Final report

Reducing nutrient loading from vegetable production

Project leaders:

T.K. Hartz
Department of Plant Sciences
University of California
Davis, CA 95616
tkhartz@ucdavis.edu

R. Smith and M. Cahn
University of California Cooperative Extension
1432 Abbott St.
Salinas, CA 93901
rifsmith@ucdavis.edu
mdcahn@ucdavis.edu

Introduction:

Vegetable growers along the central coast are under extreme scrutiny regarding potential water quality impairment resulting from their activities. The Cooperative Monitoring Program (CMP), undertaken as part of the Irrigated Agriculture Order granting a conditional waiver for the discharge of water from agricultural lands, has shown that high concentrations of nitrogen (N) and phosphorus (P) in surface water are widespread; extensive well sampling show that NO_3-N contamination of groundwater to be similarly problematic. This project was undertaken to demonstrate the potential for reducing N and P fertilization rates in lettuce production while maintaining high yield and quality. Given the rapid adoption of drip irrigation in central coast vegetable production, and the fertilizer and irrigation efficiency that can be gained with this technology, all trials were conducted in drip-irrigated fields.

Methods:

Three field trials were conducted in drip-irrigated lettuce fields in northern Monterey County during the summer and fall of 2007. In each case the cooperating grower allowed us to create replicate plots of several fertility treatments; these treatments varied among fields based on the grower's practice; the intent was to compare varying levels of N and P fertilization with the grower fertility regime, with the goal of demonstrating how fertilizer rates (and therefore, environmental nutrient loading) could be reduced. This was accomplished by varying preplant or at-planting N and P application, and by closing off the drip irrigation tapes during one or more N fertigation events. In field 1 the grower did not apply P, based on the elevated soil test P level; to provide a P treatment we broadcast 80 lb P_2O_5/acre preplant only in the P treatment. Different N treatments were established by eliminating the second and third, or all three, N fertigations applied by the grower. In field 2 the grower applied a phosphoric acid-based 'starter' fertilizer at planting, which we eliminated in the 'no P' treatment. Different N treatments were established by eliminating the first two, or all four, of the grower fertigations. In field 3 the grower's N and P regime was compared to a no P, no fertigated N treatment, and a treatment with P, but reduced N fertigation.

Field trials 4 and 5 were conducted in northern Monterey County in 2008. Given the regulatory focus on nitrate issues we decided to concentrate solely on N manipulation in these fields. In field 4 the grower applied four N fertigations, and three reduced N treatments were created by eliminating one to three of those fertigations. In field 5 the grower fertigated through sprinklers before the installation of drip tape, then applied three N fertigations through the tape; three reduced N treatments were created by skipping 1, 2 or all 3 fertigations. Cultural details on all trials are given in Table 1.

A randomized complete block experimental design was used in all fields, with 4 replications per fertility treatment. Individual plots were four beds wide by at least 100 feet long. Data were collected on the middle two beds of each plot. Field N status was monitored by soil nitrate-nitrogen (NO_3-N) concentration in the top foot of soil, wrapper leaf midrib NO_3-N, wrapper leaf total N, and whole plant N concentration periodically through the drip-irrigated portion of the season.

In addition, a digital leaf reflectance meter (commonly referred to as a 'chlorophyll' meter, model CM 1000, Spectrum Technologies, Plainfield, IL) was evaluated as a potential N monitoring tool. This meter measures the reflected light from leaves in photosynthetically active wavelengths; meter readings should theoretically be correlated with leaf N status. In each field leaf reflectance readings were taken several times during the fertigation portion of the growing season. Measurements were made on wrapper leaves from 30 or more plants per plot.

Several days before commercial harvest the trials were evaluated for crop productivity. In each plot 32-40 randomly selected whole plants were harvested and weighed. A subset of these plants were trimmed as typical for commercial sale and reweighed. Representative samples of whole plant tissue were oven-dried, ground and analyzed for N concentration, and total above-ground crop N uptake was calculated.

Results:

P fertilization was ineffective in improving lettuce growth in either field 1 or 2 (Table 2). Both fields had soil test P > 50 PPM (bicarbonate, or 'Olsen', extraction procedure), above the agronomic response threshold we established in prior research in the Salinas Valley (Johnstone et al., 2005). These results provide additional evidence to convince growers that P fertilization of soils at or above 50 PPM Olsen P is not necessary for lettuce production. Whole leaf sampling at mid-season showed leaf P concentration in the no-P treatment to be 0.52 and 0.65% in field 1 and 2, respectively; this was well above the 0.43% sufficiency threshold established in earlier research (Hartz et al., 2007), and statistically equal in both fields to the treatment receiving P application.

Unfortunately, P fertilization is increasingly being done at planting in the form of an acid-based fertilizer applied at least in part for its anticrustant properties; Valley soils can form a crust that physically impedes the emergence of lettuce plants. To eliminate the use of P-containing anticrustants in high-P fields growers must not only be convinced that crop response to P is unlikely, but also that other non-phosphorus-containing anticrustants are as effective in that function. There is limited documentation that other types of anticrustants are as effective as acid-based materials. Luckily, when used primarily for their anticrustant properties, acid-based P fertilizers are typically applied at relatively low rates (< 40 lb P_2O_5 equivalent / acre, as was done in fields 3 and 4). These low rates are roughly the amount taken up by a lettuce crop, and therefore this practice does not significantly increase the soil P levels over time as does the traditional practice of high preplant P application.

The cooperating growers used widely varying N fertilization practices, with seasonal N rates ranging from 115-237 lb N/acre. In trials 1, 2, 4 and 5 we showed that N fertigation could be substantially reduced without significantly affecting crop productivity (Table 2). In those trials an average reduction of 90 lb/acre of fertigated N was achieved with no statistically significant yield loss. In field 3 the grower applied a seasonal total of only 115 lb N/acre, with only 67 lb N fertigated; although not statistically significantly at the 5% level of probability, skipping the first fertigation resulted in a substantial decline in crop productivity, suggesting that the grower practice in this field was efficient.

Plant sampling and analysis at harvest showed that, in the grower plots, the above-ground crop N uptake averaged 102 lb N/acre; crop N uptake in the reduced N treatments averaged 90 lb/acre. Therefore, on average only about 13% of the additional 90 lb N applied by the growers was even taken up by the crop. This was consistent with previous research that showed poor nitrogen uptake efficiency by lettuce at current fertilization rates. Crop N uptake followed a similar pattern in all fields (Fig. 1). In order to standardize across fields we evaluated crop N uptake on the basis of growing degree days (GDD, an index of cumulative temperature effects on crop maturation). In the first 600 cumulative GDD after planting (approximately 30 days under northern Salinas Valley summer conditions), crop growth was minimal, and less than 10 lb N/acre was taken up during that period. From that point forward until harvest (approximately another 30 days), daily N uptake was relatively constant at between 3-4 lb N/acre. That pattern was consistent across fields and lettuce types (iceberg and romaine).

Drip irrigation was managed reasonably in all fields. Drip irrigation in lettuce is typically used only in the final 4-5 weeks of growth, after the crop has been established with sprinklers; during that stage of the growing cycle crop evapotranspiration would usually be in the range of 60-90% of reference evapotranspiration (ET_o), depending on the field configuration (bed width, number of rows per bed) and crop vigor. However, growers have to account for irrigation system inefficiency, and the delivery of up to approximately 120% of ET_o in the final month of the season may be justified. Drip irrigation in fields 1-4 was managed very efficiently, with applied water averaging just over 80% of ET_o over the monitored period. In field 5 irrigation data was only available for the final 2 weeks of the season, and the grower applied approximately 130% of ET_o over that period. Part of the ability to reduce N fertigation in these fields was related to the efficient irrigation management, which minimized the opportunity for nitrate leaching losses over the fertigation period.

The other important element of N management in these fields was the substantial amount of residual soil NO_3-N present when the growers began fertigation. To put the soil NO_3-N supply in perspective, the values given in Table 1, multiplied by 4, would approximate the lb NO_3-N/acre present in the top foot of soil. In fields 1-4 especially, the majority of N necessary to supply crop uptake was already present when the grower N fertigations began. This helped to explain why minimal additional N fertigation was sufficient to maximize crop productivity, and emphasized the value of soil nitrate testing to guide in-season N management.

The leaf reflectance meter proved to be an unreliable tool for evaluating crop nutrient status and the need for additional N fertilization. Fig. 2 shows leaf reflectance data for two dates preceding fertigations for each field; these samplings represented the early heading and late heading growth stages.. Plots receiving the growers' N fertigation regime generally had higher leaf reflectance values (deeper green color) than plots receiving no fertigation, but the differences were minor compared to the variation across fields, or between dates within fields. When the leaf reflectance data from the later evaluation date from each field were compared to the concurrently measured leaf N concentration there was no overall correlation, and only in field 2 was the correlation statistically significant (Fig. 3). Clearly, factors other than leaf N status affected the leaf reflectance reading, and hopelessly confounded the relationship between crop N status and reflectance. To overcome some of these confounding influences some researchers have suggested having an in-field ‘reference’ plot of high N status against which to compare the rest of the field. In these trials the grower plots provided the in-field reference, and still the meter did not adequately discriminate between marginal N and excessive N treatments.

In summary, these trials documented that improved fertilizer management practices previously demonstrated in sprinkler-irrigated fields are equally applicable to drip-irrigated culture. The highly efficient drip irrigation scheduling done by the cooperating growers was an encouraging sign of improved management that could significantly reduce off-site nutrient loss; such real-world examples of efficient irrigation management are helpful in our educational efforts with industry groups. The potential for significant reduction in fertilizer usage demonstrated in these trials suggests that continued grower education is required to convince the industry that current fertilization practices can be improved without risk of crop loss.

Outreach activities:

In addition to the one-on-one discussion of results with the cooperating growers, the information developed in these trials was extended through a series of presentations for industry audiences. Those events were held in:

- Salinas, February 19, 2008
- Morro Bay, September 9, 2008
- Santa Maria, November 6, 2008
- Monterey, January 7, 2009
- Salinas, February 24, 2009

Cumulative attendance at these events exceeded 250 people. The results of these trials were combined with those from other trials conducted by M. Cahn and R. Smith, and formed the basis of a poster presented at the annual California Plant and Soil Conference in Fresno on February 3, 2009. The results of the 2007 trials were highlighted in an article summarizing nitrogen management practices for lettuce production that was published in the Monterey County Crop Notes newsletter in spring, 2008; this newsletter is distributed to hundreds of growers and related industry professionals throughout the coastal region. An overall summary of the project will appear in that newsletter in spring, 2009, and in the widely distributed trade magazine Vegetables West.

Literature cited:

Hartz, T.K., P.R. Johnstone, E. Williams and R.F. Smith. 2007. Establishing lettuce leaf nutrient optimum ranges through DRIS analysis. HortScience 42:143-146.

Johnstone, P.R., T.K. Hartz, M.D. Cahn and M.R. Johnstone. 2005. Lettuce response to phosphorus fertilization in high phosphorus soils. HortScience 40:1499-1503.

Table 1. Initial soil fertility characteristics and fertilizer application.

Field	Initial soil test (PPM) Olsen P	Initial soil test (PPM) NO_3-N	Planting date	Fertility treatment	Preplant and/or at-planting fertilization (lb/acre) P_2O_5	Preplant and/or at-planting fertilization (lb/acre) N	N fertigation (lb/acre) first	N fertigation (lb/acre) second	N fertigation (lb/acre) third	N fertigation (lb/acre) fourth	Total seasonal N (lb/acre)
1	57	20 [z]	5 June	Grower N and P	80	42	50	39	38		169
				Grower N, no P		42	50	39	38		169
				Reduced N, no P		42	50	0	0		92
				No fertigated N, no P		42	0	0	0		42
2	62	27	15 June	Grower N and P	72	18	76	31	31	15	171
				Grower N, no P			76	31	31	15	153
				Reduced N, grower P	72	18	0	0	31	15	64
				No fertigated N, grower P	72	18	0	0	0	0	18
3	45	21	15 Aug	Grower N and P	18	48	48	19			115
				Reduced N, grower P	18	48	0	19			67
				No fertigated N, no P		48	0	0			48
4	55	19	3 March	Grower N	14	47	38	48	48	30	211
				Reduced N level 1	14	47	38	0	48	30	163
				Reduced N level 2	14	47	0	48	0	30	125
				Reduced N level 3	14	47	0	0	0	30	77
5	77	11	11 July	Grower N	100	52	53	45	42	45	237
				Reduced N level 1	100	52	53	45	42	0	192
				Reduced N level 2	100	52	53	0	42	0	147
				No fertigated N	100	52	53	0	0	0	105

[z] NO_3-N values represent the top foot of soil measured prior to the initial N fertigation

Table 2. Effect of fertility management on lettuce yield and biomass N content.

Field	Fertility treatment	Lettuce type	Seasonal N (lb/acre)	Lettuce yield (lb/plant) total	Lettuce yield (lb/plant) marketable	Biomass N content (lb/acre)	Reference ET_o (inches)	Drip irrigation applied (inches)
1	Grower N and P	head	169	2.29 b	1.61 b	98 ab	6.2	4.9
	Grower N, no P		169	2.38 a	1.70 a	103 a		
	Reduced N, no P		92	2.31 ab	1.63 ab	91 ab		
	No fertigated N, no P		42	2.03 c	1.41 c	84 b		
2	Grower N and P	head	171	2.16	1.50	103 ab	6.5	4.7
	Grower N, no P		153	2.18	1.43	114 a		
	Reduced N, grower P		64	2.27	1.56	101 ab		
	No fertigated N, grower P		18	2.07	1.38	89 b		
				ns	ns			
3	Grower N and P	romaine	115	1.92 a	1.54	102 a	2.4	2.8
	Reduced N, grower P		67	1.81 a	1.43	87 b		
	No fertigated N, no P		48	1.65 b	1.39	76 b		
					ns			
4	Grower N	head	211	2.61 a	1.52 a	114 ab	5.2	4.3
	Reduced N level 1		163	2.68 a	1.59 a	119 a		
	Reduced N level 2		125	2.55 a	1.48 a	99 b		
	No fertigated N		77	2.33 b	1.26 b	96 b		
5	Grower N	romaine	237	1.64	1.16	85 a	2.1	2.8
	Reduced N level 1		192	1.59	1.14	74 ab		
	Reduced N level 2		147	1.63	1.14	69 ab		
	No fertigated N		105	1.48	1.06	59 b		
				ns	ns			

[ns] means not significantly different at $p < 0.05$; means followed by the same letter not significantly different at $p < 0.05$

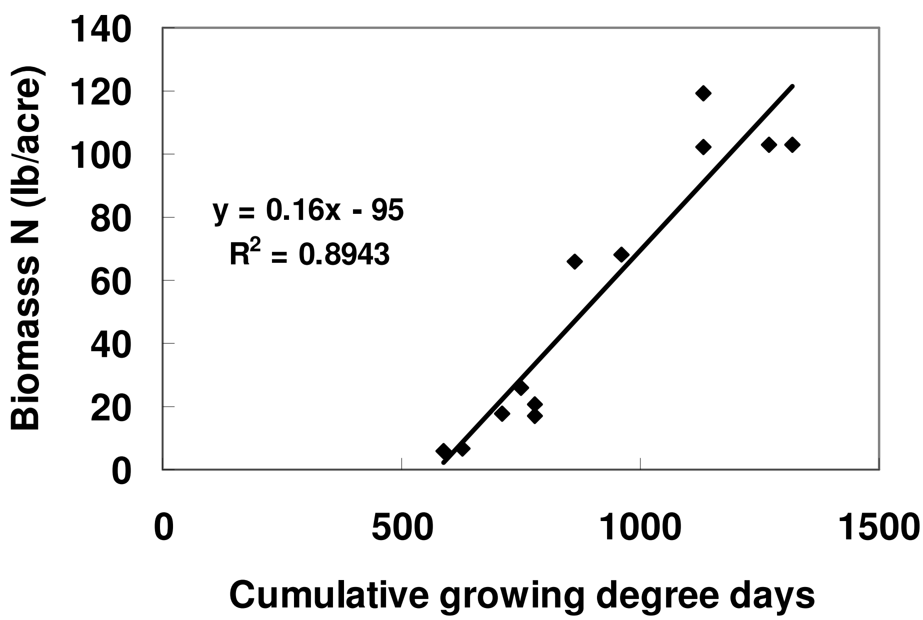

Fig. 1. Pattern of crop N uptake over the production season; growing degree days based on 86^{o}F and 40^{o}F high and low temperature thresholds.

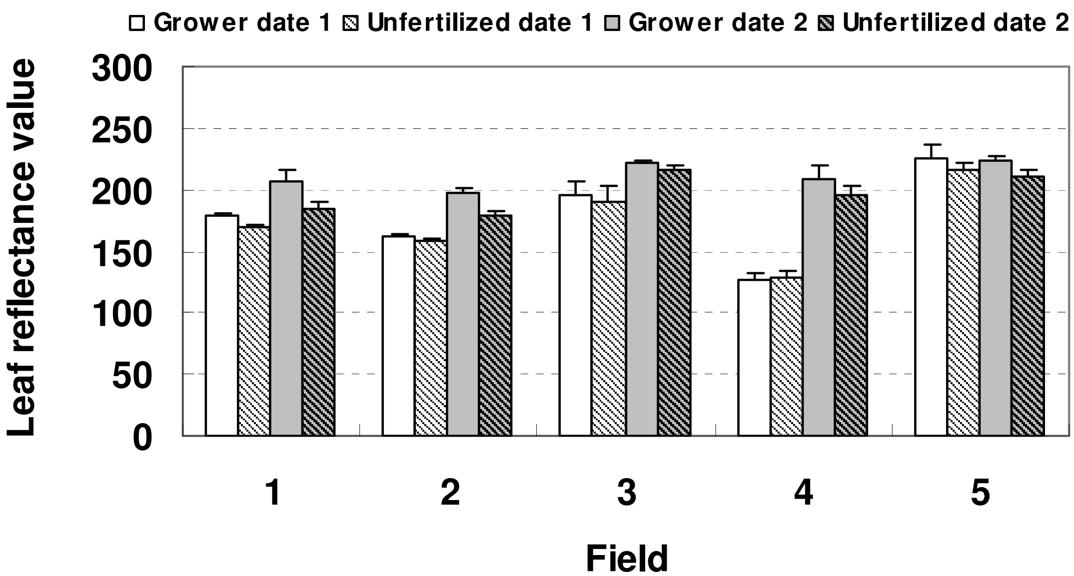

Fig. 2. Comparison of relative leaf reflectance of grower fertigated plots and plots receiving no N fertigation. Higher values indicate darker green color; bars indicate standard errors. Growth stage was early heading and late heading at dates 1 and 2, respectively.

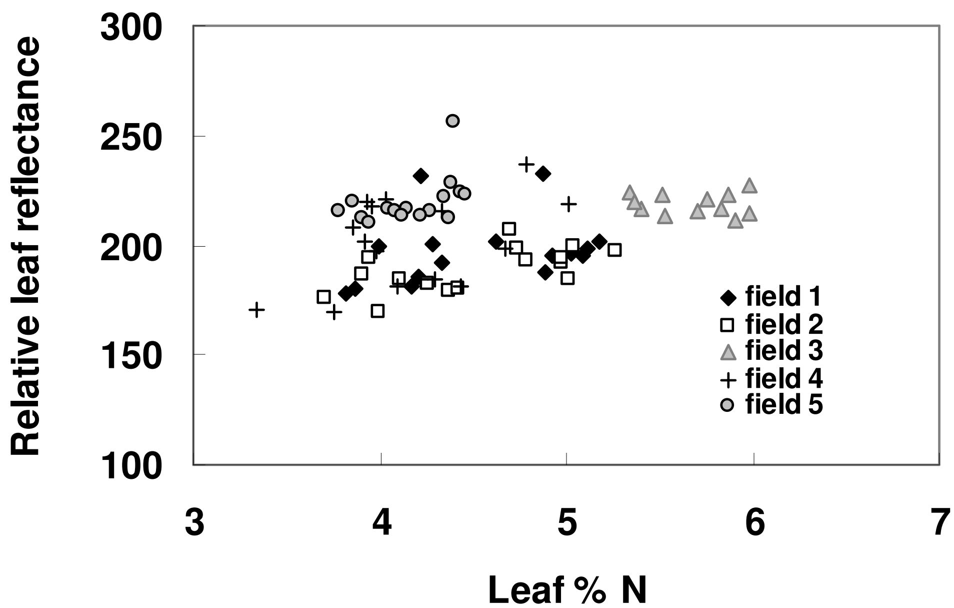

Fig. 3. Relationship between relative leaf reflectance and leaf N concentration at the late heading growth stage.

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