitrate-N

	Applied water						Average	Estimated
				Post-thinning		Average soil	nitrate-N in	N
Treatment	Post thinning		Total	drainage	Applied N	nitrate-N	leachate	leaching
	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 3. Romaine lettuce. Applied water, applied fertilizer N, average nitrate concentration in soil and leachate, and estimated leaching losses of nitrate-N

	Applied water						Average	Estimated
				Post-thinning		Average soil	nitrate-N in	leaching
Treatment	Post thinning		Total	drainage	Applied N	nitrate-N	leachate	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 4. Iceberg lettuce. Head weight, plant population, yield, and crop uptake of N

	Head Weight		Plant Population		Yield		Crop N uptake	
Treatment	Untrimmed	Trimmed	Marketable	Diseased	Marketable	Biomass	Total	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 5. Romaine lettuce. Head weight, plant population, yield, and crop uptake of N

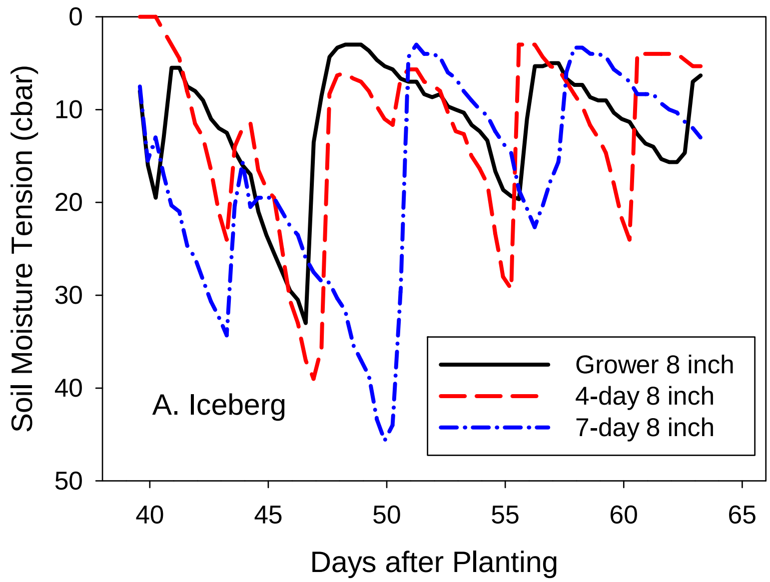
	Head Weight		Plant population		Yield		Crop N uptake	
Treatment	Untrimmed	Trimmed	Marketable	Diseased	Marketable	Biomass	Total	Harvested
	------- lb/head --------		----- plants/acre ----		------------------- lbs/acre -----------------			
4-day	1.627	0.45	34640	5200	15664	64832	129	31
7-day	1.829	0.51	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 6. 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 Standard	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.



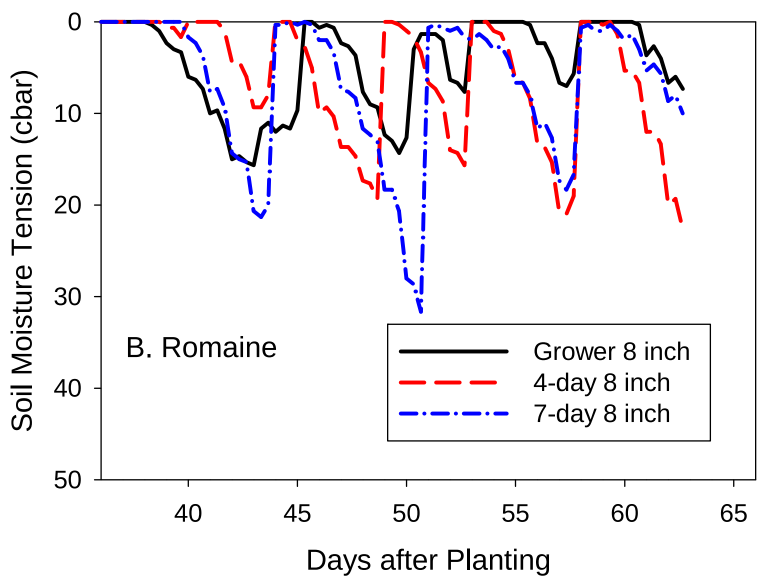


Fig. 1. Soil moisture tension at 8-inch depth for iceberg and romaine trials. High tensions indicate drier soil.

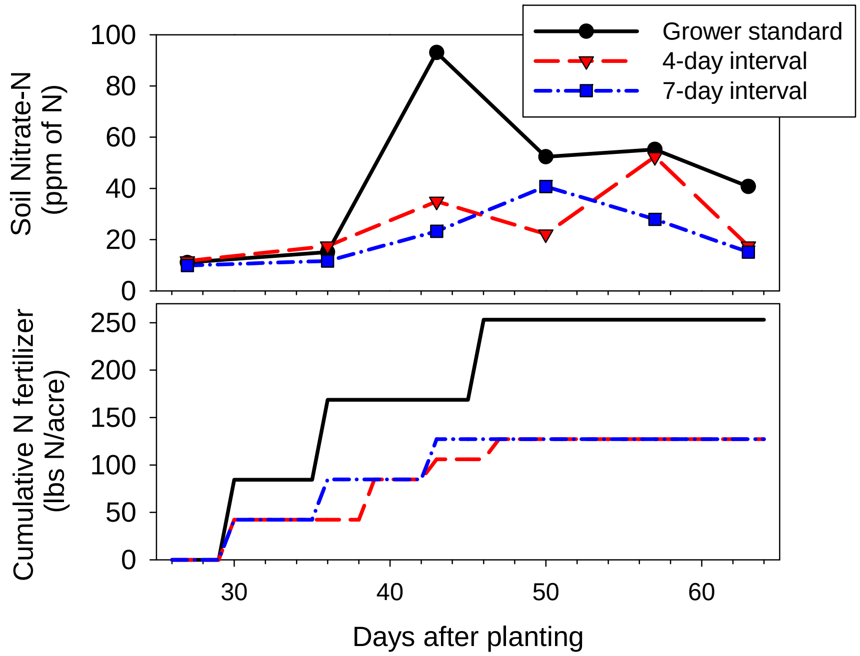


Fig. 2. Cumulative N fertilizer applied to treatments at iceberg trial and soil nitrate concentration in top foot of soil.

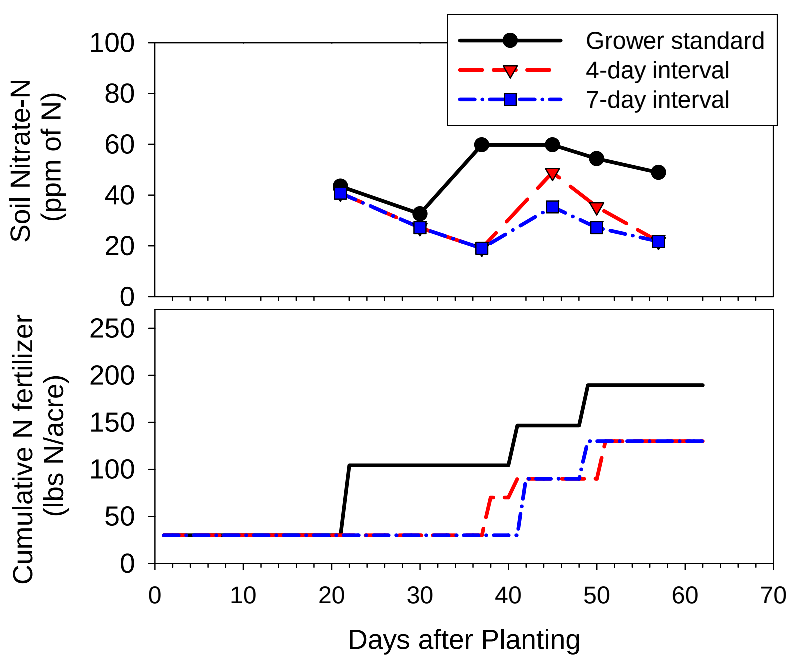


Fig. 3. Cumulative N fertilizer applied to treatments at romaine trial and soil nitrate concentration in top foot of soil.

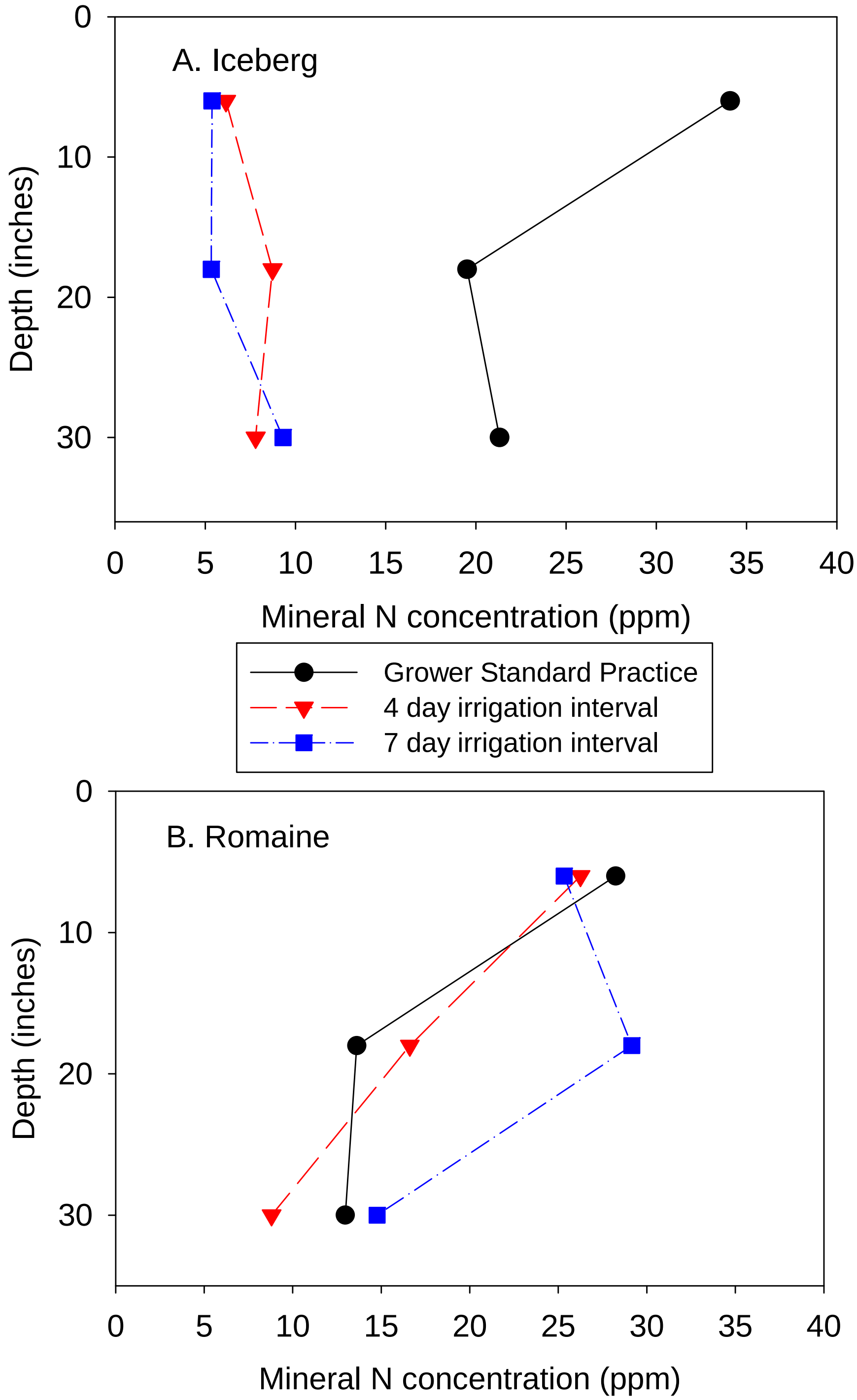


Fig. 4. Post-harvest mineral N in soil profile for iceberg and romaine.

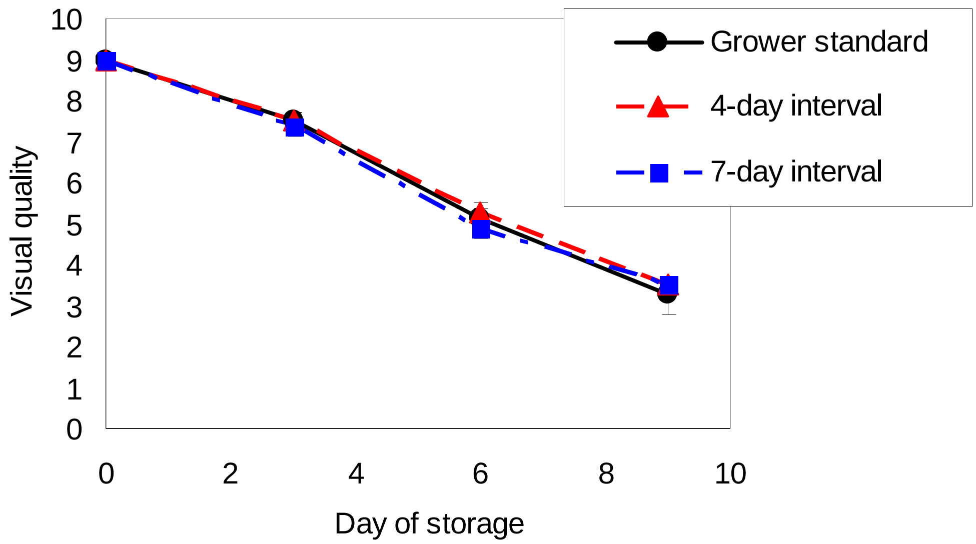


Fig. 5. Visual quality of minimally processed romaine lettuce stored at 5 ^{o}C. Each data point is the average of 4 replications; bars indicate standard error of the mean.