Presidedress Soil Nitrate Testing Reduces Nitrogen Fertilizer Use and Nitrate Leaching Hazard in Lettuce Production

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Abstract. Trials were conducted in 15 commercial fields in the central coast region of California in 1999 and 2000 to evaluate the use of presidedress soil nitrate testing (PSNT) to determine sidedress N requirements for production of iceberg and romaine lettuce (Lactuca sativa L.). In each field a large plot (0.2–1.2 ha) was established in which sidedress N application was based on presidedress soil NO3-N concentration. Prior to each sidedress N application scheduled by the cooperating growers, a composite soil sample (top 30 cm) was collected and analyzed for NO3-N. No fertilizer was applied in the PSNT plot at that sidedressing if NO3-N was >20 mg kg–1; if NO3-N was lower than that threshold, only enough N was applied to increase soil available N to ≈20 mg kg–1. The productivity and N status of PSNT plots were compared to adjacent plots receiving the growers’ standard N fertilization. Cooperating growers applied a seasonal average of 257 kg·ha–1 N, including fertilizer and sidedressings. Presidedress soil nitrate testing (PSNT) decreased total seasonal and sidedress N application by an average of 43% and 57%, respectively. The majority of the N savings achieved with PSNT occurred at the first sidedressing. There was no significant difference between PSNT and grower N management across fields in lettuce yield or postharvest quality, and only small differences in crop N uptake. At harvest, PSNT plots had on average 8 mg·kg–1 lower residual NO3-N in the top 90 cm of soil than the grower fertilization rate plots, indicating a substantial reduction in subsequent NO3-N leaching hazard. We conclude that PSNT is a reliable management tool that can substantially reduce unnecessary N fertilization in lettuce production.

The use of nitrogen fertilizer is coming under increased scrutiny in many parts of the United States due to concern over nitrate contamination of groundwater. Groundwater nitrate contamination is of particular concern in the coastal valleys of central California, where many wells now exceed the U.S. Environmental Protection Agency drinking water standard of 10 mg kg–1 NO3-N. Vegetable production dominates agriculture in these valleys, with lettuce by far the most common crop. Seasonal N application >200 kg ha–1 is common for lettuce production (Hartz et al., 2000), substantially more than crop N uptake, and perhaps three times the amount of N removed in harvested product (Doerge et al., 1991; Zink and Yamaguchi, 1962). Similar imbalance between the amount of N applied and that removed in harvested product exists for the other common vegetable crops grown in rotation with lettuce in this region. Such high rates of fertilization are due in part to conflicting research results, and in part to economic relationships. Gardner and Pew (1972, 1974) found that head lettuce yield peaked with N at 100–150 kg ha–1, while Welch et al. (1979) and MacKay and Chipman (1961) reported yield increase up to at least 250 kg ha–1. Given the high potential value of lettuce (frequently exceeding $10,000 per ha), exacting market standards for size and appearance, and the low cost of fertilizer N (currently ≈$0.80–1.20 per kilogram) there has been little economic incentive to minimize N application in the absence of regulatory pressure. Such pressure is now being brought to bear.

Presidedress soil nitrate testing (PSNT) is a potential strategy for minimizing unnecessary N application. PSNT has been widely shown to identify corn fields in which crop response to sidedressed N was unlikely (Fox et al., 1989; Heckman et al., 1995; Magdoff, 1991; Meisinger et al., 1992; Schmitt and Randall, 1994; Spellman et al., 1996). These studies reported that a soil NO3-N concentration (top 30 cm) greater than ≈20 mg kg–1 when corn was 15 cm tall (the stage at which sidedressing is usually done) indicated that no sidedress N was required to achieve maximum yield. Hartz et al. (2000), working in California, found this 20 mg kg–1 NO3-N threshold successfully identified lettuce and celery fields in which sidedress N application could be delayed or eliminated. They did not attempt to use PSNT to predict sidedress N requirements in fields below 20 mg kg–1. The current study was undertaken to evaluate the utility of PSNT as a general N management technique in lettuce production, regardless of residual soil NO3-N concentration. Our main objective was to document the effects of N management using PSNT on crop yield and quality, N application, and postseason NO3-N leaching potential across a wide range of field conditions and management practices representative of the commercial industry.

Materials and Methods

Fifteen trials were conducted in commercial lettuce fields in the central coast region of California in 1999 and 2000. These fields were directly seeded from March through July, for harvest June through September (Table 1). Soils varied in texture from sandy loam to clay. A standard planting configuration of two plant rows per 1.0-m raised bed was used. Plant population varied among fields from 56,000 to 72,000 plants/ha. All trials were initially irrigated by sprinklers, with some fields switched to furrow irrigation during head development. In-season precipitation was negligible in all fields. All fields were chosen randomly, without reference to residual soil NO3-N concentration.

In the center of each field a single plot was established in which sidedress N application was based on presidedress soil NO3-N level. Prior to each sidedress N application sched-
uled by the cooperating grower, composite soil samples (top 30 cm) were collected in both the PSNT plot and an adjacent plot receiving the grower’s standard N regime. Soil was collected in the planted row to avoid sampling concentrated bands of fertilizer applied earlier in the season for each plot at least 12 soil cores were collected and blended before analysis. Plots ranged in size among fields from 0.2–1.2 ha. Each plot covered the entire length of the field to ensure that variability in N status caused by irrigation effects was included.

Soil samples from the PSNT plots were analyzed for NO$_3$-N concentration by the ‘quick test’ method described by Hartz et al. (2000). If soil NO$_3$-N exceeded 20 mg·kg$^{-1}$, no sidedress application was made at that time in the PSNT plot. At lower NO$_3$-N concentration the amount of sidedress N applied to the PSNT plot at that sidedressing varied based on the application schedule in Table 2. This schedule was calculated to bring the top 30 cm of soil approximately up to the 20 mg·kg$^{-1}$ N threshold, based on a typical mineral soil bulk density of 1.4 g·cm$^{-3}$. Most fields received two sidedress N applications, typically one following thinning (SD-1), and the second 2 sidedress N applications, typically one following, while two fields received only one. Soil NO$_3$-N estimates from the ‘quick test’ procedure were compared with NO$_3$-N concentration in 2 x KCl extracts of field-moist soil analyzed by the diffusion-conductivity technique of Carlson et al. (1990).

PSNT N status was evaluated at SD-2 and at harvest. At SD-2 whole, recently expanded leaves, and midribs from such leaves, were collected. At harvest, tissue from harvested heads and from crop residue was collected. After oven drying and grinding the whole leaf, head and residue samples were analyzed for total N concentration by combustion (Carlo-Erba 1500, Fisons Instruments, Beverly, Mass). Midribs were extracted in 2% acetic acid and analyzed for NO$_3$-N concentration by the method of Carlson et al. (1990). To allow calculation of aboveground biomass N accumulation, 12 representative whole plants per N treatment per field were harvested, separated into marketable head and residue, and the dry mass of each determined.

Plots were harvested at commercial maturity by experienced personnel provided by the growers. Data collected included percentage of plants that were marketable, and marketable yield (number of cartons/ha if packaged for fresh market, or bulk mass/ha if harvingly destined for processing into packaged salad mixes). In nine trials in 1999, the effect of N fertilization on postharvest quality was evaluated on 24 heads per N treatment per field. The heads were stored for 10–14 d at 5 °C, above the optimal storage temperature (Maynard and Hochmuth, 1997), to simulate the stress of improper commercial handling. The heads were then evaluated for visual quality, decay severity, and degree of discoloration from bruising or russet spotting. Visual quality was rated on a scale of 1 to 10, with 10 being ideal and 5 indicating the limit of marketability. Decay and discoloration were rated on a scale of 1 to 5, with 1 indicating no decay or discoloration, and 5 indicating severe decay or discoloration.

To document the fate of grower-applied N in excess of that applied in the PSNT plots, additional soil sampling was conducted at SD-1 and at harvest. Samples were collected to 90-cm depth, by 30-cm increments. Twelve soil cores per plot were collected from the planted row. NO$_3$-N concentration in 2 x KCl extracts of field-moist soil were determined by the method previously described. The change in soil profile NO$_3$-N concentration over the growing season was calculated.

The structure of the trials allowed no within-field statistical comparison. However, to statistically compare the grower N management across fields an overall ANOVA was performed, using each field as a replication.

### Results and Discussion

Initial (pre-SD-1) soil NO$_3$-N concentration ranged from 10 to 59 mg·kg$^{-1}$, averaging 32 mg·kg$^{-1}$ (Table 3). Cooperating growers applied a seasonal average of N at 257 kg·ha$^{-1}$ for processing into packaged salad mixes). In fields 1 and at harvest. Samples were collected to 90-cm depth, by 30-cm increments. Twelve soil cores per plot were collected from the planted row. NO$_3$-N concentration in 2 x KCl extracts of field-moist soil were determined by the method previously described. The change in soil profile NO$_3$-N concentration over the growing season was calculated.

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Table 3. Soil NO$_3$-N concentration at sidedressing 1 (SD-1), number of sidedress N applications, and seasonal N application rates.

| Field | Soil NO$_3$-N at SD-1 | No. of sidedress applications | Total seasonal N (kg·ha$^{-1}$) | Total sidedress N (kg·ha$^{-1}$) |
|-------|-----------------------|------------------------------|---------------------------------|-------------------------------|
|       |                       | Grower                       | PSNT                            | Grower                        | PSNT                          |
| 1     | 27                    | 3                            | 365                             | 198                           | 331                           | 163                           |
| 2     | 18                    | 2                            | 380                             | 213                           | 336                           | 168                           |
| 3     | 37                    | 3                            | 240                             | 138                           | 213                           | 111                           |
| 4     | 10                    | 3                            | 304                             | 257                           | 235                           | 190                           |
| 5     | 26                    | 1                            | 178                             | 57                            | 136                           | 17                            |
| 6     | 59                    | 3                            | 309                             | 131                           | 180                           | 0                             |
| 7     | 39                    | 2                            | 343                             | 161                           | 230                           | 44                            |
| 8     | 15                    | 2                            | 222                             | 163                           | 161                           | 104                           |
| 9     | 26                    | 2                            | 282                             | 146                           | 247                           | 111                           |
| 10    | 55                    | 2                            | 232                             | 126                           | 106                           | 0                             |
| 11    | 55                    | 1                            | 195                             | 77                            | 153                           | 37                            |
| Mean  | 32                    | 25                           | 257                             | 147                           | 194                           | 84                            |

*NO$_3$-N concentration by laboratory analysis.  
*Represents all N applications, including preplant fertilization and early season water-run applications. 
*Includes late-season water-run application in addition to sidedressing. 
*Received 56 kg·ha$^{-1}$ N at SD-3 through application error. 
*Received 48 kg·ha$^{-1}$ N at SD-3 through application error.

**Table 2. Amount of N applied at sidedressing, based on preplanted soil NO$_3$-N concentration.**

| Soil NO$_3$-N range (mg·kg$^{-1}$) | Sidedress N application (kg·ha$^{-1}$) |
|-----------------------------------|---------------------------------------|
| 0–5                              | 90                                     |
| 5–10                             | 57                                     |
| 10–15                            | 45                                     |
| 15–20                            | 22                                     |

*Estimated by the ‘quick test’ procedure

*NO$_3$-N concentration by laboratory analysis.
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and grower treatments (Table 4). In individual fields either the PSNT or grower plots had as much as a 17% yield advantage, but these differences could be attributed to within-field spatial variability in vigor and plant population rather than an N response. The percentage of plants harvested was similar between treatments, and tissue N levels were generally well above established sufficiency standards.

There were no N treatment effects on postharvest quality (Table 4). Visual quality of the heads declined substantially during postharvest storage, but was still above the marketability threshold. The incidence of decay and discoloration was slight in most fields.

The NO$_3$-N “quick test” provided a reasonable estimate of soil NO$_3$-N across the wide range of concentration encountered in this study ($r = 0.93$, Fig. 1). While clearly less accurate than laboratory analysis, the quick test allowed timely, on-farm estimation of soil NO$_3$-N at relatively low cost (the NO$_3$-N test strips are <$0.50 each). The 20 mg kg$^{-1}$ NO$_3$-N threshold employed was robust enough to accommodate the degree of error associated with the quick test procedure, and spatial variability of soil NO$_3$-N.

From SD-1 to harvest, PSNT plots showed a large decline in NO$_3$-N in the upper 30 cm of soil (>12 mg kg$^{-1}$), while the decline in grower plots was only 5 mg kg$^{-1}$. Grower plots showed an increase in soil NO$_3$-N in the 30–90 cm region while PSNT plots showed a decline. Over the entire 0–90 cm soil profile the grower plots were enriched by an average of 3 mg kg$^{-1}$ NO$_3$-N, while the PSNT plots showed a decline of 5 mg kg$^{-1}$; this difference was significant at $P = 0.05$.

Nitrogen rates used by the cooperating growers were clearly higher than necessary to achieve maximum lettuce yield and quality. Despite a number of studies that suggested maximum lettuce yields could be obtained with 100–150 kg ha$^{-1}$ N (Gardner and Pew, 1972, 1974; Knott and Tavernetti, 1944; Lorenz and Minges, 1942), California growers are hesitant to use such conservative N rates. PSNT and Minges, 1942), California growers are hesitant to use such conservative N rates. PSNT and grower plots not significantly different across fields at $P = 0.05$.

Hartz et al. (2000) found a 20 mg kg$^{-1}$ PSNT threshold to be effective in identifying fields in which sidedressing could be delayed or eliminated without affecting crop yield. They did not attempt to use PSNT to determine sidedress rates in fields below the NO$_3$-N threshold level. The current study found that adjusting N sidedress application to bring soil NO$_3$-N up to the 20 mg kg$^{-1}$ threshold maintained lettuce productivity and quality. Neither of these PSNT studies was structured to include an N-deficient treatment; consequently, the 20 mg kg$^{-1}$ NO$_3$-N threshold employed may be higher than necessary. Further work is warranted to evaluate this issue. However, widespread adoption of the PSNT technique as employed here could substantially reduce industry-wide N use, perhaps by 40% or more.

Midrib NO$_3$-N testing to determine crop N status is widely used by commercial lettuce growers. This study calls into question the need for this practice.

**Table 4. Effect of N treatment on lettuce yield and postharvest quality.**

| Field | N treatment | 24s | 30s | Total | Marketable yield* | Bulk mass (kg ha$^{-1}$) | % of plants harvested | Postharvest rating |
|-------|-------------|-----|-----|-------|-------------------|--------------------------|----------------------|------------------|
| 1     | Grower      | 2,380 | 2,380 | 78   | 6.8              | 1.8                      | 1.3                  |                 |
| 2     | PSNT        | 2,207 | 2,207 | 74   | 6.7              | 1.5                      | 1.5                  |                 |
| 3     | Grower      | 1,878 | 1,878 | 81   | 7.1              | 1.3                      | 1.8                  |                 |
| 4     | PSNT        | 1,804 | 1,804 | 80   | 7.2              | 1.3                      | 1.8                  |                 |
| 5     | Grower      | 2,100 | 2,100 | 90   | 7.0              | 2.1                      | 2.5                  |                 |
| 6     | PSNT        | 2,503 | 2,503 | 76   | 6.5              | 2.1                      | 1.7                  |                 |
| 7     | Grower      | 2,427 | 2,427 | 72   | 7.1              | 1.9                      | 2.0                  |                 |
| 8     | PSNT        | 36,800 | 36,800 |      |                  |                          |                     |                 |
| 9     | Grower      | 2,530 | 2,530 | 84   | 6.1              | 2.5                      | 2.3                  |                 |
| 10    | PSNT        | 2,691 | 2,691 | 81   | 6.8              | 2.3                      | 2.1                  |                 |
| 11    | Grower      | 2,009 | 2,009 | 84   | 6.4              | 2.3                      | 2.2                  |                 |
| 12    | PSNT        | 1,913 | 1,913 | 83   | 6.6              | 2.1                      | 2.1                  |                 |
| 13    | Grower      | 1,161 | 1,161 | 47   | 6.4              | 2.3                      | 2.2                  |                 |
| 14    | PSNT        | 1,161 | 1,161 | 50   | 6.9              | 2.0                      | 2.0                  |                 |
| 15    | Grower      | 2,570 | 2,570 | 87   | 6.7              | 2.0                      | 2.1                  |                 |
| 16    | PSNT        | 2,392 | 2,392 | 89   | 6.7              | 1.7                      | 2.1                  |                 |
| 17    | Grower      | 36,500 | 36,500 |      |                  |                          |                     |                 |
| 18    | PSNT        | 33,500 | 33,500 |      |                  |                          |                     |                 |
| 19    | Grower      | 2,161 | 2,161 | 78   | 6.8              | 1.8                      | 1.3                  |                 |
| 20    | PSNT        | 2,184 | 2,184 | 93   | 6.9              | 1.8                      | 1.8                  |                 |
| 21    | Grower      | 1,913 | 1,913 | 93   | 6.6              | 2.1                      | 2.1                  |                 |
| 22    | PSNT        | 1,932 | 1,932 | 93   | 6.6              | 2.1                      | 2.1                  |                 |
| 23    | Grower      | 2,503 | 2,503 | 95   | 6.9              | 1.8                      | 1.8                  |                 |
| 24    | PSNT        | 2,427 | 2,427 | 95   | 6.9              | 1.8                      | 1.8                  |                 |

*Cartons/ha if boxed for fresh market; bulk weight if harvested for processing into salad mixes.

1Head count per carton.

2PSNT and grower plots not significantly different across fields at $P = 0.05$.

Fig. 1. Accuracy of the soil NO$_3$-N “quick test” procedure for estimation of soil NO$_3$-N concentration.
value of that technique to determine field-specific sidedress N requirements. At SD-1, the point at which the majority of N savings was realized by PSNT, plants are so small that insufficient tissue is available to collect the standard midrib sample. Furthermore, at SD-2 there was no correlation between midrib NO₃-N and currently available soil NO₃-N. Clearly, factors other than soil N availability have profound effects on midrib NO₃-N, severely limiting the value of that analysis at this early growth stage. We conclude, as did Hartz et al. (2000) and Pritchard et al. (1995), that soil testing is more appropriate than midrib testing to evaluate field N status, at least until SD-2.

Much of the excess fertilization in grower plots occurred early in the growing season; most of the N reduction in PSNT plots occurred at SD-1. Since more than 65% of lettuce N uptake occurs in the final third of the growing season (Gardner and Pew, 1979; Zink and Yamaguchi, 1963) heavy early-season fertilizing to evaluate field N status, at least until SD-1. Since more than 65% of lettuce N uptake occurs in the final third of the growing season (Gardner and Pew, 1979; Zink and Yamaguchi, 1963) heavy early-season fertilizing may be considered unnecessary sidedress N application. If widely adopted by the California industry a significant reduction in overall N usage could be achieved, with substantial reduction in groundwater pollution potential.

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