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The Value of Presidedress Soil Nitrate Testing as a Nitrogen Management Tool in Irrigated Vegetable Production

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***Abstract.* The utility of presidedress soil nitrate testing (PSNT) in irrigated lettuce (*Lactuca sativa* L.) and celery (*Apium graveolens* L.) production was evaluated in 15 commercial fields in California from 1996 to 1997. Fields were selected in which soil NO_3-N (5- to 30-cm depth) was >20 mg·kg^{-1} at the time the cooperating grower made the first sidedress N application. The grower's N regime was compared with reduced N treatments established by reducing or eliminating one or more sidedress applications. All fields were sprinkler and/or furrow irrigated, with minimal in-season precipitation. Reductions in seasonal N application averaging 143 and 209 kg·ha^{-1} N in lettuce and celery trials, respectively, had no effect on marketable yield in any field. Crop biomass N at harvest in the lowest N treatment in each field averaged 94% (lettuce) and 88% (celery) of that in plots receiving the full grower N program. Based on controlled-environment aerobic incubation of soil from 30 fields in long-term vegetable rotations, in-season N mineralization averaged 1% to 2% of soil organic N. A soil NO_3-N "quick test" procedure utilizing a volumetric extraction of field-moist soil and measurement by nitrate-sensitive colorimetric test strips was evaluated and proved to be a practical on-farm method to estimate soil NO_3-N concentration. Lettuce midrib NO_3-N concentration at cupping stage was poorly correlated with current soil NO_3-N level. We conclude that PSNT can reliably identify fields in which sidedress N application can be delayed or eliminated without affecting crop performance.**

The pollution of groundwater with nitrate of fertilizer origin has been recognized as a serious environmental issue in areas of intensive agriculture around the world. The problem is particularly severe in the coastal valleys of central California, where many wells now exceed the U.S. Environmental Protection Agency drinking water standard of 10 mg·L^{-1} NO_3-N. Production of cool-season vegetables such as lettuce and celery dominates agriculture in these valleys. Fields in vegetable rotations typically produce two or three crops annually, with frequent irrigation and N application rates far in excess of N removal in harvested product. The high value of vegetable crops and exacting market standards for product size and quality make it economically risky for growers to use marginal N fertilizer rates.

Many N fertilizer rate studies have been conducted on lettuce and celery, with widely varying results. Gardner and Pew (1972, 1974) reported that yields of head lettuce peaked with 100–150 kg·ha^{-1} fertilizer N, while Welch et al. (1979) and MacKay and Chipman (1961) reported yield increases up to at least 250 kg·ha^{-1} N. Lorenz (1948) observed increasing celery yield at rates of N application up to 448 kg·ha^{-1} N, while Welch et al. (1979) saw little plant response above 224 kg·ha^{-1} N. This variability in crop response to applied N undoubtedly reflected differences among sites in soil characteristics and irrigation management. Clearly, a reliable method to predict field-specific N requirement is needed.

Presidedress soil NO_3-N testing (PSNT) is effective in assessing sidedress N requirement in both rainfed (Fox et al., 1989; Heckman et al., 1995; Magdoff, 1991a; Schmitt and Randall, 1994) and irrigated (Spellman et al., 1996) corn (*Zea mays* L.) production. In these studies, soil NO_3-N concentration (top 30 cm) greater than ≈20 mg·kg^{-1}, when corn was 15 cm tall (the growth stage at which sidedressing is usually done), indicated that crop response to applied N was unlikely. Use of PSNT in corn production has been widely applied because in-season soil NO_3-N level is an indirect measurement of soil N mineralization potential; also, most soil NO_3-N present at the time of sampling will remain available for crop uptake, since uptake is accelerating at that point in the season, and in-season NO_3-N leaching losses tend to be small (Magdoff, 1991a). The PSNT method is most effective at identifying fields in which no response to applied N is likely; it has been less effective in predicting appropriate sidedress N rates in fields testing below the sufficiency threshold (Fox et al., 1989; Heckman et al., 1995; Meisinger et al., 1992).

The primary objective of this study was to evaluate PSNT as an N management tool in irrigated lettuce and celery production. Additionally, the accuracy of an on-farm soil NO_3-N "quick test" procedure that could improve utilization of PSNT by vegetable growers was evaluated over a range of soil textures and NO_3-N concentrations.

Materials and Methods

Fifteen trials were conducted in commercial vegetable fields from 1996 to 1997, all located in the coastal production areas of central California. Eleven of the fields were planted to iceberg lettuce and four to celery. Lettuce was direct seeded and celery was transplanted from February through September. Soil textures varied from sandy loam to clay loam (Table 1). All fields were irrigated, generally sprinkled to establish the crop, then switched to furrow irrigation to complete the season. Irrigation water NO_3-N concentration was determined for all fields. In-season precipitation >5 cm was received only in celery field 2. Fields were selected that had at least 20 mg·kg^{-1} soil NO_3-N (5- to 30-cm depth) just prior to the first sidedress N application, as measured by the on-farm "quick test" procedure (Hartz, 1994).

Table 1. Site characteristics and dates of planting and harvesting for 1996–97 lettuce and celery trials.

Year	Field	Soil texture	Planting date[z]	Harvest date
		Lettuce		
1996	1	Loam	12 Mar	7 June
	2	Sandy loam	28 Mar	14 June
	3	Sandy loam	23 Apr	10 July
	4	Loam	27 Apr	16 July
	5	Silt loam	23 July	25 Sept
	6	Clay loam	26 July	27 Sept
1997	7	Clay	8 Apr	24 June
	8	Loam	22 July	23 Sept
	9	Loam	16 July	17 Sept
	10	Silt loam	20 July	19 Sept
	11	Silt loam	16 July	19 Sept
		Celery		
1996	1	Loam	22 July	29 Oct
	2	Silt loam	25 Aug	13 Jan. 1997
1997	3	Loam	26 Feb	16 June
	4	Clay loam	1 Apr	2 July

[z]Lettuce seeded, celery transplanted

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The N fertilization program in each field was determined by the cooperating grower. In each field, plots of lower N rates were established by reducing or eliminating one or more sidedress N applications. Plots consisted of four beds 1.3 m wide × 30 m long; all data were collected from the middle two beds. A randomized complete-block design with four replications was used, in which one plot of each N rate, and an adjacent plot receiving the growers' full N program, were established in each quadrant of each field. Composite soil samples (5- to 30-cm depth, in the plant row, six to eight cores per plot) were collected just prior to sidedress N applications and at harvest; the top 5 cm of soil was discarded because, under furrow-irrigated, rainless conditions, the surface soil is frequently too dry to be representative of the active root zone. NO_3-N concentration in 2 N KCl extracts of field-moist soil was determined by the diffusion-conductivity method of Carlson (1978).

Initial sidedress N application occurred after thinning (two- to four-leaf stage) in lettuce fields, and several weeks after transplant establishment in celery fields. The second sidedress typically occurred 2–4 weeks later, when lettuce was at the cupping stage and celery was just entering the rapid growth phase. In some cases, a third sidedressing was applied 2–3 weeks later. In all fields, six whole plants were collected in each plot prior to the second N sidedressing and at harvest, then dried, ground, and analyzed for total N concentration by combustion (Carlo-Erba 1500; Fisons Instruments, Beverly, Mass.). In six lettuce fields, 15 midribs of recently expanded leaves were collected in each plot prior to the second N sidedressing. After oven drying and grinding, the midribs were extracted in 2% acetic acid and analyzed for NO_3-N concentration.

Plots were harvested at commercial maturity and the plants evaluated for size and condition based on current market standards. In 1996 trials, leaf color at harvest was evaluated by a hand-held meter which provided an estimate of leaf green color (Minolta 502 SPAD meter; Minolta Corp., Kyoto, Japan; Monje and Bugbee, 1992). Twenty wrapper leaves (lettuce) or leaf blades (celery) per plot were evaluated.

The accuracy of the soil NO_3-N quick test was evaluated using 40 soil samples collected during the PSNT field trials; the samples encompassed a range of soil textures and NO_3-N concentrations. Volumetrically marked tubes were filled with 30 mL 0.01 M $CaCl_2$. Field moist soil was added until the liquid level reached 40 mL, an addition of 10 mL of soil solids and adhering soil water. The weight of field-moist soil added, and its gravimetric water content, were recorded for each sample. The tubes were shaken by hand (±1 min, until soil aggregates were thoroughly dispersed) and the soil particles allowed to settle until the supernatant was cleared.

Nitrate concentration in the supernatant was estimated by nitrate-sensitive colorimetric test strips (EM Science, Gibbstown, N.J.). Color development on the strips was evaluated both visually and by a battery-operated meter (Reflectoquant®, EM Science). The actual NO_3-N content of the supernatant was determined by the method of Carlson (1978). The NO_3-N concentration in dry soil was estimated by dividing the test strip reading (in $mg \cdot L^{-1}$ NO_3) by a correction factor based on soil texture (sand, loam, or clay) and soil moisture (moist or dry); the correction factors used were 2.3, 2.0, and 1.7, or 2.6, 2.4, or 2.2 for sand, loam, or clay soil, either wet or dry, respectively. These empirically derived correction factors adjusted for the approximate extraction ratio (dry soil mass : total extractant volume) as influenced by the typical water-holding capacity for each texture class, and the conversion of the strip reading from NO_3^- to

Table 2. Response of lettuce to varying nitrogen regimes.

Field	N treatment	Soil NO_3-N ($mg \cdot kg^{-1}$)[z] SD1	SD2	Harvest	Seasonal N application ($kg \cdot ha^{-1}$) Total[y]	Sidedress	Marketable yield % Plants harvested	Mean head mass (kg)	Head N ($g \cdot kg^{-1}$)	Leaf color[x]
1	Grower practice	21	30	18	270	225	94	1.03	33	19
	Omit SD 1		10	9	155	110	95	1.03	33	19
	Omit SD 1 and 2		12	5	45	0	95	1.02	32	19
2	Grower practice	29	27	8	235	120	92	1.15	41	19
	Omit SD 1		15	10	180	55	94	1.10	34	19
	Omit SD 1 and 2		14	5	110	0	93	1.15	35	19
3	Grower practice	28	9	4	260	145	93	0.97	32	18 a[w]
	Omit SD 1		9	3	185	70	93	0.98	28	18 a
	Omit SD1 and 2		7	8	115	0	94	0.94	28	16 b
4	Grower practice	47	23	42	315	190	82	0.99	36	23
	Omit SD 1		18	37	235	110	83	0.92	37	23
	Omit SD 1 and 2		14	19	125	0	85	0.92	36	23
5	Grower practice	19		16	145	130	86	0.70	45	13
	Reduce SD 1 by 50%			13	105	90	88	0.75	47	13
	Omit SD 1			7	60	45	83	0.68	45	13
6	Grower practice	35		11	145	130	88	0.70	47	22
	Reduce SD 1 by 50%			10	105	90	81	0.68	46	22
	Omit SD 1			10	60	45	82	0.65	48	20
7	Grower practice	39		41	295	270	80	0.85	42	
	Omit SD 1			29	205	180	83	0.86	42	
	Omit SD 1 and 2			22	115	90	78	0.85	43	
8	Grower practice	28	19	29	285	270	79	0.76	36	
	Omit SD 1		16	23	195	180	84	0.79	37	
	Omit SD 1 and 2		16	12	105	90	82	0.76	34	
9	Grower practice	35	19	6	155	140	64	0.84	44	
	Omit SD		14	8	85	70	65	0.85	40	
	Omit SD 1 and 2		13	4	15	0	61	0.85	39	
10	Grower practice	18		4	140	95	75	0.85	39	
	Omit SD 1			3	40	0	79	0.83	35	
11	Grower practice	28	22	17	190	145	75	0.88	43	
	Omit SD 1		7	9	135	90	77	0.90	42	
	Omit SD 1 and 2		9	7	44	0	73	0.88	40	

[z]Immediately before sidedress (SD) 1 or 2, or at harvest; 5- to 30-cm depth.
[y]Includes preplant N and N applied in sprinkler irrigation during plant establishment.
[x]Relative color of wrapper leaf, as measured by Minolta SPAD meter; dimensionless unit, higher value indicates darker green.
[w]Mean separation within fields by Duncan's multiple range test, $P \leq 0.05$; all other differences nonsignificant.

Table 3. Response of celery to varying nitrogen regimes.

Field	N treatment	Soil NO_3-N ($mg\cdot kg^{-1}$)[z] SD 1	SD 2	SD 3	Harvest	Seasonal N application ($kg\cdot ha^{-1}$) Total[y]	Sidedress	Marketable yield % Plants harvested	Mean head mass (kg)	Plant N ($g\cdot kg^{-1}$)	Leaf color[x]
1	Grower practice	45	29	12	42	580	470	95	1.04	33 a[w]	33
	Omit SD 1 and 3		24	12	37	350	240	99	1.07	30 a	33
	Omit SD 1, 2, and 3		26	9	19	230	120	95	0.97	26 b	34
2	Grower practice	45				480	455	88	0.84	35	
	Reduce SD 1 by 50%					410	375	89	0.85	35	
	Omit SD 1					330	295	88	0.84	34	
3	Grower practice	21	32		19	475	440	79	0.90	28	
	Reduce SD 1 by 50%		22		12	395	360	83	0.91	26	
	Reduce SD 1 and 2 by 50%		20		8	315	280	79	0.83	27	
4	Grower practice	47	33		35	365	330	99	0.90	33	
	Omit SD 1		24		23	250	215	99	0.96	32	
	Omit SD 1 and 2		24		17	200	165	99	0.92	32	

[z]Immediately before sidedress (SD) 1, 2, or 3, or at harvest, 5- to 30-cm depth.
[y]Includes preplant N and N applied in sprinkler irrigation during plant establishment.
[x]Relative leaf color, as measured by Minolta SPAD meter; dimensionless unit, higher value indicates darker green.
[w]Mean separation within fields by Duncan's multiple range test, $P \leq 0.05$; all other differences nonsignificant.

NO_3-N. Actual NO_3-N concentration in dry soil was calculated by multiplying the supernatant NO_3-N concentration determined through standard laboratory analysis by the ratio of total extractant volume to sample dry mass.

The net N mineralization rate of coastal soils in vegetable rotations was estimated by aerobic incubation. Soil (5- to 30-cm depth) was collected prior to the first sidedressing in 30 representative fields, including 10 of the PSNT trial sites. Samples were air-dried, screened through 5-mm mesh, and moisture-equilibrated at 0.03 MPa in a pressure apparatus for 3 d. Subsamples of each field soil were then immediately extracted in 2 N KCl for determination of mineral N (NH_4-N plus NO_3-N). The remainder of each soil sample was incubated aerobically at 25 °C in sealed containers to maintain moisture content. After 4 weeks, four subsamples of each field soil were analyzed for mineral N concentration. Nitrogen mineralization rate was calculated as the increase in mineral N over the incubation period. Soil organic N in the soils was determined by the digestion procedure of Issac and Johnson (1976), soil organic matter by the method of Nelson and Sommers (1982).

Results

Presidedress soil NO_3-N varied among lettuce fields from 19 to 47 $mg\cdot kg^{-1}$, averaging 30 $mg\cdot kg^{-1}$ (Table 2). The cooperating growers applied an average of 170 $kg\cdot ha^{-1}$ N in one to three sidedress applications and an average of 50 $kg\cdot ha^{-1}$ N applied preplant and/or in sprinkler irrigation water during crop establishment, resulting in a mean seasonal application of 220 $kg\cdot ha^{-1}$. This is near the typical rate previously reported for California growers (Rauschkolb and Mikkelson, 1978).

Reducing or eliminating one or two sidedress N applications had no effect on marketable lettuce yield in any field (Table 2). Application rate had no effect on wrapper leaf color except in field 3, where plants in plots receiving no sidedress N were of lighter color than those in plots receiving N. The substantial color differences among fields were apparently due to cultivar characteristics, since there was no correlation between leaf color and plant N concentration. There were no visual differences in color among N treatments in any of the 1997 trials (fields 7–11). Mean marketable head mass in fields 5, 6, and 8 was considerably below the commercially desirable range (0.9–1.1 kg), but the lack of N treatment effects suggested that N availability was not the growth-limiting factor. Nitrogen content of harvested heads in all treatments in all fields exceeded the 25 $g\cdot kg^{-1}$ minimum sufficiency standard for wrapper leaves given by Lorenz and Tyler (1983).

Presidedress soil NO_3-N in the four celery fields varied from 21 to 47 $mg\cdot kg^{-1}$, averaging 40 $mg\cdot kg^{-1}$ (Table 3). Mean total N application by growers was 475 $kg\cdot ha^{-1}$. There were four sidedressings in field 1, three in field 4, and two in fields 2 and 3; additionally, there was one or more late-season N applications in the irrigation water in fields 2, 3, and 4. Reducing sidedress N application had no significant effect on celery yield in any field. The low mean marketable mass in field 2 was due to cracking of older petioles caused by heavy rain just prior to harvest, which necessitated their removal; the problem affected all N treatments similarly. Differences among treatments in N concentration of the harvested biomass were significant only in field 1, in which sidedress N treatments differed by up to 250 $kg\cdot ha^{-1}$. Leaf color did not differ among N treatments in field 1, nor were there visual differences in leaf color in the 1997 trials (fields 2, 3, and 4).

Table 4 emphasizes how ineffective early-season sidedress N application was in these fields with substantial soil residual NO_3-N. The percentage of plants harvested and mean marketable mass were virtually identical among N treatments, and mean crop N uptake varied only slightly. Comparing the grower practice with the lowest N treatment in each field, the increase in crop N uptake was only 5% (lettuce) or 15% (celery) of the additional N applied.

The soils evaluated for net N mineralization rate varied from 7 to 26 $g\cdot kg^{-1}$ organic matter and 0.5 to 1.7 $g\cdot kg^{-1}$ organic N (Fig. 1). There was a linear relationship between net N mineralization and both soil organic matter ($y = 0.8 + 0.013x$, $r^2 = 0.61$) and soil organic N ($y = 0.07 + 0.22x$, $r^2 = 0.54$). Daily net N mineralization in this assay, conducted at a temperature (25 °C) consistent with summer conditions in coastal central California, averaged ≈0.03% of soil organic N; at that rate 1.5% to 2.7% of soil organic N would be mineralized in the 50- to 90-d period from first

Table 4. Effect of reducing sidedress N application on yield and N uptake of lettuce and celery; means for 11 or four field trials, respectively.

N treatment	Soil NO_3-N at SD 1[z] ($mg\cdot kg^{-1}$)	Seasonal sidedress N application ($kg\cdot ha^{-1}$)	Marketable yield % Plants harvested	Mean head mass (kg)	Crop N uptake[y] ($kg\cdot ha^{-1}$)
Lettuce					
Grower practice	30	170	83	0.88	118
Intermediate N		95	84	0.88	113
Lowest N		27	82	0.87	111
Celery					
Grower practice	40	424	90	0.92	275
Intermediate N		298	93	0.95	274
Lowest N		215	90	0.89	243

[z]Sidedress 1.
[y]In aboveground biomass, calculated at a plant population of 77,000 or 110,000/ha for lettuce and celery, respectively.

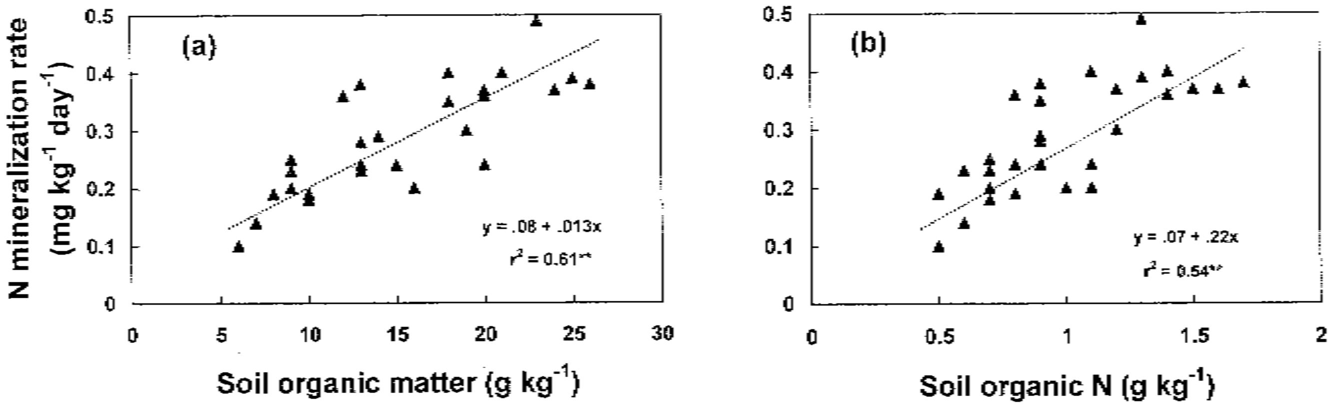

Fig. 1. Effect of (**a**) soil organic matter and (**b**) soil organic N of 30 soils in long-term vegetable rotations on net N mineralization in a 4-week aerobic incubation at 25 °C.

sidedressing until harvest. Net N mineralization rate would decrease with longer incubation (Stanford and Smith, 1972), so actual in-season mineralization may be more accurately estimated as 1% to 2%. These rates are within the range of those reported for soils from other cropping systems (Jalil et al., 1996; Magdoff, 1991b; Smith et al., 1977; Stanford and Smith, 1972).

Another source of nonfertilizer N was the irrigation water. The water applied to most fields in this study had <10 mg·L^{-1} NO_3-N, but in several fields (lettuce fields 1, 7, 8, and 9, and celery fields 1 and 4) the level was in the 10–20 mg·L^{-1} NO_3-N range. Of those fields monitored (lettuce fields 1, 2, and 7, and all celery fields) mean seasonal water application was 40 and 72 cm for lettuce and celery, respectively. On average, ≈30 kg·ha^{-1} N was added in irrigation water on the lettuce fields, ≈60 kg·ha^{-1} N on the celery fields.

The soil NO_3-N quick test was highly correlated with conventional laboratory analysis across a wide range of soil NO_3-N concentrations, whether the colorimetric test strips were read by eye (r^2 = 0.92) or by the Reflectoquant® meter (r^2 = 0.96, Fig. 2). The soil NO_3-N range of primary interest in fertility decision-making would be 0–30 mg·kg^{-1}; in that range the quick test was still highly correlated with conventional laboratory analysis (r^2 = 0.86 and 0.93 for strips read by eye or meter, respectively).

The NO_3-N concentration of lettuce midribs collected just prior to sidedress 2 was poorly correlated (r^2 = 0.25) with NO_3-N in soil samples collected concurrently (Fig. 3). Field-specific environmental and soil factors apparently had greater effect on midrib NO_3-N accumulation than soil NO_3-N level. Trial results showed that no yield-limiting N deficiency existed in any field, yet many midrib samples were below the 4 g·kg^{-1} NO_3-N sufficiency level suggested by Lorenz and Tyler (1983). Even more were below the 5 g·kg^{-1} level given by Doerge et al. (1991).

Discussion

Nitrogen rates used by the cooperating growers in this study, although typical of the California industry, were clearly higher than necessary to achieve maximum crop yield. Prior research on N requirement of these crops has yielded widely variable results, but crop response to rates as high as 440 kg·ha^{-1} N for celery (Lorenz, 1948) and 250 kg·ha^{-1} N for lettuce (Mackay and Chipman, 1961; Welch et al., 1979) have been reported. Given the high value and exacting market standards of these crops, and the fact that even a temporary interruption in N availability can reduce yield (Burns, 1987), growers are reluctant to reduce N application until a reliable N management tool is available. This study documented that PSNT could identify fields in which sidedress N application could be delayed or reduced without affecting crop productivity. The 20 mg·kg^{-1} NO_3-N PSNT threshold used in selecting fields for this study was conservative; in six of the lettuce fields soil NO_3-N was <20 mg·kg^{-1} at sidedress 2, yet omitting that application still did not affect crop performance. Additional research is needed to evaluate lower PSNT thresholds. Until that research is completed the PSNT concept can be applied in fields with <20 mg·kg^{-1} NO_3-N by sidedressing only the amount calculated to raise soil NO_3-N to the 20 mg·kg^{-1} level; at a typical mineral soil bulk density of 1.35 kg·L^{-1} that would require ≈4 kg·ha^{-1} N per mg soil NO_3-N below 20 mg·kg^{-1}.

When employing PSNT a standard sampling protocol should be followed to ensure that samples collected reflect soil NO_3-N status in the active root zone. We chose to sample within the plant row, directly between representative plants, and to discard the top 5 cm of each soil core. Sampling areas where N has recently been sidedressed should be avoided to prevent overestimating N availability.

To be used confidently, a threshold level must predict crop response across varying soil conditions and irrigation regimes. Lettuce and celery are shallow-rooted (Feigin et al., 1982; Jackson and Stivers, 1993) and frequently irrigated. In-season NO_3-N leaching can be significant, as shown by the large decrease in soil NO_3-N between sidedress 1 and 2 in non-

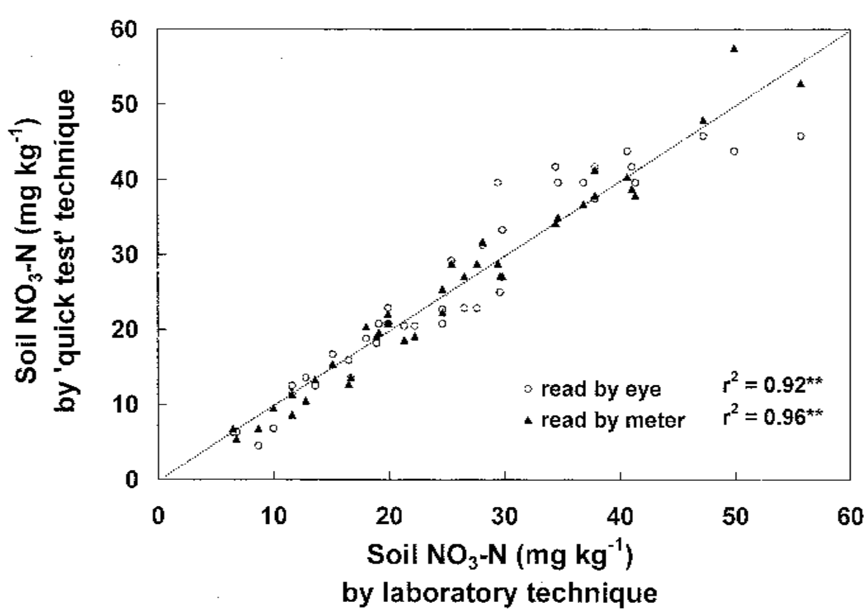

Fig. 2. Accuracy of a soil NO_3-N "quick test" procedure utilizing volumetric extraction of field moist soil; NO_3-N concentration was estimated by nitrate-sensitive colorimetric test strips, evaluated by eye or by the Reflectoquant® meter.

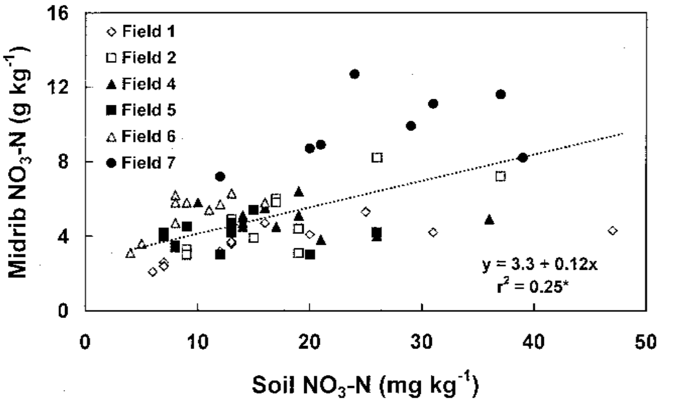

Fig. 3. Effect of soil NO_3-N (5- to 30-cm depth) on lettuce midrib NO_3-N concentration prior to the second sidedress N application.

sidedressed plots in lettuce fields 1, 2, 3, 8, 9, and 11; crop N uptake during this period averaged <20 kg·ha^{-1} N, or ≈5 mg·kg^{-1} soil. Jackson et al. (1994) reported that annual NO_3-N loss in a double-cropped lettuce field in the Salinas Valley was ≈150 kg·ha^{-1} N despite conservative fertilization (≈92 kg·ha^{-1} N per crop), mostly because of in-season leaching.

Current fertilization practices maximize in-season NO_3-N leaching potential by concentrating N application in the first half of the crop growth cycle. The majority of lettuce and celery biomass, and biomass N, accumulation occurs in the final month before harvest. Concentrating N application closer to the time of maximum crop demand would be more efficient. Unlike crops such as sweet corn or melon (*Cucurbita* sp.), where plant height or growth habit restrict late-season sidedressing, lettuce or celery can be sidedressed quite late in the growing season. Continuing soil NO_3-N monitoring into the period of rapid N uptake is important in order to ensure that the combined action of leaching and crop uptake have not depleted soil NO_3-N to a growth-limiting level. Effective monitoring for crops with high N requirements [cauliflower (*Brassica oleracea* Botrytis Group), celery, broccoli (*Brassica oleracea* Botrytis Group), etc.] may require three or more soil tests per season. In nonirrigated fields, collection of a representative soil sample may be difficult after a banded sidedress N application has been made; however, sufficient NO_3-N movement occurs with irrigation to minimize this problem.

The relationship of N rate and postharvest quality was not addressed in this study, but any diminution of quality in the reduced N treatments was unlikely. N concentration in harvested tissue was nearly equal in all N treatments within fields, and well above published N sufficiency guidelines. Prior research has suggested that high N rates may be detrimental to postharvest quality. Concentration of sugars and vitamin C in lettuce decreases with increasing rate of N fertilization (Poulsen et al., 1995). Concentration of flavor-enhancing compounds in celery decreases when high levels of mineral or organic N fertilizer are used (Van Wassenhove et al., 1990).

Undoubtedly a substantial portion of residual soil NO_3-N at first sidedress encountered in this study was from preplant and/or early water-run N application, which averaged 52 kg·ha^{-1} N, or ≈13 mg·kg^{-1} in the top 30 cm of soil. Most of the remainder represented either mineral N carried over from the prior crop or mineralization of soil organic N. N mineralization could play a significant role in crop fertility in this cropping system, particularly in fields with high residue input from the previous crop. The residue from broccoli or cauliflower, common rotational crops for lettuce and celery in these coastal areas, typically contains 120–160 kg·ha^{-1} N in a succulent, high N (>30 g·kg^{-1} N) form (Hartz, unpublished data). The net N mineralization rates measured in this study were undoubtedly lower than typical between-crop rates, since in all fields the soils were collected at the first sidedressing, at least 6 weeks after the incorporation of previous crop residue. Even so, in-season mineralization of only 1% to 2% of organic N could contribute substantially to crop fertility in fields with soil organic N >1 g·kg^{-1}. This is particularly true for lettuce, which has a relatively low N uptake requirement (test sites averaged <120 kg·ha^{-1} N).

The soil NO_3-N quick test proved to be a reliable estimate of current soil N status, with sufficient accuracy for routine on-farm use. This test is faster, simpler, and cheaper than conventional laboratory analysis. The colorimetric test strips used for visual analysis cost ≈$0.40 each, and per analysis cost of the $CaCl_2$ extractant is negligible. Collection and analysis of a composite soil sample from a typical field of 4–6 ha would take less than an hour of labor. If the test was employed before each sidedressing opportunity (2–3× per crop) a reduction in fertilizer application of as little as 10 kg·ha^{-1} N would more than offset the cost of monitoring, based on a labor cost of $15/hour and a fertilizer cost of $1.00/kg N. The use of the Reflectoquant® meter (costs ≈$550.00) and the appropriate test strip (≈$1.00 each) would be more expensive, but with routine use could still be cost effective, given the large potential reduction in N application identified in this study.

The poor correlation between lettuce midrib NO_3-N and soil NO_3-N concentration contradicted previous studies that found midrib NO_3-N to be a useful diagnostic tool (Gardner and Pew, 1972, 1974, 1979). Unlike these earlier studies, however, N was not a growth-limiting factor. Under these conditions of clear N sufficiency, midrib NO_3-N concentration was not a sensitive measure of current soil NO_3-N availability, and provided no guidance on additional fertilizer requirements. Furthermore, the large variability among fields suggested that even under potentially N-limited conditions factors other than N availability could confound diagnosis. The midrib samples were taken prior to the second sidedressing, which occurred at approximately the "cupping" stage that initiates head formation, before the rapid growth phase; under California coastal conditions <30% of total seasonal crop N uptake would have occurred at this time (Zink and Yamaguchi, 1962). Pritchard et al. (1995) reported that, because of the slow early growth rate of lettuce, well-defined differences in midrib NO_3-N levels among a range of N treatments did not consistently occur until the last one-third of the season. They concluded, as we did, that a soil N diagnostic test may be more appropriate for early season use.

Using PSNT to evaluate N sidedress requirement is only one of several steps toward environmentally-sound N management for vegetable production in coastal California. Maximizing irrigation efficiency would reduce in-season leaching. The lettuce fields monitored averaged 40 cm of seasonal irrigation; Gallardo et al. (1996) estimated lettuce evapotranspiration to be ≈25 cm under summer conditions in the Salinas Valley. Adjusting N application for soil N mineralization potential and NO_3-N content of irrigation water would further reduce wasteful application. Lastly, the use of winter cover crops would sequester residual NO_3-N from fall cropping as well as soil organic N mineralized during mild winter conditions. Jackson et al. (1993) showed that over-wintering cover crops grown following vegetables in the Salinas Valley contained as much as 200 kg·ha^{-1} N that would otherwise have been susceptible to leaching as NO_3-N with winter rainfall.

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