GRANT NUMBER:	20090179	**Progress Report**	Final
		Reporting Period:	3/01/2009 to 6/30/2011
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Agency Name: University of California

Project Title: Demonstrating best management practices for coastal vegetable production

Contractor Name:

Project Director: T. K. Hartz (Printed Name) T. K. Hartz (Signature)

Table of Deliverables

Task	Deliverable by Subtask #	Due Date	% of Work Complete	Date Submitted
		(mm/dd/yy)	(__%)	(mm/dd/yy)
1 Demonstration of efficient practices	Conduct of field demonstrations	11/01/2010	100%	4/26/2011
2 Outreach	Participation at grower meetings, development of web presentation	4/30/2011	100%	4/26/2011

List of Deliverables Submitted For Final Report

- Task 1 – conducted commercial field demonstrations of efficient nitrogen fertilization
- Task 2 – conduct initial outreach activities

Report Narrative

Demonstrations comparing commercial growers' N fertilization practices with reduced N application based on presidedress soil nitrate testing were conducted in 2009 in 18 commercial lettuce fields grown for Dole Fresh Vegetables, Inc.; these fields represented 11 different grower operations. Fields were chosen which had at least 20 PPM residual soil NO_3-N prior to the first sidedressing. In each field one strip, wide enough to accommodate a mechanized harvest crew, was designated as the 'reduced N' plot in which the first sidedressing was either skipped or reduced; this plot received all subsequent N applications made by the grower. On 7-10 day intervals throughout the season, and just prior to commercial harvest, whole plant samples were collected and evaluated for total yield and plant N status. At the time of commercial harvest the Dole crews compared marketable yields in the reduced N plot with plots on either side receiving the grower's full N regime. Averaged across the 18 fields, crop yield in the reduced N plots was statistically equivalent to that produced in the grower N plots. Seasonal N application averaged 134 and 61 lb/acre in the grower and reduced N strips, respectively. The additional 73 lb N/acre applied by growers resulted in an average of only 7 lb/acre of additional plant N uptake, emphasizing the inefficiency of early-season N sidedressing in fields with significant residual soil NO_3-N. Postharvest evaluation of lettuce quality in four of the 2009 trials, and in two additional PSNT trials in 2010, showed no significant effect of N fertilization.

A number of outreach activities have been completed. These include four educational meetings for growers, and a narrated powerpoint presentation on efficient lettuce production; this presentation, and others relating to environmental water quality protection, are accessible on a new UC-managed website on efficient nutrient management.

Summary of Activities

Task 1 - (Cumulative 100% complete)

Methods:

Given the Central Coast Region Water Quality Control Board's emphasis on reducing nitrate pollution, it was decided to concentrate efforts in this project on improving nitrogen fertilization practices; consequently, all field demonstrations involved pre-sidedress soil nitrate testing (PSNT) to reduce unnecessary sidedress N application. Working in cooperation with Dole Fresh Vegetables, Inc., 18 lettuce fields were identified during the 2009 production season in which soil residual NO_3-N concentration in the top foot of soil exceeded 20 PPM at thinning, prior to the first sidedress N application. These fields ranged geographically from Watsonville to Chualar, and represented a range of soil types from sandy loam to clay. Five fields were planted to romaine and 13 fields to iceberg lettuce. All fields were sprinkler irrigated for stand establishment, with 2 fields finished with drip irrigation, and one field finished with furrow irrigation. Detail on individual fields is given in Table 1.

Prior to the first sidedress N application, a strip in each field was identified to receive a reduced N fertilization regime. These strips were the entire length of the field long by 12 to 24 beds wide. The width of the strip varied depending on the bed width, and the expected utilization of the field (boxed whole heads or value-added processing); strip width was set to accommodate one pass of the mechanized commercial harvest equipment. At the first sidedressing the reduced N strip received either no sidedressing (15 fields) or a reduced sidedress rate (3 fields), depending on the comfort level of the cooperating grower. Following the first sidedressing, the reduced N plots received all other N fertilization subsequently applied by the grower, whether by additional sidedressing or by fertigation.

Plant and soil sampling was done on 7-10 day intervals until harvest; the head and tail ends of the reduce N plots were sampled separately, as were the ends of the adjacent plots receiving the full grower N program. Plant population was determined in a representative 4 bed wide by 100 foot long section at each end of each plot. At each sampling, soil cores (0-12 inch depth) were collected in the planted row. Randomly selected whole plants were collected for determination of fresh and dry weight, and N content. Whole wrapper leaves and midribs of wrapper leaves were collected, dried and analyzed for total N and NO_3-N, respectively.

In 13 fields an infrared camera was used to document the percentage of the ground surface covered by the plant canopy. Photos were taken on 7-10 day intervals, beginning after crop thinning. These data, combined with daily reference evapotranspiration (ET_o) data from the 'spatial CIMIS' feature of the CIMIS weather network (http://wwwcimis.water.ca.gov/cimis/cimiSatSpatialCimis.jsp), allowed the estimation of crop evapotranspiration (ET_c). In 8 fields (5 sprinkler-irrigated N trial fields, and 3 drip-irrigated fields on the same ranches) a pulse output water meter equipped with a datalogger was installed on the main irrigation line to document the timing and volume of irrigation applied. In these fields the seasonal irrigation requirement was calculated based on ET_c and a typical irrigation system distribution uniformity of 70% for sprinkler irrigation and 90% for drip irrigation.

Just prior to commercial harvest, total plant biomass was estimated by the collection of 32 to 40 randomly selected whole plants in each end of the reduced N plot and the adjacent grower N plots (32 plants were collected in two row, 40 inch-wide beds while 40 plants were collected in 5 row, 80 inch-wide beds). In the last 11 fields harvested, a digital leaf reflectance meter (Fieldscout CM-1000, commonly referred to as a 'chlorophyll' meter) was used to evaluate the green color of the youngest wrapper leaf of each harvested plant. A subsample of whole plant tissue was dried, weighed and analyzed for total N concentration. Commercial harvest crews recorded marketable yield separately in the reduced N strip and in the neighboring strips receiving the full grower N regime. In four fields that were used for processed salad, bulk bins of lettuce from both N treatments were processed separately at the Dole salad facility in Soledad; Dole quality control personnel evaluated bags of shredded lettuce from each N treatment after approximately 2 weeks of refrigerated storage. Quality scores were based on a 0 to 3 scale, 0 being no decay or significant discoloration, and 3 being unmarketable due to decay and/or discoloration.

To gather more data on the effects of N fertilizer management on postharvest lettuce quality, detailed quality analysis was conducted on lettuce from two nitrogen management trials conducted by UC Farm Advisors Richard Smith and Michael Cahn in 2010; one trial was on iceberg lettuce and the other was on romaine. In each trial, 4 replicate plots of the cooperating grower's drip irrigation and N fertilization program were compared with plots managed according to irrigation and N fertigation best management practices (BMPs); the primary BMP for N management was in-season soil nitrate sampling. At harvest, 8 randomly selected heads from each plot (32 per treatment per trial) were transported to UC Davis, where they were processed to simulate commercial production of bagged salad. A major quality defect in lightly processed lettuce is tissue browning. The level of activity of phenylalanine ammonia lyase (PAL), an enzyme that catalyzes the biosysnthesis of the phenolic compounds responsible for browning, was determined after 0, 3, 6 and 9 days of storage at 5 ^oC. The intensity of tissue browning was also determined spectrophotometrically on those dates.

Results:

The cooperating growers for the 2009 trials used widely varying amounts of N fertilizer; seasonal N rates ranged from 76 to 233 lb/acre, averaging 134 lb/acre (Table 1). Seasonal N rates in the reduced N plots ranged from 0 to 127 lb/acre, averaging 61 lb/acre. In six fields there was only a single sidedressing applied, meaning that the reduced N plot received no fertilizer after thinning. In the other fields from 2 to 5 in-season N applications were made, by some combination of sidedressing or fertigation (injection into irrigation water).

Averaged across these 18 fields, reducing N fertilization at first sidedressing had no overall effect on crop productivity (Table 2). The comparison of productivity between grower and reduced N plots varied somewhat among fields, but these differences were assumed to be due mostly to spatial variability rather than to effects of N fertilization. In field #7 sections of the reduced N plot developed a distinctly yellow cast late in the season, indicative of N deficiency, although productivity did not appear to be substantially affected. After this observation we collected pre-harvest leaf color readings in all subsequent fields. Note that field #7 only received one sidedress N application, meaning that the reduced N plot received no N fertilization after planting; late season soil NO_3-N analysis did show low soil N availability in the reduced N plot.

Despite receiving on average 73 lb/acre less fertilizer N than the grower plots, the reduced N plots had similar total crop N uptake. At harvest, total N in above-ground biomass in the reduced N plots averaged132 lb/acre, compared to 139 lb/acre in the grower N plots (Table 3). Some of the field-to-field variability in N uptake related to plant population; fields grown with 5-6 rows of plants on 80 inch beds had higher plant population, and higher N uptake, than fields with two plant rows on 40 inch beds. The only field with a large difference between N treatments in crop N uptake was field #7, and that was also the only field in which whole plant N concentration at harvest was below 3% of dry weight, the established sufficiency threshold for maximum growth rate. Based on these field trials, typical crop N uptake in the above-ground biomass of lettuce (iceberg or romaine, grown for mature heads) ranges between 120-150 lb N/acre; 14 of 18 trials fell in this range.

Leaf color in the reduced N plots of fields 8-18 was marginally lighter green on average than the grower plots (Table 3). The color differences between N treatments were not visually apparent, and thus were of no commercial significance. Field-to-field color variability was far greater than variability between N treatments within fields. Romaine had a much darker color than head lettuce.

Crop N uptake data were normalized across fields using growing degree days (GDD) to account for the effects of temperature on growth rate. Daily GDD was calculated using temperature in ^{o}C, by the formula:

$$\text{GDD} = ((\text{daily maximum} + \text{daily minimum})/2) - 5$$

Crop N uptake of grower N plots showed a similar pattern across fields (Fig. 1). Initial uptake was slow in the first weeks after planting, and then increased linearly until harvest. Part of the variability in N uptake rate related to plant population, with fields on 80 inch beds trending toward higher N uptake. Fig. 2 shows the timing of crop N uptake in the grower N plots, adjusted for typical summer temperatures in the Castroville (a) and Soledad (b) areas. In the initial month following planting, no more than 10 lb N/acre was taken up. From that point until harvest, growth and N uptake followed a linear trend, with daily N uptake averaging between approximately 3.6 and 4.3 lb per acre per day. These uptake rates overstate the actual N uptake requirement for lettuce; N uptake in the reduced N plots during this portion of the season averaged about 0.2 lb per acre per day less, but produced equivalent growth.

Crop canopy development followed a trend similar to crop N uptake (Fig. 3). Slow development in the 3-4 weeks after planting was followed by rapidly increasing canopy development; the rate of canopy development slowed in the final 7-10 days preceding harvest. Final canopy coverage topped out between 80-90%, with lettuce grown on 80" beds having marginally higher values. Within a particular bed width the similarity in canopy development among fields will allow the development of an irrigation template to improve irrigation efficiency.

Fig. 4 shows the relative irrigation efficiency achieved in the 8 fields in which irrigation was monitored. Three of sprinkler-irrigated fields received an irrigation efficiency rating (seasonal ET_c / seasonal irrigation applied) below 50%, while an irrigation efficiency rating of >70% was achieved in two of the sprinkler-irrigated fields and two of the drip-irrigated fields. Much of the seasonal irrigation inefficiency related to management during crop establishment, a time at which many growers apply substantially more water than required in an attempt to keep the seed beds moist until plant establishment.

Nitrogen fertilization rate had no consistent effect on postharvest lettuce quality. Across the four fields evaluated for post-storage quality of bagged, shredded lettuce in 2009, the N treatments performed similarly. The postharvest quality score of the grower N treatment averaged across fields was 0.75, compared to 0.50 for the reduced N treatment (lower score indicating higher quality); the scores were not statistically different. In the 2010 trials, N management did not affect postharvest PAL activity or browning intensity (Table 4); following nutrient management BMPs reduced seasonal N application by 126 and 59 in the iceberg and romaine trials, respectively.

These results clearly show that reducing or eliminating early season N application in fields with high residual soil NO_3-N can significantly reduce N loading rates with minimal risk of reduced lettuce yield or quality. Demonstrating the utility of this management technique across such a wide range of growers and production environments should improve grower confidence in PSNT.

Table 1. Cultural detail on the 2009 demonstration fields.

Field	Crop	Irrigation method	Harvest date	Seasonal N applied (lb/acre)		# of in-season N applications*	
				Grower	Reduced N	Grower	Reduced N
1	head	sprinkler	6/9	129	23	1	0
2	head	sprinkler	6/17	123	36	1	0
3	head	sprinkler	6/27	118	26	1	0
4	head	sprinkler/drip	7/13	100	58	1	0
5	romaine	sprinkler	7/27	132	102	1	1
6	head	sprinkler	8/8	128	43	2	1
7	head	sprinkler	8/13	127	0	1	0
8	romaine	sprinkler	8/26	127	42	2	1
9	head	sprinkler/drip	9/5	181	103	5	4
10	head	sprinkler/furrow	9/14	80	32	2	1
11	head	sprinkler	9/14	100	44	2	1
12	romaine	sprinkler	9/18	233	127	2	1
13	head	sprinkler	9/24	76	44	1	1
14	head	sprinkler	9/24	170	106	3	2
15	romaine	sprinkler	9/29	132	87	1	1
16	head	sprinkler	10/6	170	106	3	2
17	romaine	sprinkler	10/10	160	96	3	2
18	head	sprinkler	10/23	129	23	1	0
Ave				**134**	**61**		

* sidedress and / or fertigation

Table 2. Lettuce productivity as influenced by nitrogen treatment.

		Total yield (lb/acre)		Marketable yield
Field	Crop	Grower	Reduced N	(reduced N as a % of grower)
1	head	71,160	70,090	94
2	head	97,500	90,450	107
3	head	73,570	75,890	102
4	head	85,360	84,550	97
5	romaine	65,980	69,640	111
6	head	75,800	76,430	98
7	head	85,270	82,770	97
8	romaine	63,570	64,460	92
9	head	87,770	87,950	106
10	head	75,890	75,890	101
11	head	89,820	88,750	96
12	romaine	48,040	48,210	91
13	head	74,730	75,360	96
14	head	77,140	76,160	107
15	romaine	68,570	68,210	97
16	head	106,520	100,450	109
17	romaine	66,070	66,880	93
18	head	112,320	114,110	104
Ave		**79,170**	**78,680**	**100**

Table 3. Lettuce N uptake, tissue N concentration and leaf color at harvest.

		Total N application (lb/acre)		Biomass N (lb/acre)		Plant % N		Wrapper leaf color*	
Field	Crop	Grower	Reduced N	Grower	Reduced N	Grower	Reduced N	Grower	Reduced N
1	Head	129	23	125	121	3.7	3.6		
2	Head	123	36	170	158	3.9	3.7		
3	Head	118	26	136	135	3.8	3.7		
4	Head	100	58	141	131	3.6	3.0		
5	Romaine	132	102	141	151	4.5	4.7		
6	Head	128	43	137	143	4.2	4.1		
7	Head	127	0	140	96	2.9	1.9		
8	Romaine	127	42	135	102	3.8	3.0	258	253
9	Head	181	103	143	138	3.3	3.1	77	79
10	Head	80	32	129	130	3.3	3.2	75	74
11	Head	100	44	140	153	3.2	3.1	76	65
12	Romaine	233	127	110	100	4.0	3.8	247	234
13	Head	76	44	121	120	3.5	3.2	82	81
14	Head	170	106	131	132	3.6	3.4	105	101
15	Romaine	132	87	122	107	3.9	3.7	231	226
16	Head	170	106	179	176	3.9	3.9	78	78
17	Romaine	160	96	136	124	3.8	3.5	184	178
18	Head	129	23	168	168	3.5	3.5	97	95
Ave		**134**	**61**	**139**	**132**	**3.7**	**3.4**	**137**	**133**

*dimensionless unit, higher number indicating darker green color

Table 4. 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.

			Field management treatment	
Trial	Parameter	Days of storage	Grower standard	BMP
Iceberg	PAL activity	0	.03	.04
		3	.06	.04
		6	.03	.03
		9	.03	.03
Romaine		0	.03	.07
		3	.15	.15
		6	.09	.08
		9	.04	.06
			ns	ns
Iceberg	Browning intensity	0	0.27	0.27
		3	0.38	0.45
		6	0.54	0.67
		9	0.63	0.70
Romaine		0	0.40	0.38
		3	0.42	0.46
		6	0.47	0.52
		9	0.56	0.59
			ns	ns

^{ns} not statistically significant at $p < 0.05$

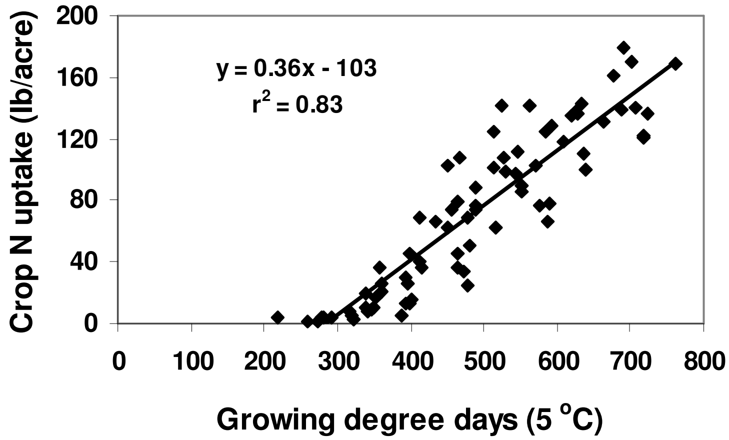

Fig. 1. Crop N uptake of grower N plots as a function of cumulative growing degree days.

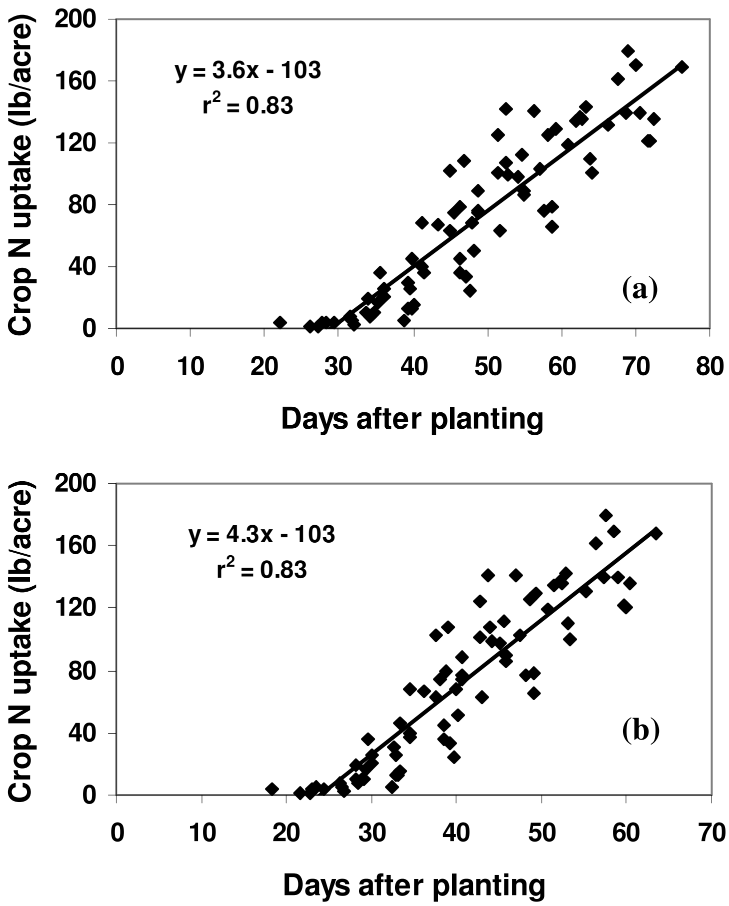

Fig. 2. Crop N uptake as a function of days after planting, based on average summer temperatures in the Castroville (a) and Soledad (b) area.

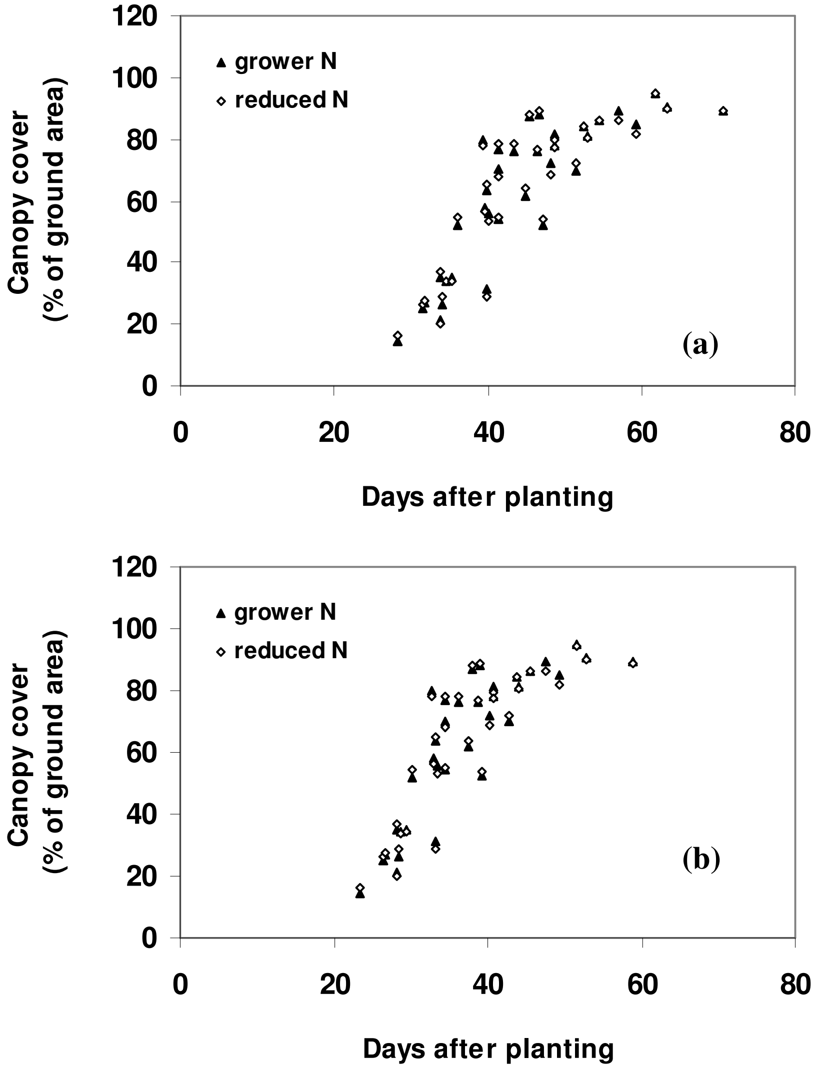

Fig. 3. Crop canopy development as a function of days after planting, based on average summer temperatures in the Castroville (a) and Soledad (b) area.

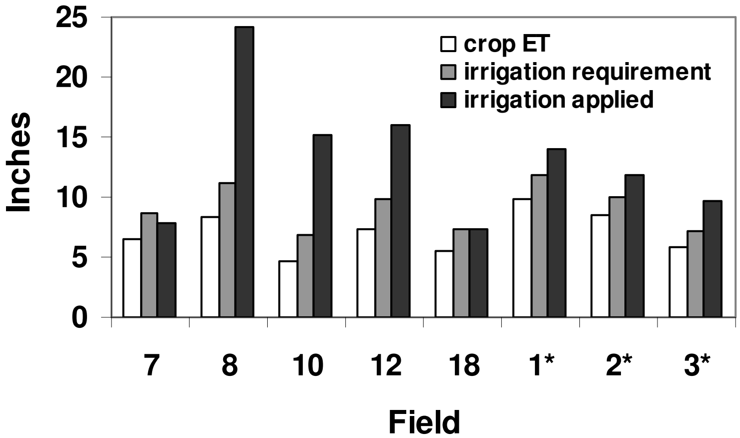

Fig. 4. Relative seasonal irrigation efficiency achieved in lettuce fields; * denotes drip-irrigated fields not in the N demonstration program. Irrigation requirement calculated as crop ET adjusted for assumed irrigation distribution uniformity (70% for sprinkler, 90% for drip).

Task 2 - (Cumulative 100% complete)

Grower outreach:

A number of outreach activities have been undertaken. On January 28, 2010, a meeting was held in Monterey specifically for growers supplying Dole Fresh Vegetable, Inc.; representatives from all Dole grower operations attended. Results of these demonstrations were presented in depth, and each cooperating grower received detailed information on the demonstration conducted on his ranch. The results of these trials also formed the basis of presentations made at grower meetings in Salinas and Santa Maria (February 23 and April 22, 2010, respectively); a presentation on efficient N management was made at a second grower meeting in Salinas on February 23, 2011. The powerpoint presentations used for the Salinas events are posted on the Monterey County UCCE website: (http://cemonterey.ucdavis.edu/Vegetable_Crops/).

A narrated powerpoint presentation was developed on agronomically and environmentally efficient lettuce fertilization using the results of these field demonstrations, combined with our prior lettuce fertility research. This presentation can be viewed at http://stream.ucanr.org/vric/lettuce/index.html . Companion presentations on efficient phosphorus management (http://stream.ucanr.org/vric/phosphorus_manage/index.html) and water quality protection (http://stream.ucanr.org/vric/waterquality/index.html) have also been developed and posted. The Executive Board of the California Certified Crop Advisor program has agreed that these educational presentations will qualify for continuing education credit for holders of CCA licenses. UC information technology professionals are currently developing a web-based platform that will handle data management for on-line training for the CCA program; upon completion, the availability of on-line continuing education credits will be publicized through the CCA organization, and UCCE media.

Project evaluation:

We view this project as being successful on both criteria we proposed. Across all field trials we demonstrated that total N fertilizer application could be reduced substantially (by 54% on average) in fields with high residual soil nitrate; such fields can be identified simply by presidedress soil nitrate testing. By strategically selecting trial sites to reflect a wide range of soil conditions and grower practices we feel that we have demonstrated the broad applicability of this technique. The irrigation monitoring done for this project was only part of a wider monitoring program conducted with other grant support. The combined dataset covering several dozen fields is a very useful teaching tool, in that showing growers on the inefficient end of the spectrum how much less water (and fertilizer) their more efficient neighbors use demonstrates the competitive disadvantage of their less efficient practices.

Regarding the level of industry interest in our work, cumulative attendance at the grower educational events exceeded 250, with representatives of most major lettuce producers present for one or more events. Grower interest in improved irrigation and fertilization practices appears to be increasing as regulatory pressure builds; the 2011 irrigation and nutrient management meeting in Salinas had the largest attendance (> 100) in recent history of this annual event.

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