GRANT NUMBER: 2011-0676

Progress Report Final Report

Reporting Period: Sept 1, 2011 to December 21 2012

Submittal Date March, 2013

Agency Name: University of California Cooperative Extension, Monterey County

Project Title: Optimizing irrigation and nitrogen management in strawberries for improved water quality – Phase 2, Monterey County

Contractor Name: Michael Cahn

Project Director: Michael Cahn

Printed Name Signature

Table of Deliverables

(Place your Table of Deliverables here for both your midterm and final reports. It should be the same Table of Deliverables that was sent to Foundation along with your signed award letter. See sample below.)

Table 1. Deliverables Schedule

Tasks	Description of Deliverables	Completion Dates
	WORK TO BE PERFORMED BY GRANTEE	
1.0	Determine water and nitrogen use in strawberries and estimate nitrate leaching	
1.1	Photo documentation of established field sites	11/30/11
1.2	Field table with water use information	Updated in mid, draft and final reports
1.2	Water use uptake curves	3/31/12
1.3	Field table with nitrogen use information	Updated in mid, draft and final reports
1.3	Nitrogen use uptake curves	3/31/12
1.4	Field table with nitrate leaching losses information	6/30/12
2.0	Analyze, report, and extend results to the strawberry industry	
2.1	Summary report with analysis and field trial results	09/30/12
2.1	List of potential management practices	09/30/12
2.1	Description of management practices and implementation recommendations	09/30/12
2.2	Copies of meeting agendas where results are presented	12/31/12
2.3	Copies of newsletters and trade journal articles where results are presented	12/31/12
3.0	REPORTING	
3.1	Progress reports by the twentieth (20th) of the month following the end of the project quarter (April, July, October, January)	01/20/12 4/20/12 6/30/12* 10/20/12
3.2	50% Midterm report	6/30/12
3.3	Draft and Final Project Reports	

3.3.1	Draft Final Project Report	11/30/12
3.3.2	Final Project Report	12/31/12

List of Deliverables Submitted For Midterm *(by subtask number, please clearly mark the subtask number at the top left hand corner of each deliverable)*

- 1.1, 1.2, 1.3, 1.4
- 2.1,2.2,2.3

Progress Report Narrative

(Provide a brief introduction or summary of the report (e.g., "During the reporting period, project activities focused on completing design of the three sediment basins".... Or "Activities were largely focused on organizing and hosting 4 tailgate meetings to discuss ..." Or "Water Quality data was collected monthly at 6 sites, with data analysis indicating that..." etc.)

Introduction:

Commercial strawberries are often produced using high rates of water and nitrogen fertilizer which can potentially lead to a loss of nitrate-nitrogen by leaching. Despite the economic importance of strawberries and their potential impacts to water quality, little data exists on typical water use and nitrogen fertilization practices in commercial production. The purpose of this project is to gather base-line data that will determine current water-use and nitrogen management practices in commercial strawberry fields. The project will also estimate nitrate leaching losses, develop nitrogen uptake guidelines, and water use model for strawberries. This second phase of the project extends the original project funded in February 2010 in order to collect a second season of data during production.

The objective during first phase of the project (year 1) was to determine water and nitrogen use of central coast strawberries and evaluate the potential risk for nitrate losses during the production season (March – October). Our hypothesis was that commercial production of strawberries on the central coast has a low N-use efficiency (< 70%) and a low water-use efficiency (< 70%) which leads to excessive leaching of nitrate to ground water supplies. During the first phase of this project we evaluated the N fertilizer application rates used by participating growers, N uptake rates for 2 of the major day-neutral varieties, soil nitrate status during the production season, as well nitrate concentration in leachate collected below the rooting zone. In addition we evaluated applied water volumes to strawberries from January through October and evaluated water uptake demand of strawberries during this period using crop evapotranspiration data. Estimates of nitrate loading to the aquifer were estimated from the applied water, crop ET, and leachate data, The results of the first phase of this project indicated that on average strawberry producers applied the approximate volume of water used by their crops during the production season (March – October) and N fertilizer rates equaled the amount of N taken up by the crop for vegetated growth and fruit production phases. Lysimeter and soil nitrate data confirmed that the load of nitrate-N lost by leaching was on average represented less than 15% of the applied fertilizer during the production season.

Though the results from the first phase of the project suggested that strawberries are produced more efficiently than we hypothesized, they represent a single season of data, Furthermore, weather conditions were cooler than normal which may have contributed to lower than normal water use. We believe a second season of data is needed to confirm the results of the first year during the second phase of this project.

Also, although results from the production season indicated that leaching of nitrate was relatively low compared to other commodities produced in the region, a significant amount of nitrate leaching would be expected to have occurred during transplant establishment:

1. following a vegetable crop soil nitrate levels can be high,
2. preplant N fertilizer is applied during bed listing, and
3. rainfall and applied water often greatly exceed crop water use.

Transplant establishment period
Although monitoring applied water and rainfall during transplant establish was done in 6 fields during the first year of the project, additional sites would produce a more accurate estimate of water use during this period. Soil nitrate levels and leachate concentration were not monitored during transplant establishment. We propose to add this task to the second phase of the project.

- The second phase of this project will provide data for estimating the nitrate leaching risk during establishment of strawberries.
- Finally, the second phase of the project will also focus on the contribution of fall applied fertilizer to nitrate leaching, and
- Whether rates of fertilizer could be reduced without impacting fruit production. Potentially this would be a simple BMP that growers could implement to minimize nitrate leaching risks during the fall and winter.
- In addition we would investigate the losses of nitrate from fall fertilizer applications during crop establishment.

Results from the trials will be presented to the agricultural community through oral presentations, and in newsletter and trade journal articles by the co-PI's of the project.

Summary of Activities

Task 1 – Determine water and nitrogen use in strawberries and estimate nitrate leaching (100% complete)

(Describe by sub-task activities, problems, successes, milestones… If a deliverable is complete, please state that, and add a copy of the deliverable (listed above). If a deliverable is not complete, please state that, and describe progress towards completing the deliverable).

Subtask 1.1. Establish Field Sites (100% complete). Meet with grower cooperators; determine appropriate field sites; interview growers for standard practices for management of water and nitrogen fertilizer. This task includes installing flow meters and dataloggers, measuring the irrigated area, collecting soil samples for physical and chemical analyses, collecting samples of irrigation water for chemical (salinity, nitrate, etc.) analyses.

We established 14 field sites during the 2011 production season (4 more than proposed) to determine water and nitrogen fertilizer use. At each site we installed flow meters that were interfaced with data loggers for recording the irrigation pattern and applied water volume. We collected soil samples for physical and chemical analyses, as well as irrigation water for chemical (salinity, nitrate, etc.) analyses. Additionally, 3 sites were established for monitoring applied water and nitrate status of the soil during crop establishment (Nov – Mar). Sites have been photo documented, which were sent at the time of submission of the January Quarterly report.

Subtask 1.2. Measure applied water and estimate water use of strawberries during establishment and fruit production (100% complete)

Flow meters were installed in approximately 0.5- to 1-acre sections of 14 commercial strawberry fields throughout the Salinas-Watsonville production region between January and February of 2011. The flow meters were interfaced with dataloggers to record the irrigation scheduling pattern at all sites, and granular matrix blocks were installed at 11 of the sites to monitor soil moisture. Periodic infra-red photos of the canopy development were processed for estimating crop coefficients for strawberry. Spatial CIMIS was used to estimate the reference ET associated with each field site. Samples of irrigation water were collected for analysis of nitrate and salinity content for sites 1-10 Table 2. Undisturbed cores of soil were collected for determining the water retention pattern for each soil type. Soil samples were also collected for texture analysis. Flow meters were installed at 3 additional sites in October 2011 so that the volume of water used for transplant establishment could be determined.

Results:

The 14 monitoring sites had soil textures ranging from sandy loam to clay (Table 1). Salinity of the irrigation water at these sites ranged from 0.54 to 0.94 dS m^{-1} (Table 2)

Total applied water to strawberries between January and October 2011 for 14 sites is summarized in Fig. 1. Water use starting in January was all drip applied. Average seasonal volume applied was 25.5 inches (this does not include rainfall) and ranged from 13.2 to 40.2 inches. Although the average applied water for the 2011 season was greater than the average volume (21 inches) applied during the 2010 season, less rainfall occurred between January – mid February in 2011 (Fig. 2), which required supplemental irrigation to maintain adequate moisture around the root balls of the young transplants. Applied water during the period between January and May 2011 averaged 8.8 inches, 34% of the total applied water for the season. Water applied by sprinklers for establishment averaged 3.2 inches in 6 fields monitored from October 2011 – December 2011.

Rainfall averaged 11.7 inches between January and May 2011 (Fig. 2). Although some rainfall likely supplemented the water needs of the crops, 90% of the precipitation occurred between January and end of March when crop water needs were minimal due to low reference ETo values and small canopy cover. Much of the rainfall would have likely contributed to drainage and run-off during the winter months.

Crop ET estimates for the sites, developed from measures of canopy cover and spatial CIMIS reference ET data, averaged 17.5 inches and ranged from 11.4 to 22.9 inches (Fig. 3). Growers applied an average of 146% of crop ET from January – October, with a range of 116 to 186% of crop ET (Fig. 4). From January – April, applied water volume averaged 256% of Crop ET (data not presented), whereas from June – October, the applied water volume averaged 123% of Crop ET (Fig. 5), indicating that most of the over- application of water occurred during the winter months when evapotranspiration demand was low.

Soil moisture data recorded using watermark sensors was generally consistent with the applied water data. Soil moisture tensions were low during January – March when applied water and rainfall exceeded crop ET (Table 3) indicating that the soil was kept near saturation during this period. Soil tensions increased during the production season when crop ET increased. Sites 1 and 6, where more than 150% of crop ET was applied during June through October (Fig. 5), had soil water tensions generally less than 15 cbars at the 6 and 12 inch depths (Table 3). In contrast, sites 3, 7 10 and 11, where less than 100% of crop ET was applied during June through October (Table 3) had soil water tensions generally greater than 15 cbars at the 6 and/or 12 inch depths. The relationship between soil moisture and crop ET was not always well correlated. For example, although applied water was significantly less than crop ET at site 11 during June-October (Fig. 5.), soil moisture tensions were not correspondingly high (Table 3). Soil moisture would be expected to vary within a field due to variation in the application rate of the irrigation system, leaks in the drip tape, and variation in soil properties. Across all sites, soil moisture tension was related to applied water when expressed as a percentage of crop ET. Figure 6 shows that average monthly soil moisture tension was often greater than 30 cbars, indicating a depleted soil moisture, when the average volume of applied water was less than 125% of crop ET (Fig 6.)

The volume of water applied per irrigation event during the production season was generally less than the water holding capacity of the soil; and therefore would presumably not cause excessive drainage. The average volume of water applied per irrigation for all 14 sites was 0.27 inches (Table 4), and the average water holding capacity of the soil between 5 and 30 cbars of tension was 0.35 inches per foot of depth for the top soil layer (Table 5).

The volume of water applied for crop establishment was evaluated in 3 sites between November 2011 and March 2012. An average of 6.2 inches were applied to establish transplants during November and December 2011. In addition to the establishment water, an average of 5.6 inches were applied between January and March 2012 (Table 6). Rainfall ranged from 5.1 to 8 inches between November 2011 and March 2012 (Table 7).

The results of the 2011 season are consistent with results reported for the 2010 season, demonstrating that many growers under-irrigated during the production season. At 6 sites grower applied equal or less than crop ET (Fig. 5). Applied water was less than 130% of crop ET at 10 of the 14 sites during June – October (Fig. 5). Applying 130% of crop ET would be an approximate irrigation requirement for strawberries to maximize production, considering that most drip systems have a distribution uniformity of less than 85%, and that a leaching fraction of 15% may be needed for salt management. In addition, the volume of water applied per irrigation was generally small (averaging 0.27 inches), and would be unlikely to exceed the water holding capacity of the soil and contribute significantly to leaching. These irrigation results indicate that a majority of growers were unlikely to significantly contribute to the leaching of nitrate-N beyond the root zone between June - October. As discussed above, most of the potential leaching of nitrate-N would likely have occurred during the rainy season when the sum of applied water and rainfall greatly exceeded crop ET. Subtask 1.4 addresses leaching of nitrate-N during the establishment and the winter months.

Table 1. Location, soil, and soil texture of sites 1-14.

Site #	Location	Soil	% Sand	% Silt	% Clay
1	Salinas	Salinas clay loam	25	55	20
2	Salinas	Chualar loam	60	26	14
3	Salinas	Chualar loam	53	26	21
4	Salinas	Clear Lake clay	40	25	35
5	Castroville	Pacheco clay loam	10	36	54
6	Watsonville	Pacheco clay loam	33	38	29
7	Watsonville	Elder sandy loam	72	15	13
8	Watsonville	Conejo loam	44	36	20
9	Watsonville	Metz fine sandy loam	52	44	4
10	Watsonville	Emigdo Variant sandy loam	51	27	22
11	Moss Landing	Elkhorn Fine sandy loam	61	28	11
12	Salinas	Mocho silty clay loam	37	33	30
13	Salinas	Mocho silty clay loam	39	37	24
14	Salinas	Chualar loam	72	15	14

Table 2. Salinity and nitrate concentration of irrigation water used at sites 1-10.

Site	Electrical Conductivity	NO_3-N
	dS/m	ppm
1	0.86	4
2	0.86	4
3	0.54	12
4	0.38	<1
5	0.94	5
6	0.57	<1
7	0.83	22
8	0.54	8
9	0.61	<1
10	0.84	<1

Table 3. Average monthly soil moisture tension at the 6- and 12-inch depths for 11 commercial strawberry fields during the 2011 season.

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8		Site 9		Site 10		Site 11		AVG		Max		Min	
Month	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"
							soil moisture tension (cbars)																					
Jan	7	4	2	2	17	10	10	7	6	4	--	--	--	--	--	--	--	--	7	7	--	--	8	6	17	10	2	2
Feb	5	4	6	1	16	9	13	8	12	13	5	4	1	5	10	2	--	--	7	12	14	2	9	6	16	13	1	1
Mar	8	4	12	1	25	14	16	16	13	16	9	7	6	8	14	8	13	4	9	19	13	5	12	9	25	19	6	1
Apr	14	1	9	0	15	9	8	8	30	12	4	8	0	1	10	7	16	13	6	14	6	0	11	7	30	14	0	0
May	13	1	9	0	17	10	17	10	30	14	9	6	5	1	11	4	15	7	19	19	16	2	15	7	30	19	5	0
Jun	8	1	2	0	20	11	14	7	23	17	12	7	9	1	10	3	16	8	52	29	9	3	16	8	52	29	2	0
Jul	4	0	0	0	23	9	14	6	13	5	6	3	18	0	10	2	18	7	85	25	17	13	19	6	85	25	0	0
Aug	3	0	0	0	23	9	5	4	10	4	4	1	16	2	10	1	18	6	80	43	10	18	16	8	80	43	0	0
Sep	2	0	0	0	23	14	10	5	10	3	5	1	15	1	11	1	28	4	90	115	6	17	18	15	90	115	0	0
Oct	8	2	0	1	21	14	41	14	18	4	21	3	17	2	20	7	30	6	55	51	43	41	25	13	55	51	0	1

Table 4. Volume of water applied per irrigation in commercial strawberry fields between June and October 2011.

Site Number	Irrigation Volume		
	Average	Maximum	Minimum
	inches		
1	0.37	1.14	0.06
2	0.25	0.67	0.06
3	0.46	0.83	0.19
4	0.20	0.33	0.11
5	0.51	1.26	0.09
6	0.33	0.67	0.15
7	0.36	0.54	0.14
8	0.30	0.43	0.16
9	0.18	0.37	0.07
10	0.10	0.18	0.06
11	0.15	0.34	0.07
12	0.14	0.33	0.05
13	0.27	0.46	0.07
14	0.20	0.34	0.11
AVG	0.27	0.56	0.10

Table 5. Available soil moisture at 2011 monitoring sites.

Site	Soil	Available soil water (5 to 30 cbars) 0-1 foot	1-2 feet
		inches of moisture per foot of depth	
2	loam	0.34	0.18
4	clay	0.20	0.13
7	sandy loam	0.49	0.19
8	loam	0.33	0.27
9	fine sandy loam	0.30	0.23
10	sandy loam	0.42	0.32
AVG		0.35	0.22

Table 6. Water used for establishment and post-establishment of strawberries.

Location	Transplant Establishment Method	volume	Post Establishment method	volume	Applied Water by Month Nov	Dec	Jan	Feb	Mar
		inches		inches	------------inches-------------				
Watsonville	sprinkler/drip	5.6	sprinkler/drip	9.9	0.0	5.6	3.5	3.5	2.9
Castroville	sprinkler/drip	6.1	drip	2.5	1.2	4.9	1.0	0.0	1.4
Salinas	sprinkler/drip	7.0	sprinkler/drip	4.3	3.8	3.2	0.4	1.4	2.5
Average		6.2		5.6	1.7	4.6	1.7	1.6	2.3

Table 7. Precipitation at strawberry establishment sites.

Location	Monthly Precipitation Nov	Dec	Jan	Feb	Mar	Total
	--------------------inches-------------					
Watsonville	1.9	0.1	2.3	0.6	3.2	8.0
Castroville	0.0	0.0	2.5	0.6	2.0	5.1
Salinas	0.7	0.3	2.1	0.8	2.5	6.4

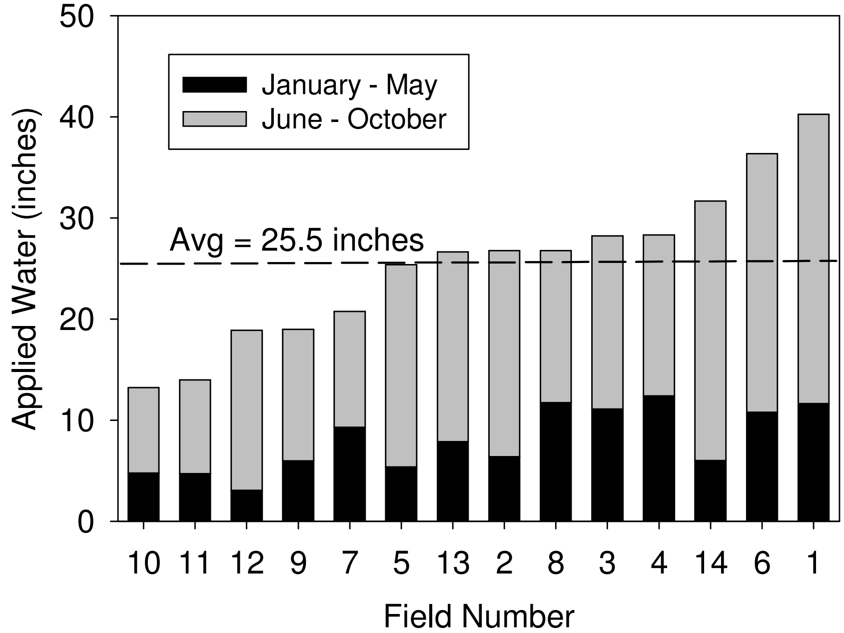

Fig. 1. Seasonal applied water to 14 strawberry fields (January – October 2011).

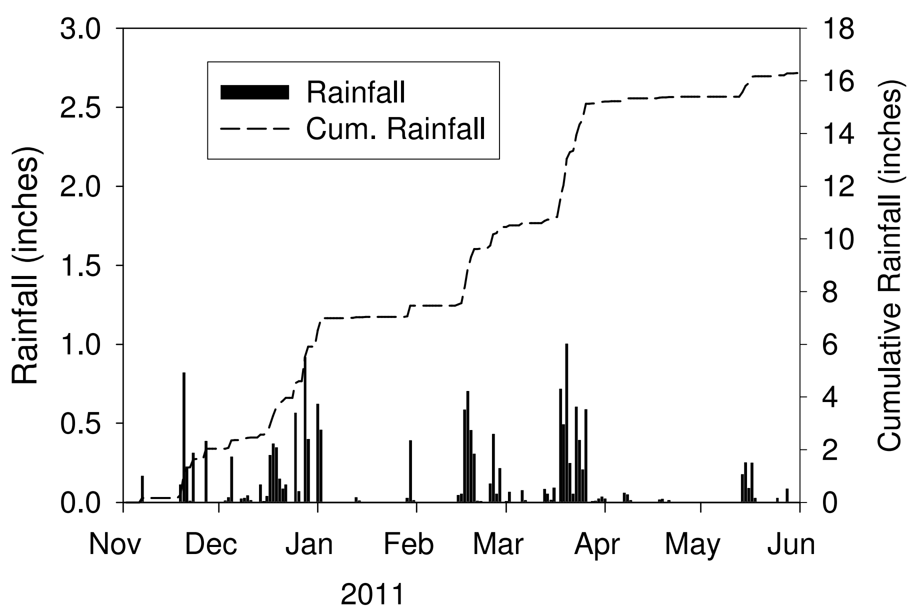

Fig. 2. Average rainfall for the Watsonville area (Nov. 2010 – June 2011).

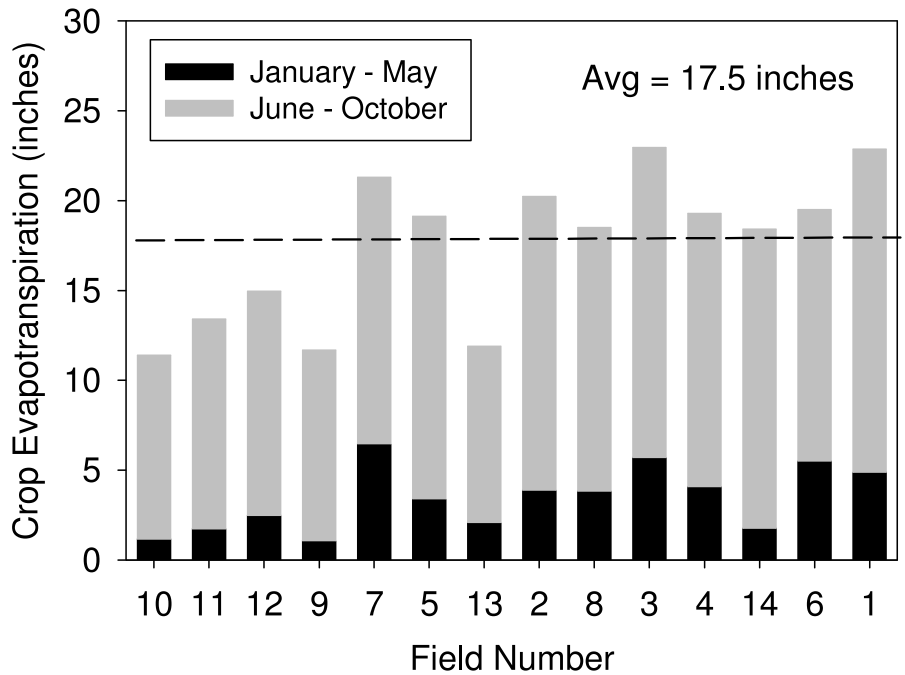

Fig. 3. Seasonal estimates of crop evapotranspiration for 14 strawberry fields (January – October 2011).

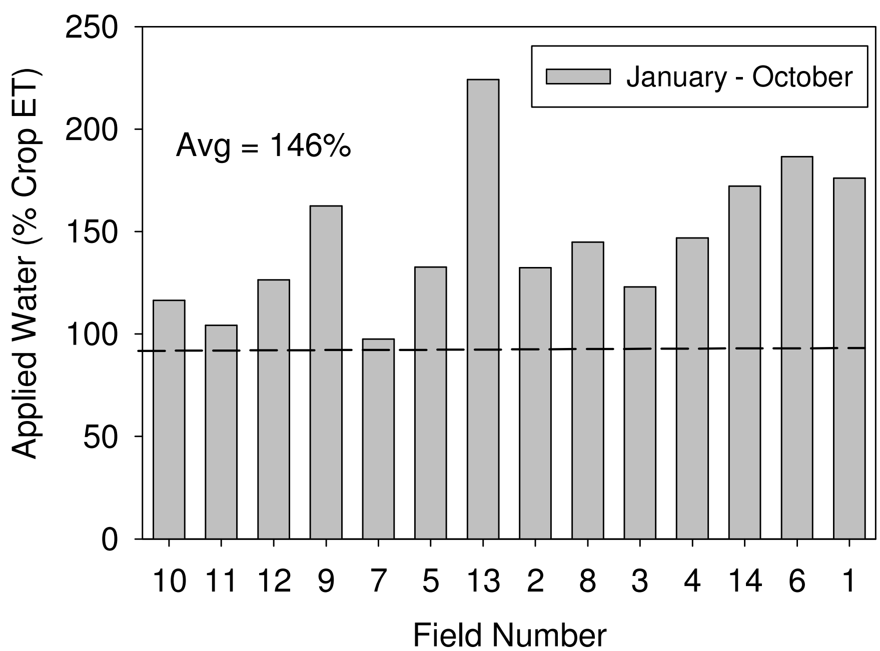

Fig. 4. Seasonal applied water as a percentage of crop ET for 14 strawberry fields (January – October 2011).

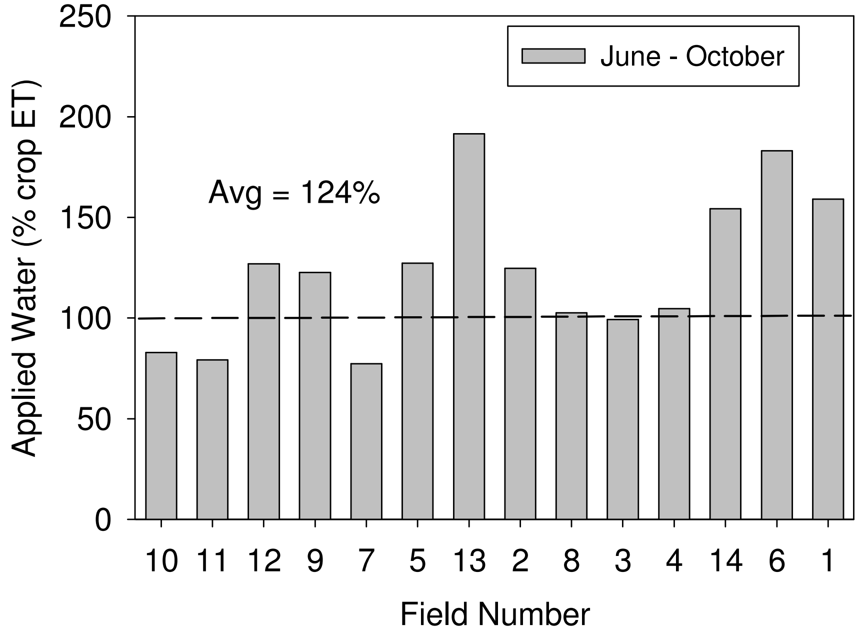

Fig. 5. Seasonal applied water as a percentage of crop ET for 14 strawberry fields (June – October 2011).

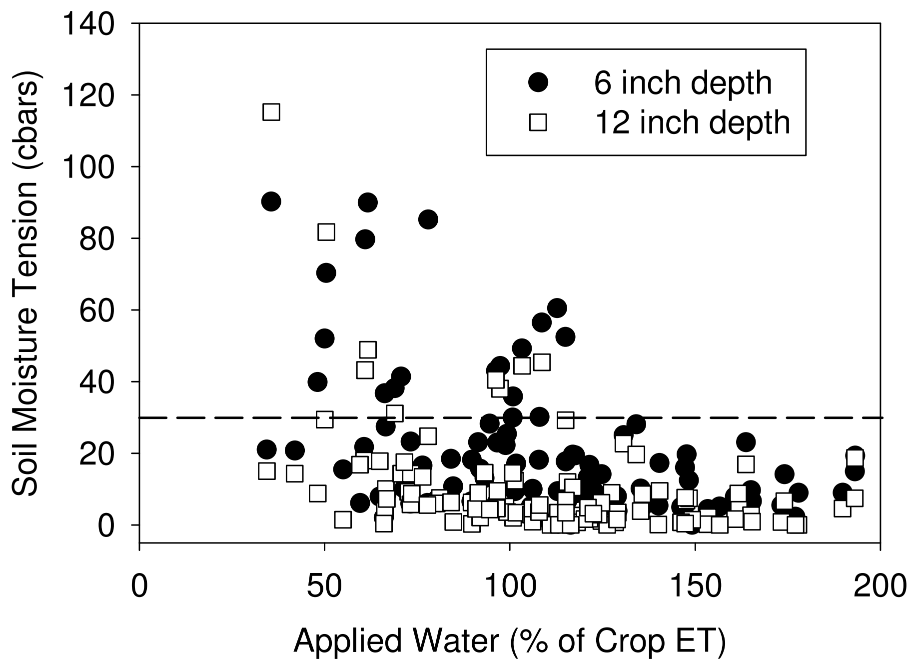

Fig. 6. Average monthly soil moisture tension *vs* average monthly applied water expressed as a percentage of crop ET (May – October 2011).

Subtask 1.3 Measure soil nitrogen status and nitrogen uptake of crop (100% complete). Soil nitrate concentration was determined every 6-8 weeks in all fields; in a subset of fields whole plant sampling for total crop N uptake was performed to allow the development of an N uptake curve for strawberries. Grower fertilizer practices were surveyed for each of the field sites. Plant N uptake and soil nitrate data have been analyzed and summarized.

Results:

Nitrogen management in the monitored fields varied substantially, with total seasonal N application averaging 278 lbs/acre and ranging from 162 to 433 lbs/acre (Fig. 7). Most fields received a preplant application of controlled release fertilizer (CRF), a practice that is nearly universal in the California strawberry industry. Average rate of preplant N was 100 lbs/acre. The common CRF products used are typically rated as 6-8 month nutrient release. In-season N fertigation was concentrated during the fruit production portion of the season (April - September). Marketable fruit yield, which ranged from 25 - 33.5 tons/acre was not correlated with preplant, fertigated or total seasonal N rates.

Average strawberry nitrogen uptake

Crop N uptake showed a consistent pattern across fields (Fig. 8). Plant growth and N uptake was slow through the winter, with above-ground biomass N less than 18 lbs/acre by 1 April. N uptake appeared to be linear from April to September, with biomass N increasing by approximately 1 lb/acre/day over that period. At the last sampling date (27 Aug and 13 Sept in 2010 and 2011, respectively) biomass N averaged 145 lb/acre, and marketable fruit constituted 46% of biomass N. Cull fruit (estimated to average approximately 15% of total fruit mass) was not included in these measurements, but would represent an additional 12 lb acre biomass N (167 lbs/acre). Fields kept in production later in the fall would continue to take up N, although presumably at a slower rate as temperature declined and plants senesced. Additionally, we found that the proprietary variety took up and additional 30 lbs/acre of N compared to Albion which summarized in Figure 8. Combining the results of phase 1 and phase 2 of this project, the average amount of nitrogen uptake by strawberries is approximately 200 lbs/acre depending on the variety and the number of months the crop is in production. The similarity of crop N uptake across fields, despite large differences in seasonal N application, indicated that strawberry N requirements were modest, and luxury N uptake limited. The consistent crop N uptake rate over the entire fruiting season suggested that a program of small, uniform N fertigations throughout that time period would be an efficient practice that would minimize summer NO_3-N loss potential.

Soil NO3-N in summer months (June – October)

Soil NO_3-N was below 10 ppm in the top foot in most fields throughout the summer irrigation period (Fig. 9); the exceptions were fields 1 and 2, which received the greatest N rate by fertigation.

Soil NO3-N in winter months (January – March)

Soil NO_3-N at crown planting was between 19-25 ppm in the 2010-11 fields; these high soil NO_3-N levels at crown planting are a common occurrence in this production system, in which strawberries are typically planted following heavily fertilized vegetable crops. Soil NO_3-N declined substantially by the April sampling, despite the fact that N release from the preplant CRF (applied approximately 5 months earlier at an average of 100 lb N/acre) was undoubtedly much greater than crop N uptake over that time (< 27 lb N/acre). These observations suggested that substantial movement of NO_3-N below the root zone occurred over the winter, and call into question the efficiency of the current practice of applying 30-50% of seasonal N preplant in the form of a 6-8 month release CRF.

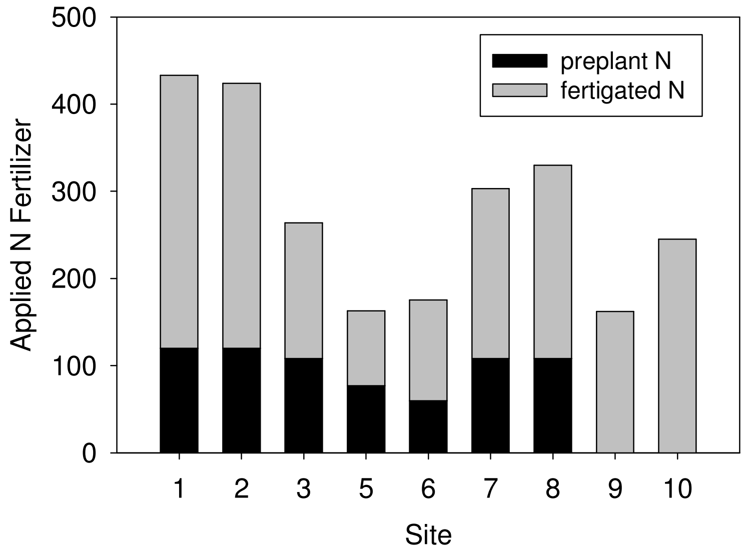

Fig. 7. Applied preplant and fertigated N at sites monitored during the 2011 season.

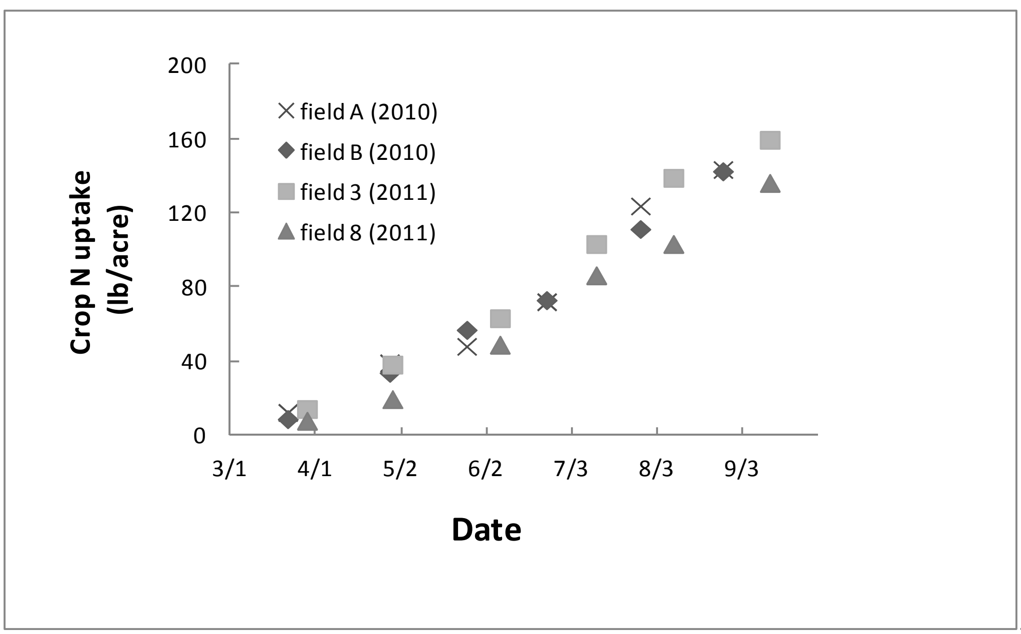

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Fig. 8. Crop N uptake for commercial strawberry near Watsonville CA. Fields A and B were from 2010 season and Fields 3 and 8 were from the 2011 production season.

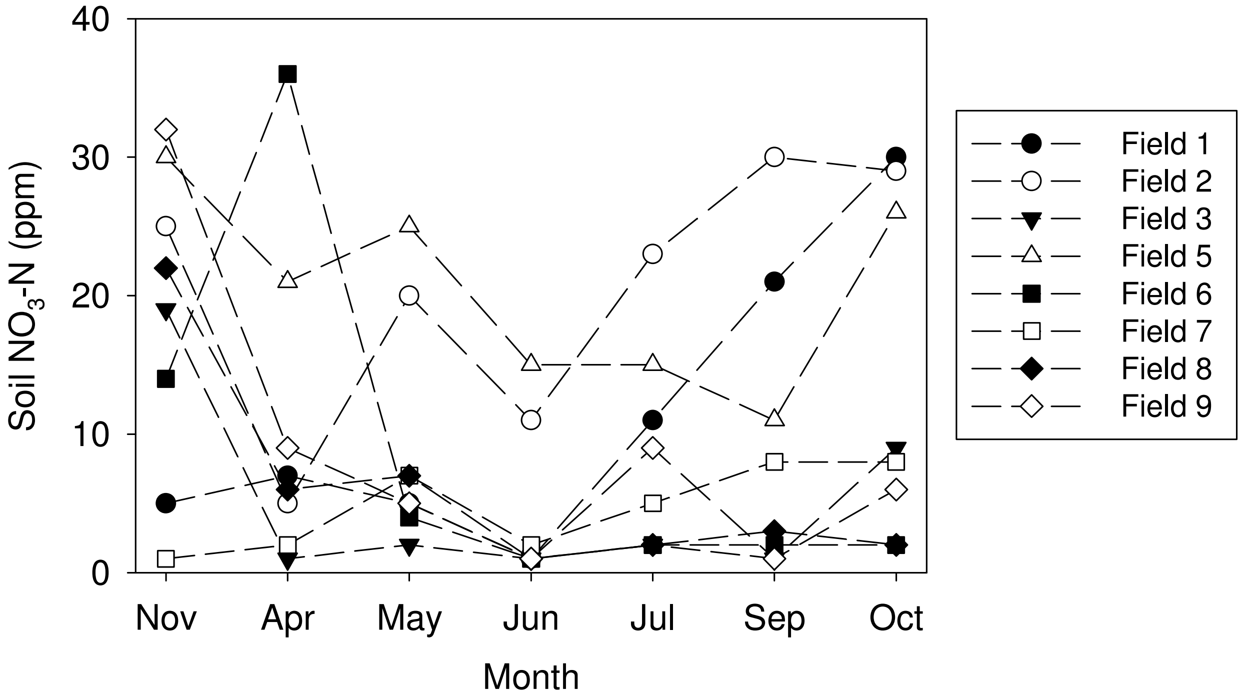


Fig. 9. Soil nitrate in upper foot of strawberry fields near Watsonville and Salinas CA during 2011.

Subtask 1.4 Estimate nitrate leaching losses (100% complete). Nitrate leaching losses will be measured in 3 to 4 fields during the production season (May through September) and in 2 fields during crop establishment in the fall. Nitrate leaching will be calculated from estimates of percolation during irrigation or rain events and by sampling leachate from below the root zone of the crop using an automated suction lysimeter. This subtask will be coordinated by Michael Cahn and Tim Hartz

Production season fields (May – October)
Suction lysimeters (6 per field) were installed on the bed tops at a 24 inch depth in 3 fields during April 2011 to monitor nitrate leaching during the production season. Once per week a 20 centibar vacuum was applied to the lysimeters during an irrigation event, and samples of gravitational water were collected and analyzed for NO_3-N concentration. On each day of leachate collection root zone soil NO_3-N was also measured. Drainage volume was estimated by the following relationship:

Drainage volume (inches) = Applied Water (inches) – Crop ET (inches) – change soil moisture (inches)

Applied water was measured using the flow meter installed on the submain of the field. Rainfall volume was negligible during the production season (May –August) and was not factored into the calculations, Crop ET was estimated by the procedures described above. Volumetric soil moisture was monitored using decagon 10HS sensors. N loss was calculated from the volume of drainage multiplied by the concentration of nitrate-N of the leachate samples.

Newly established fields (December – March)
Suction lysimeters were installed at a 24-inch depth in 2 newly planted strawberry fields in December 2011. Lysimeter tubes were located in 4 areas of each field, with one tube in each area dedicated to furrow, shoulder of bed, and middle of the bed (12 lysimeter tubes per field). Sprinkler and drip applied water was monitored with flow meters and rainfall was measured from November to April. Surface run-off was measured using a weir interfaced with a datalogger. A 20 cbar vacuum was applied to the lysimeters during the entire winter to collect gravitational water at the 24 inch depth during irrigation and rainfall events. Samples were collected 1 to 2 times per week. Leachate was analyzed for NO_3-N and drainage estimates were calculated as described above.

Results:

Production season (May – October).
Soil water NO_3-N concentration at the 24-inch depth, and estimated NO_3-N leaching below that depth, were functions of irrigation and N fertigation management (Figs. 11 and 12). Concentration of nitrate-N in the soil water at 24 inches was higher at sites with higher soil nitrate concentrations (Figs. 10 and 11). Field 3 had a combination of low soil water NO_3-N and a small leaching volume; estimated NO_3-N leaching loss over the monitored period was 6 lbs/acre. In the other fields higher soil water NO_3-N, and greater leaching volume, led to much greater NO_3-N leaching losses, ranging from 33 lbs/acre in field 8 to 60 lbs/acre in field 3. Across fields, the average summer (June – August) NO_3-N leaching loss was estimated at 29 lbs/acre Nitrate leaching was less at the end of the season than at the beginning for all sites.

Winter season (Mid November – March). In comparison to the production season, estimated NO_3-N losses by leaching during the winter months were high, ranging from 167 to 239 lbs of N per acre (Fig.13). Preplant fertilizer N totaled 108 and 81 lbs N/acre for the Watsonville and Salinas sites, respectively. An additional 117 and 42 lbs N/acre were applied by fertigation at the Watsonville and Salinas sites, respectively, during the monitoring period. A combination of factors contributed to the nitrate-N losses. Applied water and rainfall were substantially higher than crop ET (Fig. 14) which resulted in significant drainage, that ranged from 11 (Salinas) to 18 inches (Watsonville) during the winter season (Fig. 15). Nitrate concentration of the soil water at the 24 inch depth was high. Nitrate concentration of the soil water at the 24-inch depth at the Watsonville site was 100 ppm NO_3-N in December and declined to 40 ppm by March. At the Salinas site, NO_3-N concentration of the soil water sampled at 24 inches ranged between 40 and 80 ppm (Fig. 16). Soil nitrate-N concentration declined from 40 ppm in October to less than 10 ppm in the 0-1 foot soil layer by December at the Salinas site (Fig. 17). Soil nitrate concentration at the 0-1 foot soil layer declined slower at the Watsonville site (Fig 17). However, 100 lbs more N per acre were applied at the Watsonville than the Salinas site.

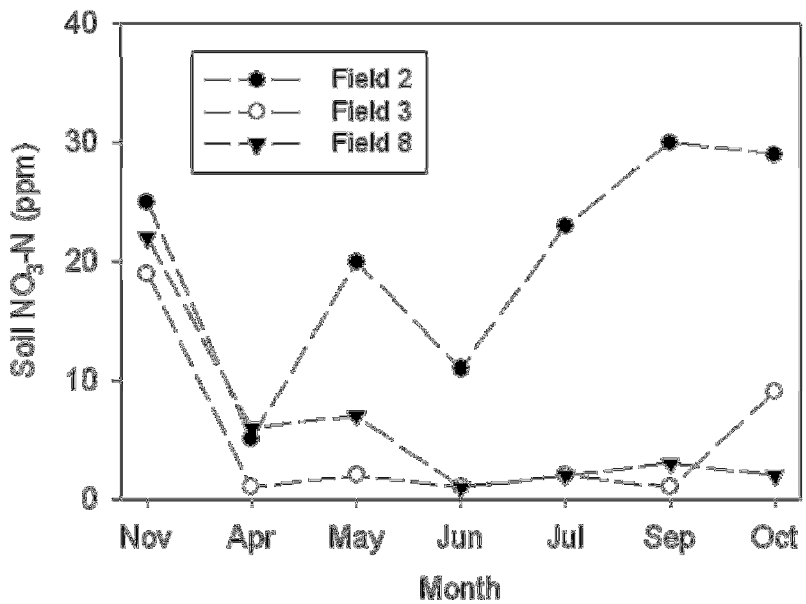


Fig. 10. Soil nitrate at the 0-1 foot depth in commercial strawberry fields near Watsonville and Salinas CA during 2011. Fields 2 and 3 were located near Salinas and Field 8 near Watsonville.

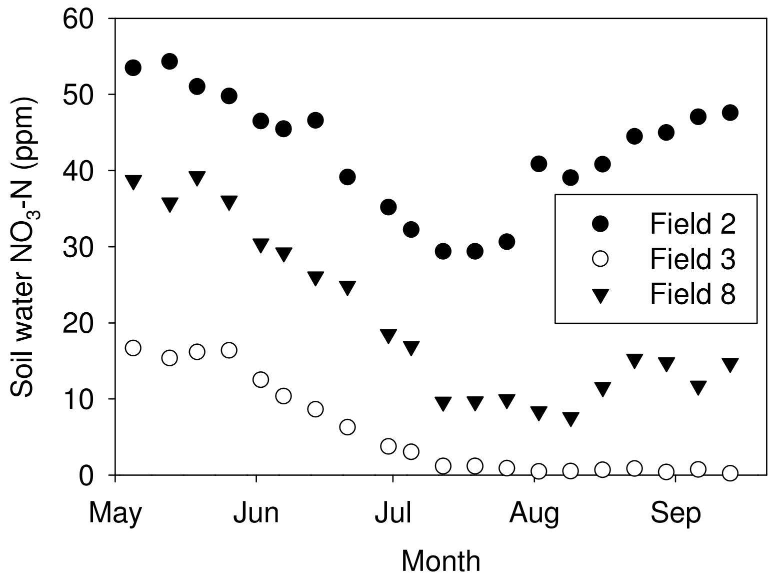


Fig. 11. Nitrate concentration of leachate collected with suction lysimeters from commercial strawberry fields (2011 production season).

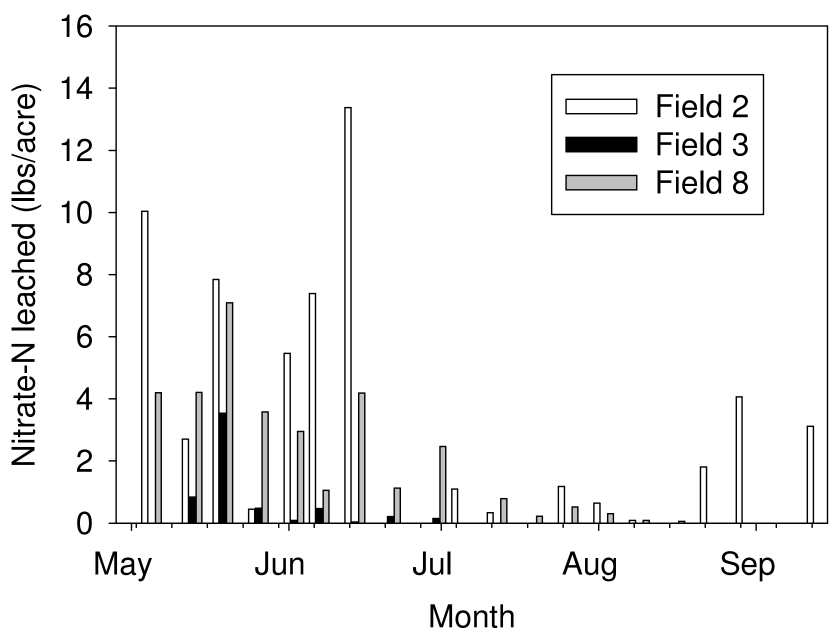


Fig. 12. Estimated leaching of NO_3-N in strawberry during the 2011 production season.

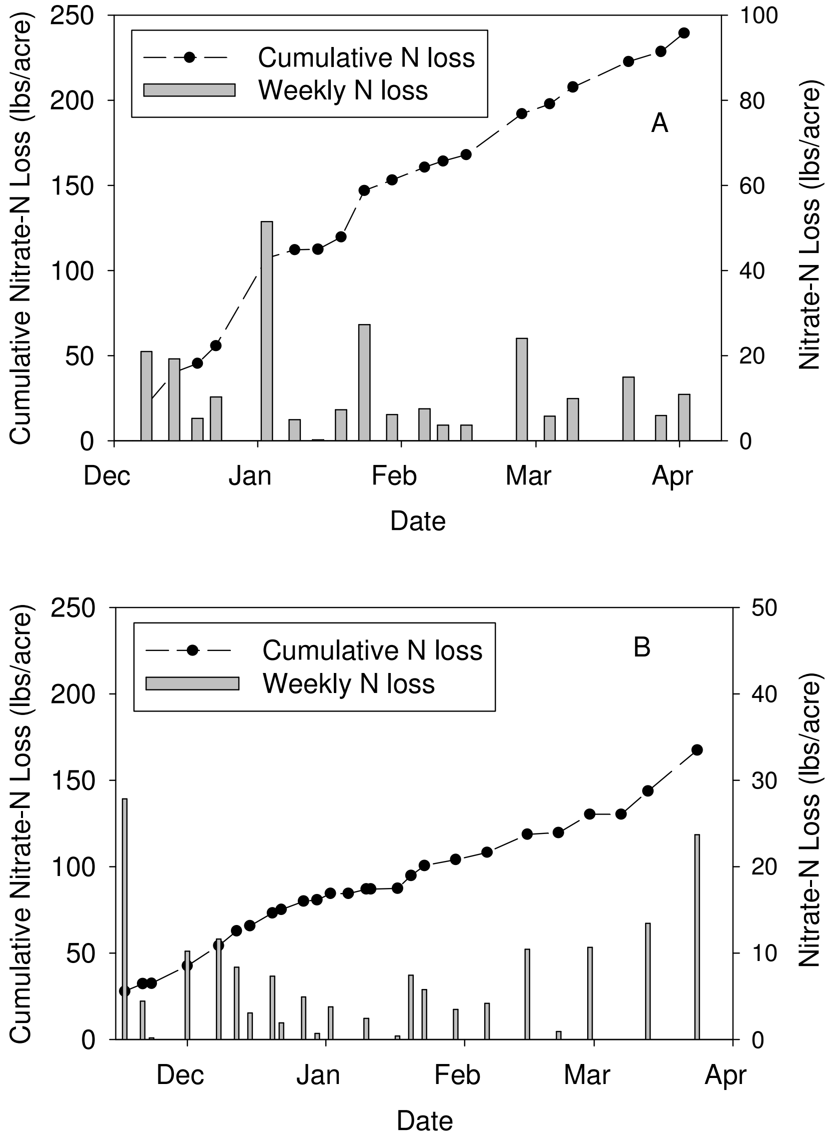
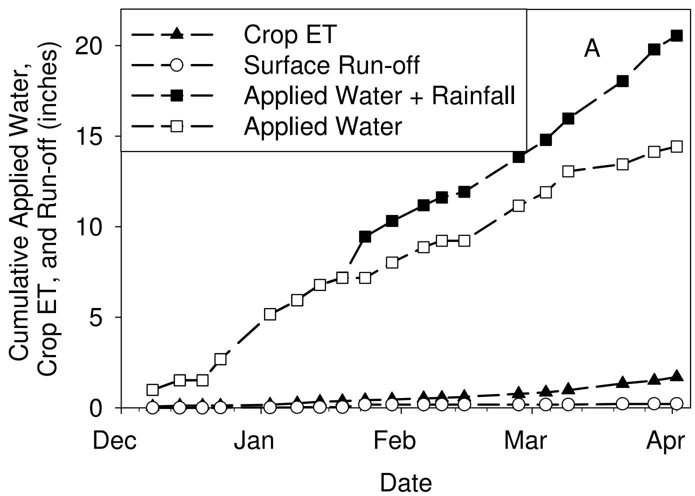


Fig. 13. Estimated nitrate-N loss from 2 commercial strawberry fields located near Watsonville (A) and Salinas (B) during the 2011-2012 season.



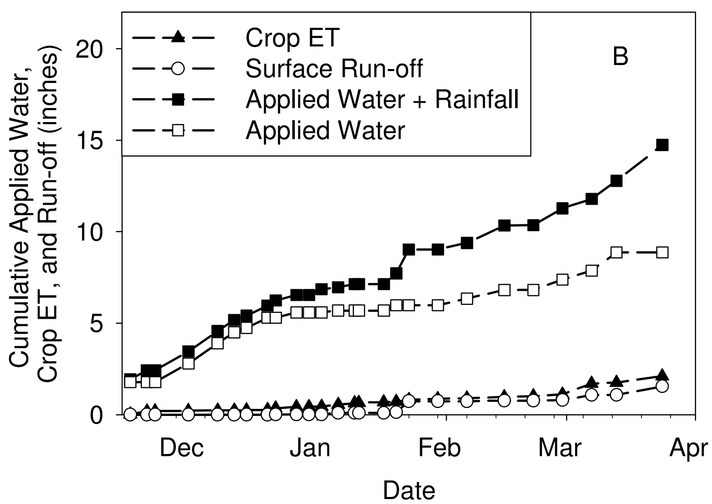


Fig. 14. Cumulative applied water, rainfall, crop ET, and surface run-off for 2 commercial strawberry fields located near Watsonville (A) and Salinas (B) during the 2011-2012 season.

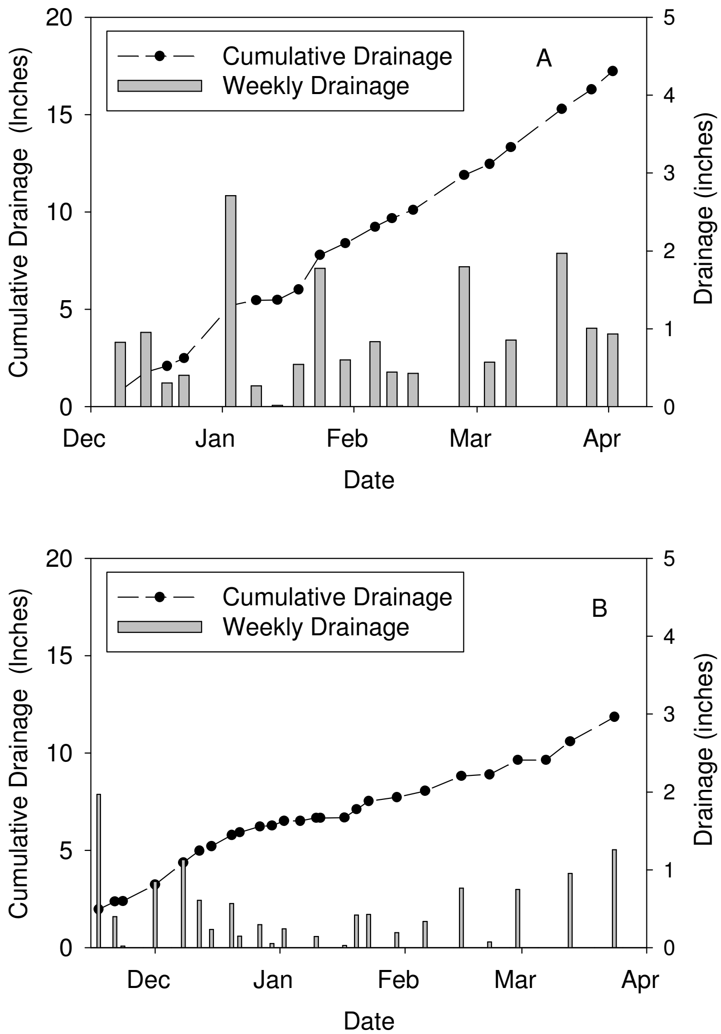


Fig. 15. Estimated drainage in 2 commercial strawberry fields located near Watsonville (A) and Salinas (B) during the 2011-2012 season.

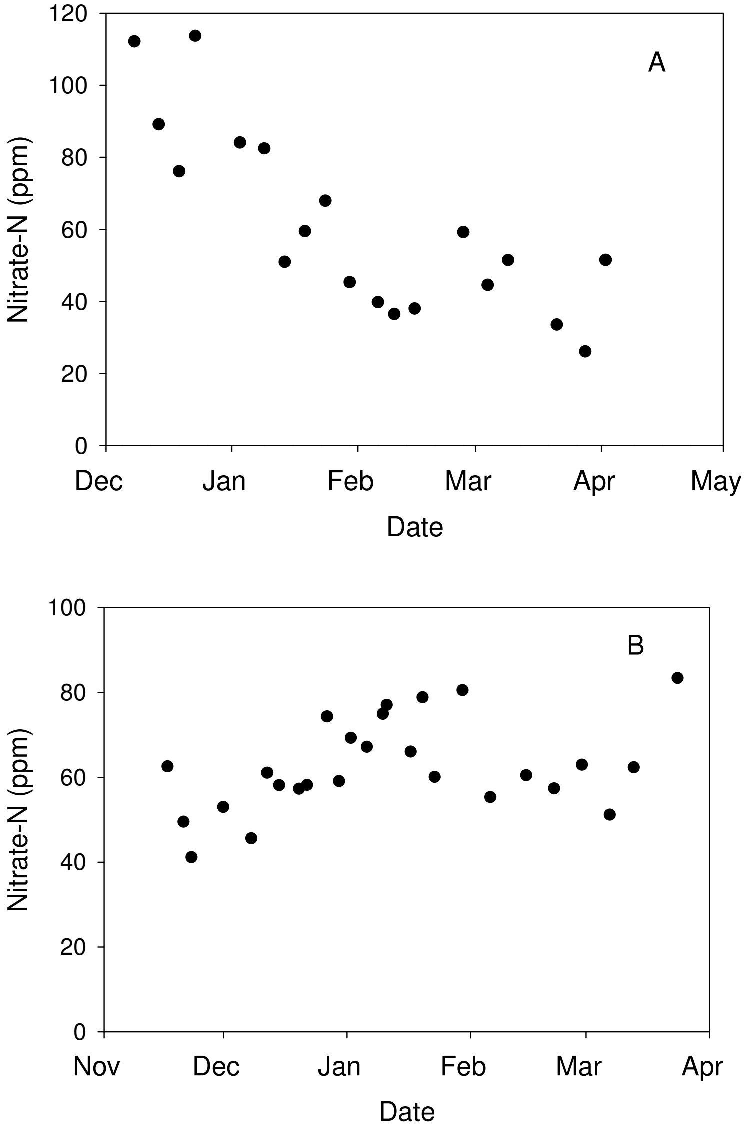


Fig. 16. Lysimeter nitrate-N concentration from 2 commercial strawberry fields located near Watsonville (A) and Salinas (B) during the 2011-2012 season.

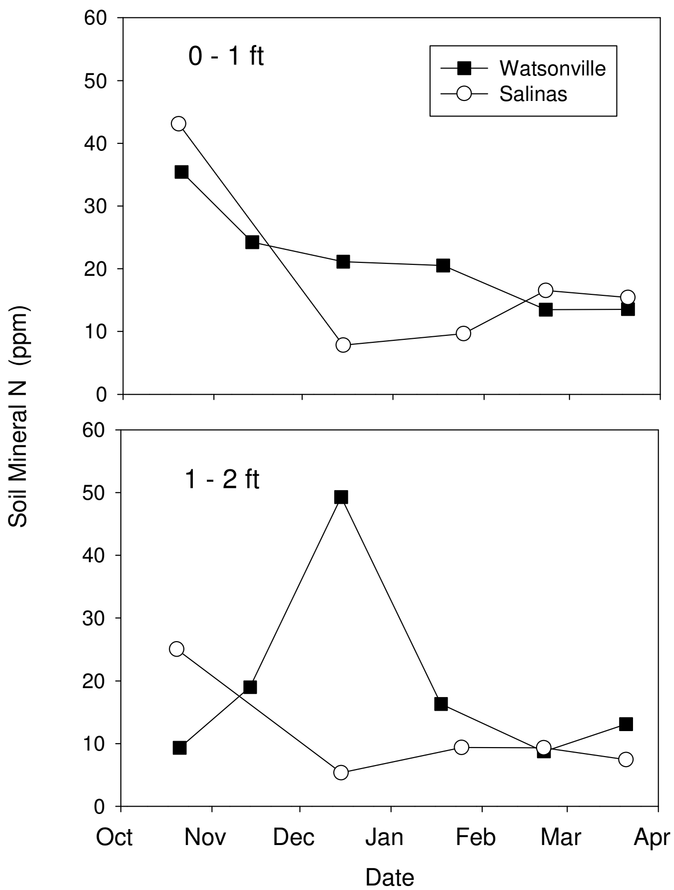


Fig. 17. Soil nitrate-N concentration from 2 commercial strawberry fields located near Watsonville and Salinas during the 2011-2012 season.

Subtask 1.5 Evaluate fate of fall applied fertilizer in new plantings (100% complete). Three field trials were established in commercial strawberries to evaluate the fate of fall applied nitrogen fertilizer. Treatments, replicated 4 times at each site, will include full and reduced rates of N fertilizer. Soil mineral N status will be monitored through the fall and winter, and during the production season. Yield of commercial fruit will be compared among treatments. This subtask was coordinated by Michael Cahn and Tim Hartz

Three commercial field trials were conducted to evaluate the performance of preplant, controlled release fertilizer (CRF). Site 1 and 2 were near Salinas and Watsonville, respectively, and were planted with 'Albion'; soil texture at both sites was a loam. Site 3 was a clay loam soil near Castroville, and was planted with a proprietary day-neutral cultivar. At sites 1 and 2 the growers' standard CRF application (18-8-13, 6 month release rating, 108 lb N/acre) was compared to a half rate application; at site 3 both a half rate and a zero CRF rate were compared to the grower standard (18-8-13, 6 month release rating, 77 lb N/acre). Each trial utilized a randomized block experimental design, with 4 replicate plots per CRF treatment. Individual plots were 150 feet long (sites 1 and 2), or 60 feet long (site 3). At all sites marketable yield data were collected by experienced commercial harvest personnel from

April to October. Each field was instrumented with a water meter and a rain gauge to monitor irrigation and precipitation.

Results:

The results of the CRF rate comparison trials reinforced the conclusion that current CRF use patterns are not efficient. At the end of April, by which time the 6 month-rated CRF fertilizers used by all cooperating growers would have released the vast majority of their N, crop N uptake averaged only 31 lb/acre across sites. Reducing preplant CRF application by half (site 1) or eliminating it (site 3) had no effect on crop N uptake. At site 2 there was a small reduction in crop N uptake in the half rate CRF treatment (20 vs. 23 lb/acre) by the end of April (Fig. 18). Seasonal fruit yield followed the same trend, with preplant CRF rate having no effect at sites 1 and 3; reducing the CRF rate at site 2 resulted in a statistically significant 9% yield reduction (Fig. 19). Crop response to the full CRF rate at site 2 may have been due to the much greater winter rainfall received (22 inches by April 1 vs. 14 and 13 inches at sites 1 and 3, respectively).

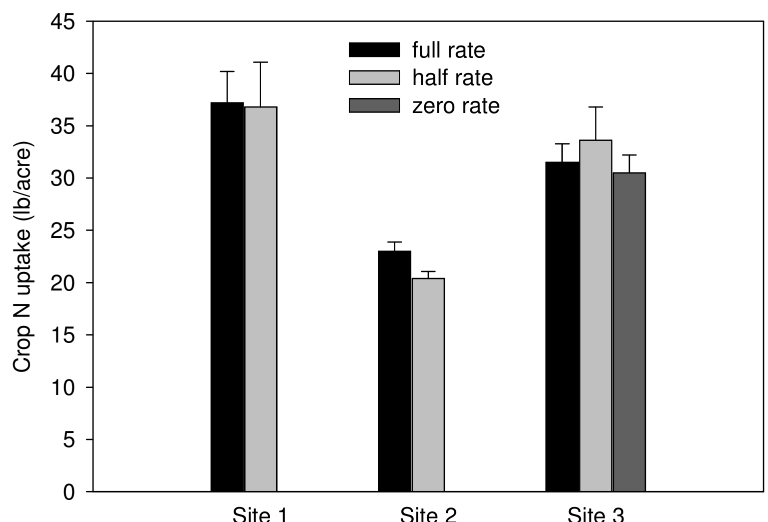


Fig. 18. Effect of preplant controlled release fertilizer rate on total crop nitrogen uptake by the end of April.

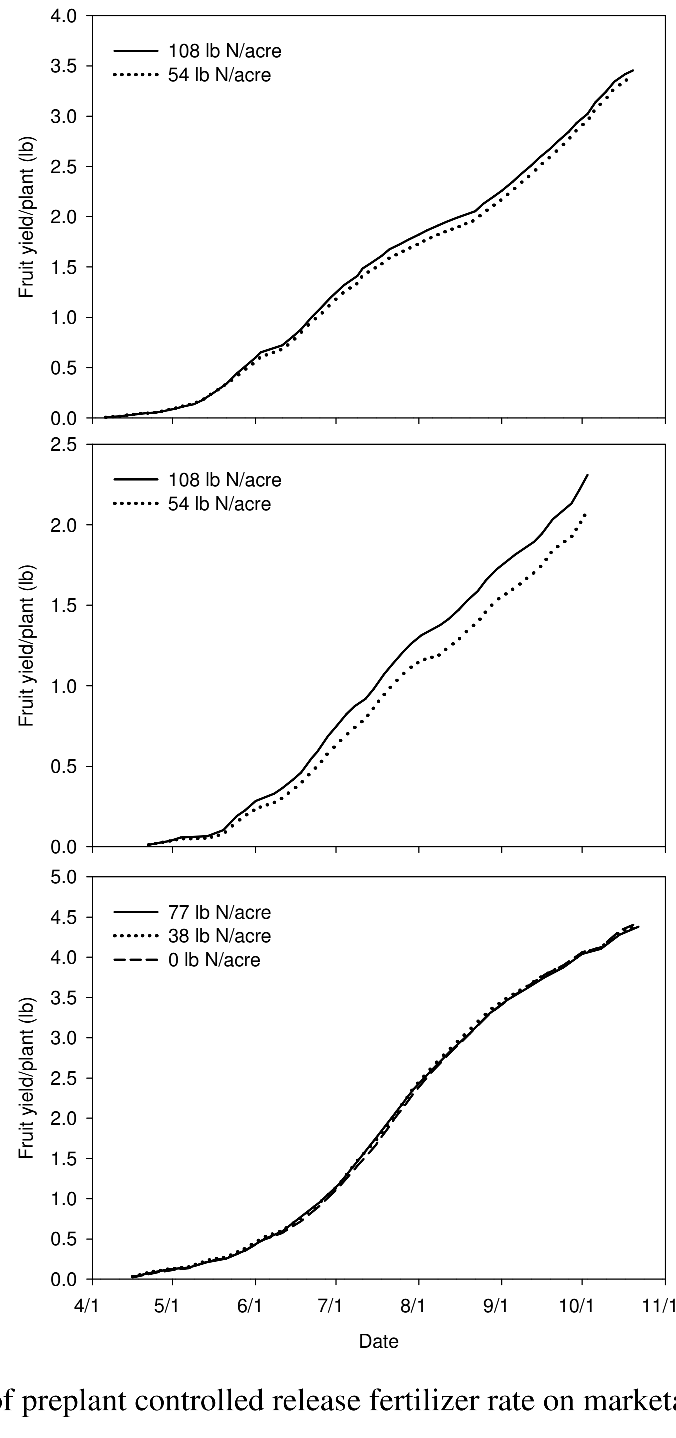


Fig. 19. Effect of preplant controlled release fertilizer rate on marketable fruit yield (Sites 1 – 3).

Subtask 1.6 Evaluate the release rate of controlled release fertilizers (100% complete). Two trials will be established in commercial strawberries to evaluate the release rate of controlled release fertilizer products. Mesh bags of 3 CRF products will be buried into newly established strawberry plantings at 2 sites on the central coast. The bags will be extracted from the beds at monthly intervals for 6 months. The fertilizer N remaining in the bags will be determined and N release curves will be developed for each CRF product. Soil temperature will be monitored at the depth of the bags. By comparing the N release pattern of the CRF products with rainfall and crop N uptake, we can evaluate the potential for the CRF N to be lost by leaching during the winter. This subtask will be coordinated by Michael Cahn and Tim Hartz.

Samples of three types of polymer coated controlled release fertilizer (CRF) used in berry production in California were obtained from the manufacturers (Table 7). The products differed marginally by nutrient analysis but substantially by time release characteristics (based on information supplied by the manufacturers). The 18-8-13 and 19-6-12 materials are standard products for strawberry production in the Watsonville-Salinas area. The slower release characteristic of the 18-6-12 would make its use in strawberry production uncommon, but it was included here to observe whether that slower release would more closely coincide with the N uptake rate of strawberry as documented in the 2010 and 2011 production seasons.

Table 7. Characteristics of the controlled release fertilizers.

Fertilizer analysis	Manufacturer	Release rating
18-8-13	Everris NA, Inc.	6-8 months
18-6-12	Everris NA, Inc.	12-14 months
19-6-12	J. R. Simplot	8-10 months

Eight gram samples were sealed inside pouches made of nylon mesh. These pouches were buried approximately 4 inches deep in plastic-mulched beds in two commercial strawberry fields on 21 Nov., 2011, simulating the placement of CRF in normal production; burial of these pouches was approximately one month later than typical grower CRF application. Field 1 was near Watsonville, field 2 just south of Salinas. Two soil temperature sensors were installed in each field, and logged temperature every 3 hours. Three pouches of each fertilizer from each field were recovered at approximately monthly intervals until May. The CRF prills were removed from the pouches, rinsed to remove adhering soil, then oven dried and weighed. Prills were then ground to pass a 40 mesh screen in preparation for N analysis.

Despite the difference in field location, the soil temperature patterns were very similar at both sites (Fig. 20). Mean daily temperature averaged approximately 50 ^{o}F through January, then rose steadily to above 70 ^{o}F in May. The pattern of CRF weight loss over time is shown in Fig. 21. Weight loss is a reasonably accurate surrogate for N released from the CRF; actual N release tends to be slightly greater than weight loss because over time the polymer coating constitutes a larger portion of the weight of the prills. Weight loss appeared to be linear across the 6 month field incubation period; because nutrient release from polymer coated CRF is a diffusion phenomenon not mediated by soil microbes, soil temperature has less effect than was the case with earlier types of controlled release fertilizers (sulfur-coated urea or urea polymers, for example). Soil moisture content does have an influence on diffusion of fertilizer from the CRF prills, but in plastic-mulched, drip-irrigated strawberry beds soil moisture is typically maintained near field capacity. The industry standard rating system is based on the time period required for approximately 80% of the fertilizer to be released. By that criterion, the 18-6-12 and the 19-2-12 fertilizers matched their release ratings; averaged across the two fields, weight loss of these fertilizers after 6 months was 35% and 60%, respectively. However, the 18-8-13 showed a much slower weight loss than its release rating would indicate. This same fertilizer was evaluated in similar trials in 2010-11 and found to be somewhat faster release than 19-6-12; since the release rate of the 19-6-12 has been consistent over both seasons, the implication is that the 18-8-13 sample supplied by the manufacturer this year was mislabeled.

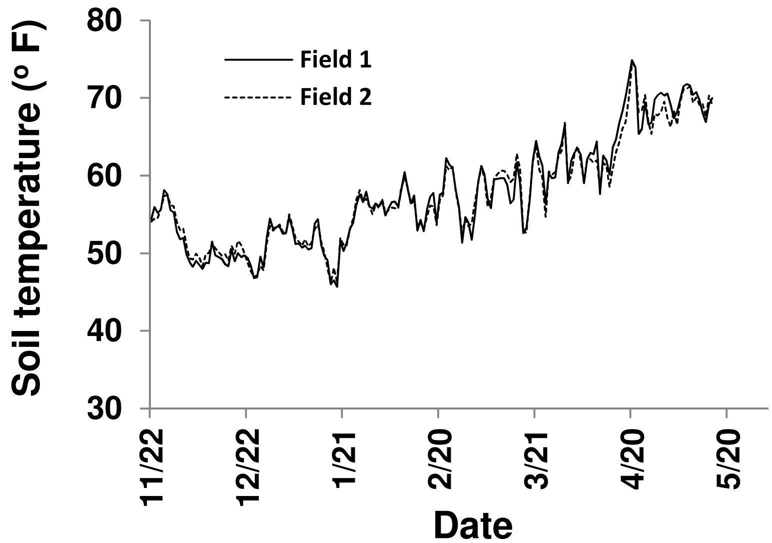


Fig. 20. Soil temperature at 4 inch depth during field incubation of the controlled release fertilizers.

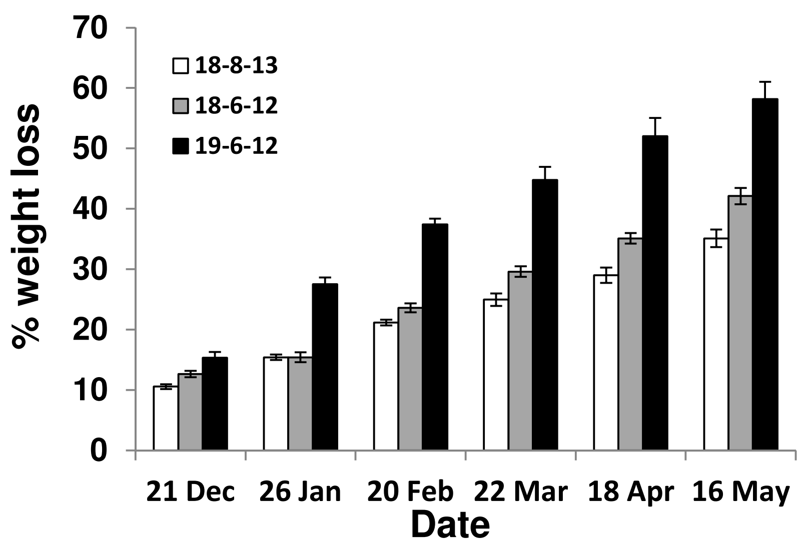


Fig. 21. Weight loss (expressed as % of original weight) of the controlled release fertilizers over time. Data are averages across fields; bars indicate the standard error of measurement.

Subtask 1.7 Midterm report (100% complete). We will submit a midterm progress report summarizing accomplishments. This subtask will be coordinated by Michael Cahn.

This subtask will be completed with the review and acceptance by the Central Coast Regional Water Control Board Staff.

Task 2 – Analyze, report, and extend results to the strawberry industry (100% complete)

Results from field sites will be analyzed to identify potential management practices that may improve water and nitrogen management in strawberries. Results will be extended to growers through educational meetings and newsletter and trade journal articles. Specific tasks are outlined in the subtasks below:

Subtask 2.1 Analysis and summary of results (100% complete). We will analyze data collected from the field sites described in Task 1 to characterize the nitrogen uptake pattern and water use of strawberries. We will also estimate leaching losses of nitrogen from specific irrigation events. We will compare nitrogen fertilizer and water applications with the nitrogen and water uptake pattern of the crop. The results of the analysis will be used to identify potential management practices that may improve water and nitrogen management in strawberries.

We have analyzed all of data collected in task 1. The main conclusions were:

1. Water use during the production season (May – October) is not excessive for a majority of fields, and would be unlikely to result in substantial drainage that would cause leaching of nitrate-N. Two seasons of data demonstrated that a majority of fields received less than the estimated irrigation requirement of 130% of crop ET for strawberries, and some fields received less than 100% of crop ET.
2. Water applied during post establishment of strawberries (January – March) was excessive for the majority of field monitored and would likely result in substantial drainage that would cause leaching of nitrate-N. Data for this season demonstrate that the majority of fields received an average of 256% of estimated crop ET, and average of approximately 11 inches of water from rainfall.
3. Average uptake of N by strawberry equaled about 200 lbs/acre per season depending on the variety and how long the crop remains in production. On average, growers applied a total of 278 lbs of N/acre by a combination of pre-plant and in-season applications. The amount of N applied among growers varied substantially: from 162 to 433 lbs N/acre and the rates were not correlated to yield. In fields where N applications were moderate, soil nitrate-N levels were < 10 ppm during June – October. These results suggest that it may be possible for growers to apply N in amounts that closely match crop uptake without reducing marketable yield and minimize the potential for nitrate losses by leaching.
4. The greatest risk of nitrate leaching was during establishment and winter months (December – March). The total applied water and rainfall during this period greatly exceeded crop ET and would be likely to cause substantial drainage. In addition, soil

nitrate-N levels were greater than 30 ppm in the top foot of soil at planting. Nitrate-N concentrations in leachate collected from a depth of 24 inches were frequently greater than 60 ppm nitrate-N during the winter months. Estimates of nitrate leaching for 2 fields monitored ranged from 167 to 239 lbs N/acre.

5. Controlled released pre-plant fertilizers released a majority of the N during the winter months when the crop uptake of N was minimal and the potential for leaching was high due to rainfall and water applied for crop establishment. Better matching fertilizer release rates with crop uptake patterns could potentially reduce nitrate leaching losses. Based on our study, the recommended practices for using N efficiently in strawberries are:

   1. For fields that have high residual N (> 20 ppm NO_3-N), consider reducing the rate of preplant N fertilizer.
   2. Choose a controlled release fertilizer that releases N in a pattern appropriate for your production area, to better match the pattern of crop N uptake.
   3. During the production season the crop N uptake rate is approximately 7 lbs of N/acre per week.
   4. During the production season, a root zone soil NO_3-N level of 5-10 PPM is adequate to support good production. In-season soil NO_3-N testing can be used to delay additional fertigation when a higher level of soil NO_3-N is present.
   5. Minimize over-application of irrigation water which would lead to nitrate leaching.
   6. Use crop ET, soil moisture monitoring, or similar tools to guide irrigation scheduling.
   7. Maximize the distribution uniformity of the irrigation system.
   8. Fertigate following practices that achieve a uniform distribution of fertilizer in the field.
   9. Minimize applying water in amounts that exceed the water holding capacity of the soil (< 0.3 inches/irrigation).

Subtask 2.2 Grower educational meetings (100% complete). We will present the results from field sites described in Task 1 at educational meetings hosted by UC Cooperative Extension. Additionally, we will present the trial results at grower-industry meetings. This subtask will be coordinated by Michael Cahn and Mark Bolda.

Results of the study have been extended in 6 oral presentations. Tim Hartz and Michael Cahn each made presentations at the UC strawberry meeting that was held in Watsonville, CA on February, 2 2012 and in Santa Maria on May 11th 2012. In addition, Michael Cahn presented at the Driscoll's grower meeting in Aromas, CA on April 27, 2012 and at the Cachuma RCD workshop in Santa Maria on October 27, 2012. All presentations were simultaneously translated into Spanish, except for the RCD workshop where the presentation was in Spanish. Agendas of all workshops are listed in the Appendix section.

Subtask 2.3 Final report, newsletter and trade journal articles (100% complete). Results of the project will be reported in the final report, as well as summarized in newsletter and trade journal articles. Reports and articles will be coordinated by Michael Cahn and Tim Hartz

We submitted the final report draft on December 26, 2012. We presented a paper on the results of this project at the international society of horticultural science (ISHS) irrigation meeting in July 2012. We have written 3 newsletter articles about the results of this project that have been posted to the UCCE Salinas Valley Agriculture Blog and Monterey County Crop Notes website.

Appendix: Newsletter and Proceedings Articles, Meeting Agendas.

Improving nitrogen use in strawberry production

Tim Hartz, Michael Cahn and Tom Bottoms

Strawberry growers are well aware of the increasing regulatory pressure on agriculture to reduce nitrate-nitrogen (NO_3-N) leaching to groundwater. For the first time, the Regional Water Quality Control Board has proposed a numerical target for seasonal N fertilization for strawberry production; that target is 120% of total crop N uptake. Over the 2009-10 and 2010-11 production seasons we conducted extensive monitoring in several dozen strawberry fields in the Watsonville-Salinas area to develop an understanding of the nitrogen dynamics of current production practices, and to identify ways in which nitrogen use efficiency might be improved.

All fields were planted either with 'Albion' or a common proprietary day-neutral variety. Root zone (top 12 inch) soil sampling for NO_3-N concentration was done on a monthly basis from April through September; in 8 fields we also conducted soil NO_3-N sampling at the time of planting in the fall. Cooperating growers provided detailed records of their fertilizer management. In seven fields crop N uptake was documented by collecting 8-12 whole plants per field on a monthly basis from March to September. Fruits were removed, and the vegetative portion (leaves and crowns) were oven-dried, ground and analyzed for N content. At each sampling date ripe fruit were also analyzed, and the amount of N contained in fruit was estimated by multiplying the fruit N concentration by the marketable yield during each sampling period.

In three fields we also evaluated the efficiency of current preplant controlled release fertilizer (CRF) use. Sites 1 and 2 were fields near Salinas and Watsonville, respectively, and were planted with 'Albion'; soil texture at both sites was a loam. Site 3 was a field of clay loam soil near Castroville, and was planted with a proprietary day-neutral cultivar. At sites 1 and 2 the growers' standard CRF application (18-8-13, 7-9 month release rating, 108 lb N/acre) was compared to a half rate application; at site 3 both a half rate and no CRF were compared to the grower's standard application (18-8-13, 7-9 month release rating, 77 lb N/acre). Each trial utilized a randomized block experimental design, with 4 replicate plots per CRF rate. At all sites marketable yield data were collected by experienced commercial harvest personnel from April to October. To document the pattern of N release from the CRF, polyester mesh bags containing 4 g of the 18-8-13 CRF were buried in soil beds on November 4 at site 1 and November 23 at site 2. On approximately monthly intervals, 3 replicate bags of each CRF were recovered, and the amount of N remaining in the CRF granules was determined.

Results:

Crop N uptake showed a characteristic pattern in all fields (Fig. 1). From crown planting through March, crop N uptake was slow, averaging less than 25 lb N/acre by the first of April. From that point forward crop N increased at a steady rate of approximately 1 lb/acre/day through August; vigorous fields were slightly above that rate, with less vigorous fields somewhat below. By the end of August seasonal N uptake in these fields averaged about 170 lb/acre. This estimate was based only on above-ground vegetation and marketable fruit; adding the N content of roots and cull fruit would add approximately 30 lb/acre, meaning that total crop N uptake would average about 200 lb N/acre/season. Crops that continued to be harvested through the fall would obviously continue to take up N, although at a slower rate as the weather cooled and growth rate declined.

Complete fertilizer records were obtained for 15 of the monitored fields. Growers had widely varying fertilization programs, ranging from a seasonal total of 126-433 lb N/acre (Fig. 2). All but one grower applied preplant CRF, with an average application rate of about 90 lb N/acre. Neither preplant CRF rate, nor total seasonal N application rate, was correlated with the marketable yield obtained.

There was a trend toward declining root zone soil NO_3-N as the season progressed (Fig. 3). Averaged across fields, soil NO_3-N at planting was typically high; most strawberry plantings in this region follow vegetable crops, and therefore often begin the strawberry season with high residual soil NO_3-N. By June the average soil NO_3-N had fallen below 10 PPM, where it remained for the rest of the season. There were individual fields in which summer soil NO_3-N was maintained above 20 PPM by high levels of fertigation, but as a group they were no more productive than fields with lower soil NO_3-N levels.

The pattern of N release from the 18-8-13 CRF, averaged over the two field sites, is shown in Fig. 4. Approximately 75% of the initial N content had been released by the end of March. This rate of N release was much faster than the rate of strawberry N uptake over the winter; a 90 lb N/acre preplant application would release more than 60 lb N by the end of March, while plant sampling showed that crop N uptake by that time was typically less than 25 lb/acre.

The results of the CRF rate comparison trials reinforced the conclusion that current CRF use patterns are not efficient. At the end of April crop N uptake averaged only 31 lb N/acre across sites, with CRF rate having minimal effect on crop N uptake (Fig. 5). Reducing preplant CRF (site 1) or eliminating it altogether (site 3) did not affect marketable fruit yield (Fig. 6). However, reducing the CRF rate at site 2 resulted in a statistically significant 9% yield reduction. Fruit yield improvement with the full CRF rate at site 2 may have been related to greater NO_3-N leaching at that site resulting from high rainfall (22 inches by April 1 vs. 14 and 13 inches at sites 1 and 3, respectively), as well as heavy irrigation applied by the grower in April and May. Rather than routinely using high preplant CRF rates to protect against such unusually high winter rainfall or inefficient irrigation, a program of more accurate irrigation scheduling, soil NO_3-N testing in the spring, and earlier fertigation (where appropriate) would be a more nitrogen-efficient practice.

Conclusions:

Our results contain some good news and some bad news. The good news is that the proposed seasonal N fertilization target of 120% of crop N uptake is currently being met by a number of growers; assuming a seasonal crop uptake of 200 lb N/acre, more than half of the monitored fields for which we obtained fertilization records met the target. The bad news is that some growers are substantially above that target. For those growers, our data suggests two ways to reduce N fertilization rates with minimal risk to crop productivity. First, reconsider current CRF practices. Reducing CRF rates, at least in field situations in which winter N availability is likely to be adequate (medium- to heavy-textured soils being rotated out of vegetable crops), and/or switching to a CRF with a slower N release pattern that more closely matches crop N uptake, will likely reduce the amount of CRF N that is lost from the field. Second, use a fertigation program that supplies N at a rate similar to crop N uptake. Fertigation far in excess of crop N demand (about 1 lb N per acre per day) is likely to lead to NO_3-N leaching, not improved growth.

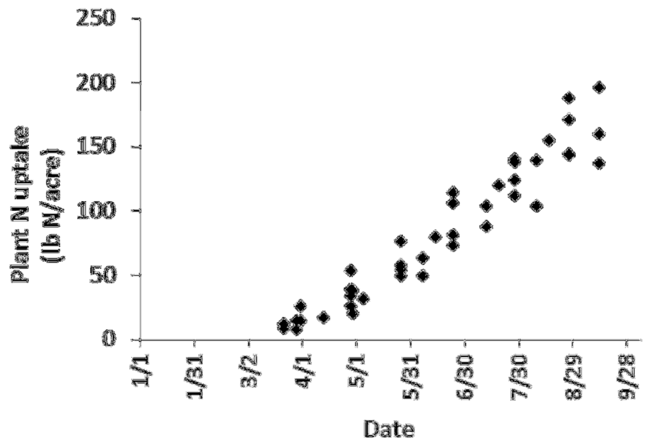


Fig. 1. Pattern of strawberry N uptake over the season; data from 7 commercial fields.

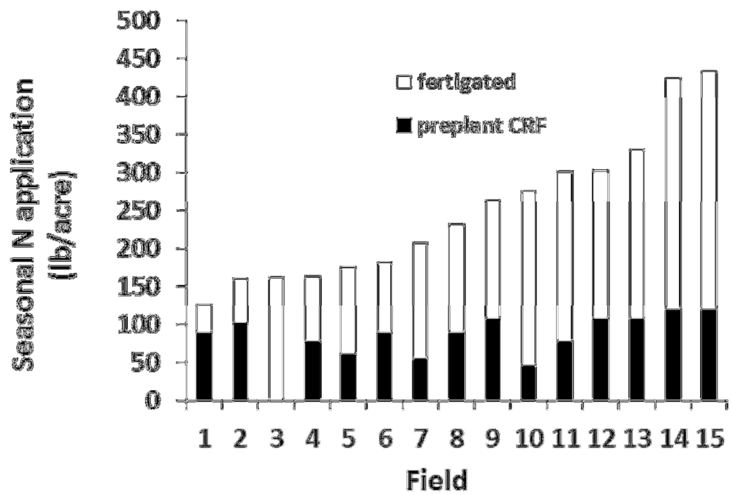


Fig. 2. Seasonal N application in 15 of the monitored fields.

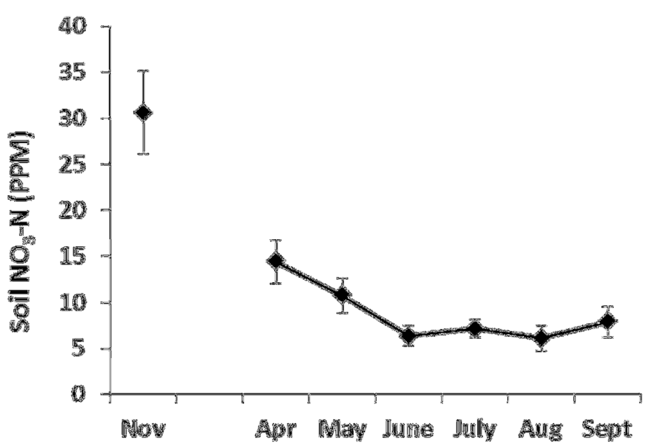


Fig. 3. Pattern of root zone (top 12 inch) soil NO_3-N over the production season.

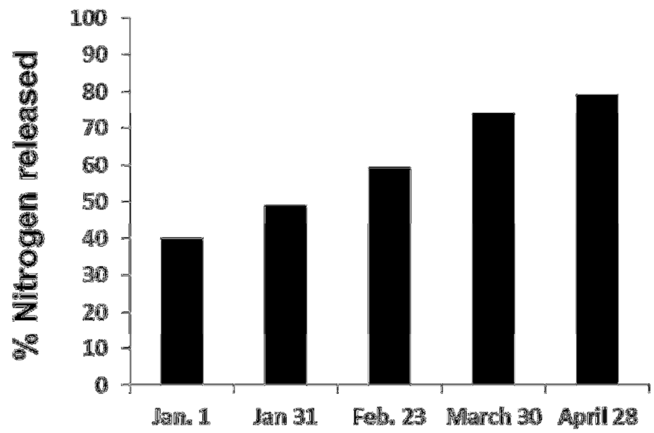


Fig. 4. Pattern of nitrogen release from 18-8-13 controlled release fertilizer (CRF).

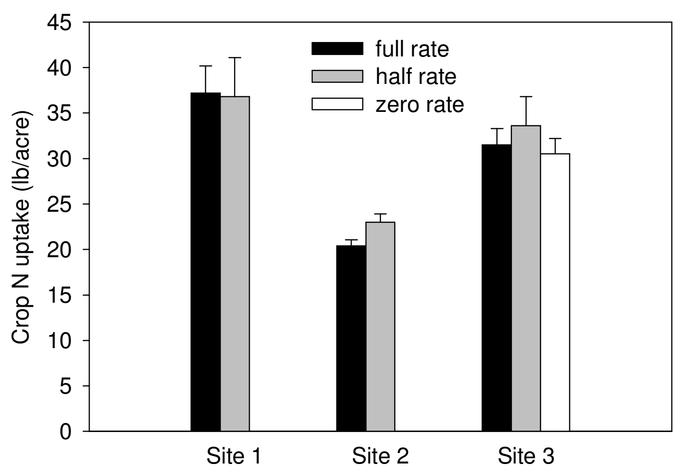


Fig. 5. Effect of preplant controlled release fertilizer rate (CRF) on crop nitrogen uptake by the end of April; bars indicate the standard error of measurement.

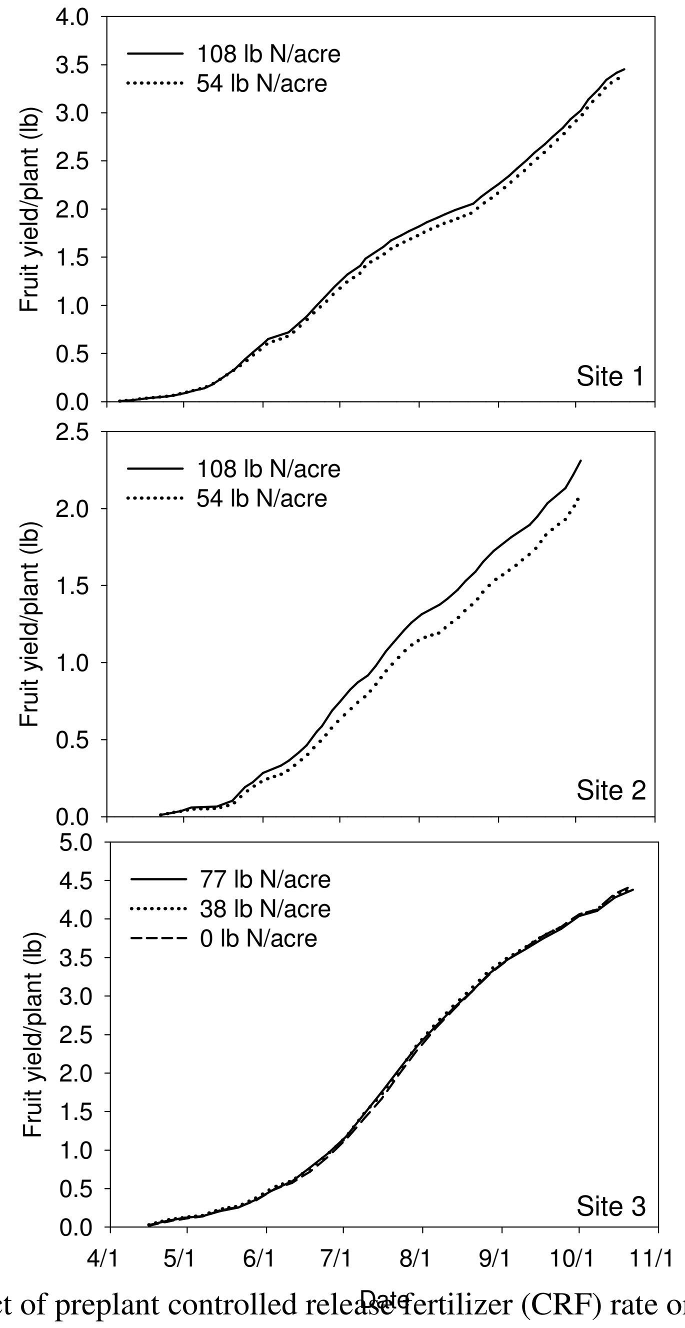


Fig. 6. Effect of preplant controlled release fertilizer (CRF) rate on marketable fruit

Estimated Crop Coefficients for Strawberry

Michael Cahn and Barry Farrara

Several strawberry growers have expressed interest in using evapotranspiration data for scheduling irrigations in strawberries, especially during the production season when crop water needs are greatest. Weather-based approaches to scheduling irrigations are used for many cultivated crops. Windspeed, air temperature, relative humidity, and solar radiation affect plant water-use, or more specifically the water lost by evaporation from the soil and by transpiration from the leaves of the crop. Using evapotranspiration (ET) data (evaporation + transpiration) from the California Irrigation Management Information System (CIMIS) the consumptive water use of a crop in units of inches or mm per day, can be estimated.

CIMIS ET data is available from the Department of Water Resources website (http://wwwcimis.water.ca.gov/cimis/welcome.jsp) for more than 120 locations in California, and is generated by weather stations located on irrigated grass, which serves as a reference crop. The MyCIMIS feature of the website allows the user to customize the reporting of CIMIS crop ET data, such as specifying type of weather data, stations, time period, and file format to display. MyCIMIS also allows the user to select for the data to be emailed to their account. Spatial CIMIS is another feature of the website that produces estimates of reference ET at a 2 km (1.2 mi) resolution using GOES satellite information and by triangulating humidity, temperature and wind speed data from the closest CIMIS stations to the point of interest. A Google map feature allows the user to locate a field of interest. Similar to MyCIMIS, a user can select to have updated Spatial CIMIS estimates of reference ET emailed.

ET can be estimated for a specific crop by multiplying reference ET data and the appropriate crop coefficient (Kc):

$$ET_{crop} = ET_{ref} \times Kc$$

The value of Kc can range from almost 0 to greater than 1 and is closely related to the percentage of ground shaded by the canopy. Irrigation method and physiological stages, such as flowering and senescence are also factored into the crop coefficient. Crop ET values should be adjusted down by 20% to 30% for crops grown under macro tunnels or greenhouses because of shading.

Because accurate crop coefficients are not available for many crops, estimates of canopy cover serve as a close substitute for the Kc values. We have taken overhead photos of the UC strawberry variety Albion using an infra-red camera during the last 2 years. Photos were taken on a monthly schedule for fields with 48-, 52-, and 64- inch wide beds. After analyzing canopy images from 9 fields, we have estimated the Kc values on a weekly schedule during a 12 month period (Table 1). Because these data represent the average of several fields, values may need to be adjusted for site-specific conditions. Also, these Kc values for Albion represent Salinas and Pajaro Valley growing conditions and methods.

By irrigating enough to replace water lost by evapotranspiration it is possible to optimize irrigations for production and minimize percolation below the root zone. Also, it is possible to avoid under-irrigating during periods of high water consumption, which can result in stress and reduced growth. ET_c estimates can be used to determine day by day soil water depletions from field capacity and thus can be used to also estimate when to irrigate. For detailed descriptions and examples of this technique, visit http://wwwcimis.water.ca.gov/cimis/infoIrrSchedule.jsp

Table 1. Estimated crop coefficient (Kc) for UC strawberry variety Albion

		48-inch bed width		52-inch bed width		64-inch bed width	
Plant Date	DAP	% canopy cover	Kc	% canopy cover	Kc	% canopy cover	Kc
11/1/2011	0	1	0.02	1	0.01	1	0.02
11/8/2011	7	1	0.02	1	0.02	1	0.03
11/15/2011	14	1	0.02	1	0.02	2	0.03
11/22/2011	21	1	0.03	1	0.02	2	0.04
11/29/2011	28	2	0.03	1	0.02	3	0.04
12/6/2011	35	2	0.04	1	0.03	3	0.05
12/13/2011	42	2	0.04	2	0.03	4	0.06
12/20/2011	49	3	0.05	2	0.04	4	0.07
12/27/2011	56	3	0.06	2	0.04	5	0.08
1/3/2012	63	4	0.06	3	0.05	6	0.09
1/10/2012	70	5	0.08	4	0.06	7	0.11
1/17/2012	77	5	0.09	4	0.07	8	0.13
1/24/2012	84	6	0.10	5	0.08	10	0.15
1/31/2012	91	8	0.12	6	0.10	11	0.17
2/7/2012	98	9	0.14	7	0.11	13	0.20
2/14/2012	105	10	0.16	9	0.13	15	0.23
2/21/2012	112	12	0.18	10	0.15	18	0.26
2/28/2012	119	14	0.21	12	0.18	20	0.29
3/6/2012	126	16	0.23	14	0.21	23	0.33
3/13/2012	133	18	0.27	16	0.24	26	0.37
3/20/2012	140	21	0.30	19	0.28	29	0.41
3/27/2012	147	23	0.33	22	0.32	33	0.46
4/3/2012	154	26	0.37	25	0.36	36	0.50
4/10/2012	161	29	0.41	28	0.40	40	0.54
4/17/2012	168	32	0.44	32	0.44	43	0.58
4/24/2012	175	35	0.48	35	0.49	47	0.62
5/1/2012	182	38	0.52	39	0.53	50	0.66
5/8/2012	189	40	0.55	43	0.57	54	0.70
5/15/2012	196	43	0.58	46	0.61	57	0.73
5/22/2012	203	46	0.61	49	0.65	60	0.76
5/29/2012	210	48	0.64	53	0.69	62	0.79
6/5/2012	217	50	0.66	55	0.72	65	0.81
6/12/2012	224	52	0.69	58	0.75	67	0.83
6/19/2012	231	54	0.71	61	0.77	69	0.85
6/26/2012	238	56	0.72	63	0.79	70	0.87
7/3/2012	245	57	0.74	65	0.81	72	0.88
7/10/2012	252	59	0.75	66	0.83	73	0.89
7/17/2012	259	60	0.76	68	0.84	74	0.90
7/24/2012	266	61	0.77	69	0.85	75	0.91
7/31/2012	273	61	0.78	70	0.86	76	0.92
8/7/2012	280	62	0.79	71	0.87	76	0.92
8/14/2012	287	63	0.79	71	0.88	77	0.93
8/21/2012	294	63	0.80	72	0.88	77	0.93
8/28/2012	301	64	0.80	72	0.89	78	0.94
9/4/2012	308	64	0.81	73	0.89	78	0.94
9/11/2012	315	64	0.81	73	0.90	78	0.94
9/18/2012	322	65	0.81	74	0.90	79	0.95
9/25/2012	329	65	0.82	74	0.90	79	0.95
10/2/2012	336	65	0.82	74	0.90	79	0.95
10/9/2012	343	65	0.82	74	0.90	79	0.95
10/16/2012	350	65	0.82	74	0.91	79	0.95
10/23/2012	357	65	0.82	74	0.91	79	0.95
10/30/2012	364	66	0.82	75	0.91	80	0.95

Water Use of Strawberries on the Central Coast

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As acreage of strawberries has steadily increased in central coast valleys, concerns about the impacts of production on water supplies have been raised. Since most of the central coast is reliant on ground water, a major commodity such as strawberries can affect regional water supplies. In the Pajaro Basin, where ground water is currently in over-draft, conservation by agriculture is considered one of several paths to restoring parity between pumping and ground water recharge. To determine if conservation is possible without reducing economic returns, it is important to examine the present water-use patterns of major crops such as strawberries. Many of the practices that growers currently use such as drip irrigation and soil moisture monitoring, would suggest that strawberry producers are already efficient users of water. We conducted a 2-year study measuring water use in commercial strawberry fields in Monterey and Santa Cruz counties. Our objective was to determine the amount of water currently used to grow strawberries and to identify strategies that could help growers improve water management of their crops and potentially conserve water. The following describes the 2nd year of the study and compares the results with the first year.

Procedures

Flow meters were installed in approximately 0.5 to 1-acre sections of 35 commercial strawberry fields located in the Salinas-Watsonville production region during January and February of 2011. Fields with a proprietary day-neutral variety and UC Albion were included in the study. Planting configurations ranged from 48-inch and 52-inch wide beds with 2 plant rows, and 64-inch wide beds with 4 plant rows. Drip tape discharge rates in fields ranged from low flow (0.34 gpm/100 ft) to high flow (0.67 gpm/100 ft) and drip systems varied between either 1 or 2 drip lines per bed. Soil texture among sites varied from clay to loamy sand and the salinity of the irrigation water ranged from 0.3 to 0.9 dS/m.

Applied water was monitored with flow meters until the end of the crop in October 2011. In 14 of the 35 fields, flow meters were connected to dataloggers to record the irrigation scheduling pattern and granular matrix blocks (irrometer watermark) were installed to monitor soil moisture tension at 6 and 12 inch depths. Infra-red photos of the canopy were taken at each of the 14 field sites at monthly intervals, and used to estimate crop coefficients of strawberry and to determine crop evapotranspiration (ETc) from reference evapotranspiration data available from the California Irrigation Management and Information System (CIMIS). Samples of irrigation water were collected for analysis of nitrate and salinity content. Undisturbed cores of soil were collected for determining the water retention pattern for each soil type. Collected data was analyzed to determine if water-use was consistent with the water requirements of the crops. In addition to the fields monitored during the 2011 production season, flow meters were installed at 3 additional sites in October 2011 so that the volume of water used for transplant establishment could be determined.

Results

Average water applied to strawberries between January and October 2011 for the 35 sites ranged from 12 to 42 inches of water and averaged 24.8 inches (Fig. 1). Average seasonal volume applied for the 14 intensively monitored fields was 25.5 inches and ranged from 13 to 40 inches (Fig 2.). Although the average applied water for the 2011 season was greater than the average volume (21 inches) applied during the 2010 season, less rainfall occurred between January – mid February in 2011, which required supplemental irrigation to maintain adequate moisture around the root balls of the young transplants. Applied water during the period between January and May 2011 averaged 8 inches, 32% of the total applied water for the season. Rainfall averaged 11.7 inches between January and May 2011. Although some rainfall likely satisfied the water needs of the crops, 90% of the precipitation occurred between January and end of March when crop water needs were minimal due to low evapotranspirational demand. Much of the rainfall would have likely contributed to drainage and run-off during the winter months.

Crop ET estimates for the sites, developed from measures of canopy cover and spatial CIMIS reference ET data, averaged 17.5 inches and ranged from 11.4 to 22.9 inches. Growers applied an average of 146% of crop ET from January – October, with a range of 116% to 186% of crop ET (Fig. 3). From June – October, applied water averaged 123% of Crop ET (Fig. 4), indicating that most of the application of water above ET occurred during the winter months when evapotranspiration demand of the crop was low. Applied water during the winter and early spring (January – April) averaged 276% of crop ET and ranged from 112% to 576% of crop ET. In addition, rain contributed significantly to the applied water to the crop.

Soil moisture data recorded with watermark sensors provided a cross-check of flow meter and ET data. Average monthly soil moisture tensions were low (< 15 cbars) during January – March when applied water and rainfall exceeded crop ET (Table 3). Soil tensions increased during the production season when crop ET increased. Sites 1 and 6, where more than 150% of crop ET was applied during June through October (Fig. 4), had soil water tensions averaging less than 15 cbars at the 6 and 12 inch depths (Table 1). In contrast, sites 3, 7, 10 and 11, where less than 100% of crop ET was applied during June through October (Table 1) had soil water tensions averaging greater than 15 cbars at the 6 and/or 12 inch depths. Across all sites, soil moisture tension was related to applied water, expressed as a percentage of crop ET. Figure 5 shows that average monthly soil moisture tension was often greater than 30 cbars, indicating depleted soil moisture, when the average volume of applied water was less than 125% of crop ET.

The volume of water applied per irrigation event during the production season (June – October) was usually less than the water holding capacity of the soil; and therefore would presumably not cause excessive drainage. The average volume of water applied per irrigation for all 14 sites was 0.27 inches (Table 2), and the average water holding capacity of the soil between 5 and 30 cbars of tension was 0.35 inches per foot of depth for the top soil layer (Table 3).

The volume of water applied for crop establishment was evaluated in 3 fields between November 2011 and March 2012 (Table 4). An average of 6.2 inches was applied to establish transplants during November and December 2011. In 2010, the amount of water applied to establish transplants averaged 4 inches for 6 monitored fields. The lower amount of water used in 2010 was presumably due to early rain events that supplemented crop water demands during November and December. In addition to the establishment water in November and December, an average of 5.6 inches was applied between January and March 2012 (Table 4). In 2010, an average of 2.4 inches of water was applied during the same months. Rainfall ranged from 5.1 to 8 inches for these 3 sites between November 2011 and March 2012.

Conclusions

The results of the 2011 season are consistent with results reported for the 2010 season demonstrating that many growers under-irrigated during the production season. Because only 2 fields (14% of total) were irrigated with more than 150% of crop ET during the production season, the potential to conserve water may be limited during this period. In addition, nitrate leaching may not be a significant issue during the production season. The volume of water applied per irrigation was generally small (averaging 0.27 inches), and would be unlikely to exceed the water holding capacity of the soil. Our previous study has shown that soil nitrate levels are often less than 10 ppm nitrate-N between May and October. The combination of minimal drainage and low soil nitrate levels during the production season would suggest that a majority of growers were unlikely to leach significant amounts of nitrate beyond the root zone.

The greatest opportunity to conserve water appeared to be during the winter months, when applied water amounts greatly exceeded crop ET. Approximately one third of the irrigation water was applied during the winter and early spring when evapotranspirational demand of the crop was minimal. In 12 of the 14 monitored fields an average of 300% of crop ET was applied during this period. Although ET is low during the winter, growers may be challenged to reduce water applications because of concerns with maintaining sufficient soil moisture to establish young transplants and leach salts. They may also need to irrigate for the purpose of fertigating, and to maintain sufficient moisture in beds to protect the crop from frost damage. However the combination of monitoring soil moisture status and following the crop ET demand would be useful ways to determine if applied water could be reduced. Finally, because soil nitrate levels are generally higher during the fall and winter than during the summer, and applied water and rainfall greatly exceed crop water demand, the greatest potential for nitrate leaching would be during the winter.

Table 1. Average monthly soil moisture tension at the 6- and 12-inch depths for 11 commercial strawberry fields during the 2011 season.

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7		Site 8		Site 9		Site 10		Site 11		AVG		Max		Min	
Month	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"	6"	12"
	soil moisture tension (cbars)																											
Jan	7	4	2	2	17	10	10	7	6	4	--	--	--	--	--	--	--	--	7	7	--	--	8	6	17	10	2	2
Feb	5	4	6	1	16	9	13	8	12	13	5	4	1	5	10	2	--	--	7	12	14	2	9	6	16	13	1	1
Mar	8	4	12	1	25	14	16	16	13	16	9	7	6	8	14	8	13	4	9	19	13	5	12	9	25	19	6	1
Apr	14	1	9	0	15	9	8	8	30	12	4	8	0	1	10	7	16	13	6	14	6	0	11	7	30	14	0	0
May	13	1	9	0	17	10	17	10	30	14	9	6	5	1	11	4	15	7	19	19	16	2	15	7	30	19	5	0
Jun	8	1	2	0	20	11	14	7	23	17	12	7	9	1	10	3	16	8	52	29	9	3	16	8	52	29	2	0
Jul	4	0	0	0	23	9	14	6	13	5	6	3	18	0	10	2	18	7	85	25	17	13	19	6	85	25	0	0
Aug	3	0	0	0	23	9	5	4	10	4	4	1	16	2	10	1	18	6	80	43	10	18	16	8	80	43	0	0
Sep	2	0	0	0	23	14	10	5	10	3	5	1	15	1	11	1	28	4	90	115	6	17	18	15	90	115	0	0
Oct	8	2	0	1	21	14	41	14	18	4	21	3	17	2	20	7	30	6	55	51	43	41	25	13	55	51	0	1

Table 2. Volume of water applied per irrigation in commercial strawberry fields between June and October 2011.

Site Number	Irrigation Volume Average	Maximum	Minimum
	inches		
1	0.37	1.14	0.06
2	0.25	0.67	0.06
3	0.46	0.83	0.19
4	0.20	0.33	0.11
5	0.51	1.26	0.09
6	0.33	0.67	0.15
7	0.36	0.54	0.14
8	0.30	0.43	0.16
9	0.18	0.37	0.07
10	0.10	0.18	0.06
11	0.15	0.34	0.07
12	0.14	0.33	0.05
13	0.27	0.46	0.07
14	0.20	0.34	0.11
AVG	0.27	0.56	0.10

Table 3. Available soil moisture at 2011 monitoring sites.

Site	Soil	Available soil water (5 to 30 cbars) 0-1 foot	1-2 feet
		inches of moisture per foot of depth	
2	loam	0.34	0.18
4	clay	0.20	0.13
7	sandy loam	0.49	0.19
8	loam	0.33	0.27
9	fine sandy loam	0.30	0.23
10	sandy loam	0.42	0.32
AVG		0.35	0.22

Table 4. Water used for establishment and post-establishment of strawberries.

	Transplant Establishment		Post Establishment		Applied Water by Month				
Location	Method	volume	method	volume	Nov	Dec	Jan	Feb	Mar
		inches		inches	------------inches-------------				
Watsonville	sprinkler/drip	5.6	sprinkler/drip	9.9	0.0	5.6	3.5	3.5	2.9
Castroville	sprinkler/drip	6.1	drip	2.5	1.2	4.9	1.0	0.0	1.4
Salinas	sprinkler/drip	7.0	sprinkler/drip	4.3	3.8	3.2	0.4	1.4	2.5
Average		6.2		5.6	1.7	4.6	1.7	1.6	2.3

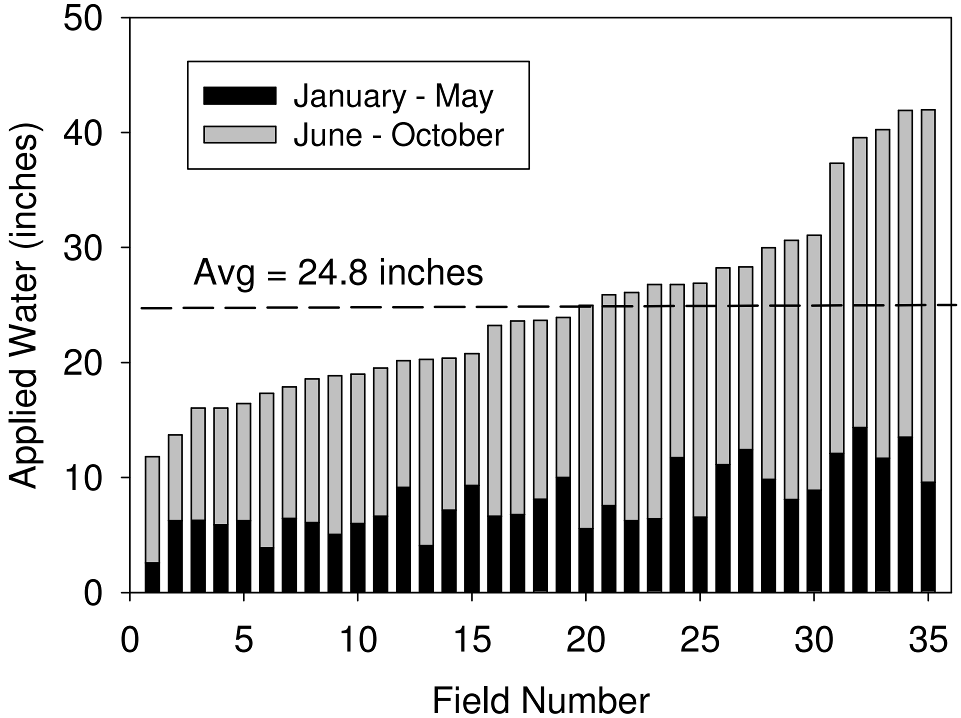

Figure 1. Seasonal volumes of irrigation water applied to 35 commercial strawberry fields (January – October 2011).

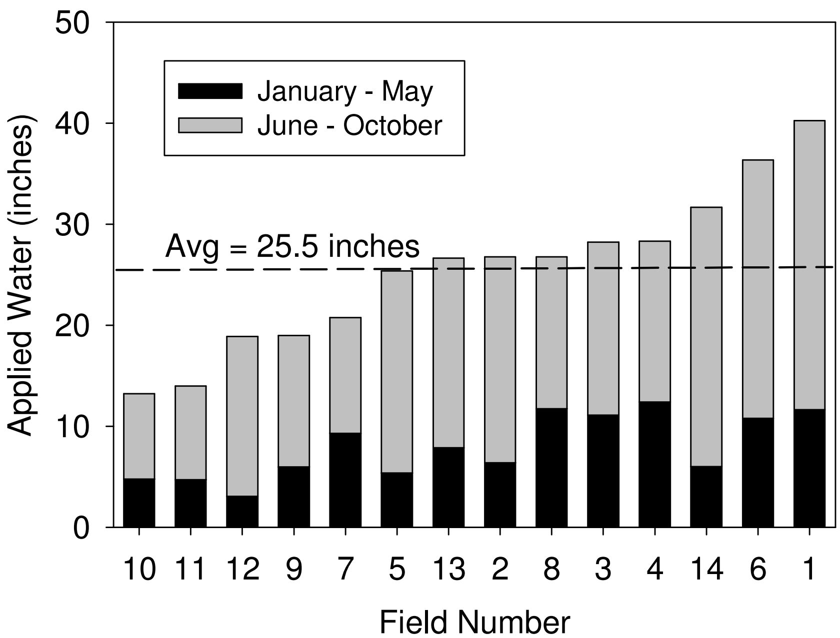

Figure 2. Seasonal applied water to 14 strawberry fields intensively monitored (January – October 2011).

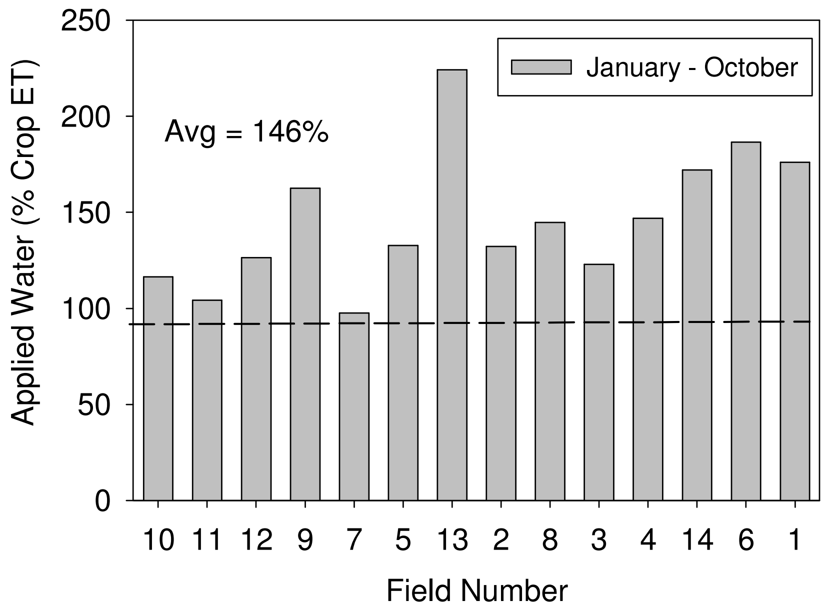

Figure 3. Seasonal applied water as a percentage of crop ET for 14 strawberry fields (January – October 2011).

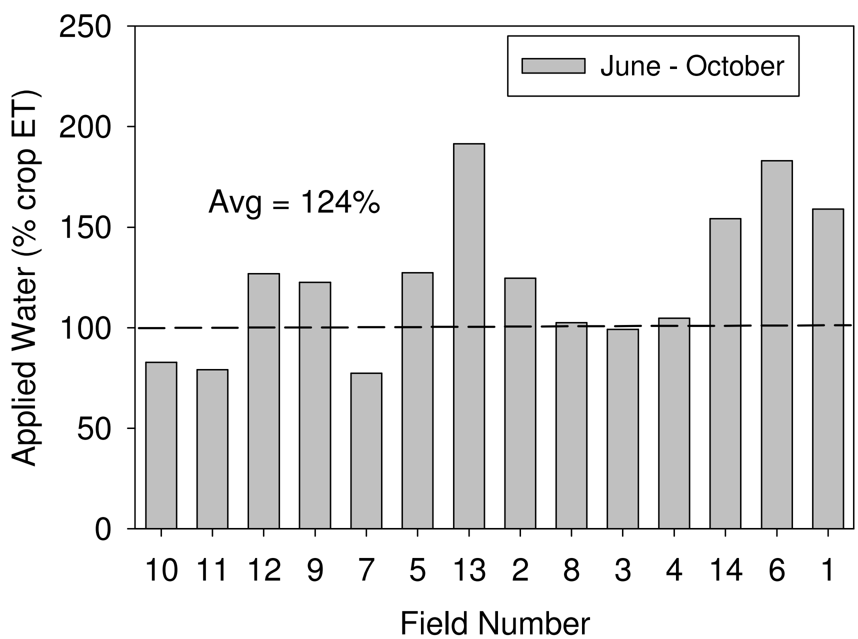

Figure 4. Seasonal applied water as a percentage of crop ET for 14 strawberry fields (June – October 2011).

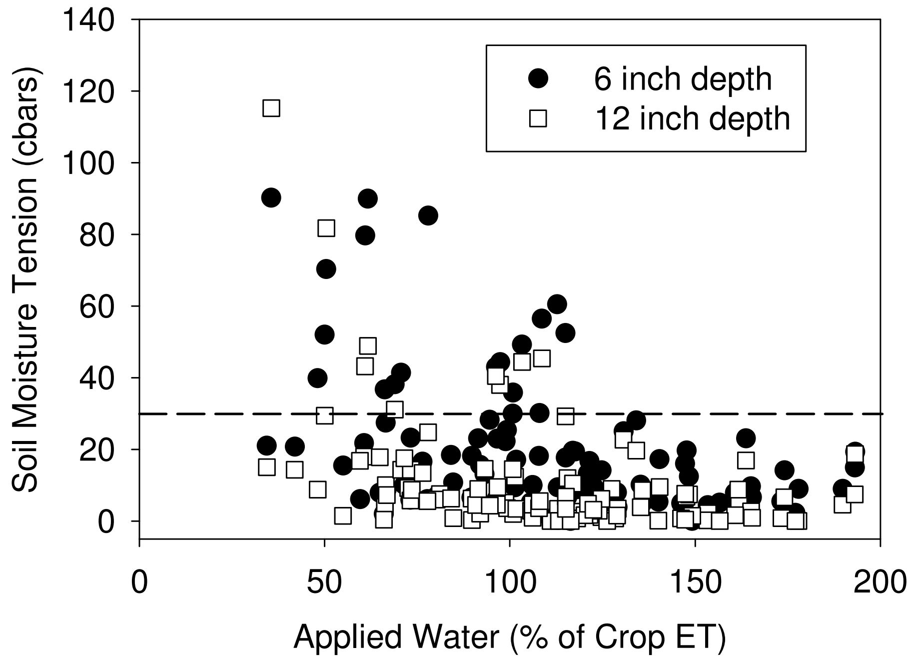

Figure 5. Average monthly soil moisture tension *vs* average monthly applied water expressed as a percentage of crop ET (May – October 2011).

Irrigation and N fertilization management affects nitrate leaching in strawberry production

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Keywords: environmental water quality, groundwater, drip irrigation, N fertigation

Abstract:
The annual strawberry (*Fragaria x ananassa* Duch.) production system used in the coastal valleys of central California is highly productive (often reaching fruit yields of 70 Mg ha^{-1}), and has been widely adopted around the world. Strawberry growers in this region have recently come under regulatory scrutiny for potential nitrate pollution of groundwater resulting from their production practices. In this study irrigation and N fertilization practices were monitored in a total of six commercial strawberry fields during the 2009-10 and 2010-11 production seasons. Irrigation volume and timing were documented using water meters. Crop evapotranspiration (ET_c) was estimated from daily reference evapotranspiration (ET_o) and crop canopy development as determined by infrared imaging. N fertilization records were obtained from cooperating growers. Crop N uptake was determined by monthly destructive plant sampling. Soil leachate NO_3-N was measured weekly using suction lysimetry from May through August, the period during which most of the seasonal irrigation was applied. Irrigation management varied widely among fields, ranging from deficit irrigation to an estimated 175% of ET_c. N fertilization was similarly variable, with the seasonal total ranging from 141-476 kg ha^{-1}. Total seasonal crop N uptake averaged 163 kg ha^{-1}, with marketable fruit accounting for 46% of the total. Estimated summer NO_3-N leaching loss ranged from 1-67 kg ha^{-1}, averaging 33 kg ha^{-1}. Soil NO_3-N monitoring in the 2010-11 fields indicated that N loss over the winter may have exceeded summer NO_3-N leaching.

INTRODUCTION

Pollution of groundwater with nitrate-nitrogen (NO_3-N) of fertilizer origin is a growing problem worldwide. Strawberry growers along the central coast of California have come under increasing regulatory pressure to improve irrigation and fertilization practices to reduce NO_3-N leaching potential. In this region crowns of day-neutral strawberry cultivars are planted into fumigated, plastic mulched beds in the fall and grown for 10-12 months. Drip irrigation is used, and nitrogen fertility is managed by a combination of preplant application of controlled release fertilizer (CRF) and N fertigation. Seasonal N rates currently range from less than 200 to more than 300 kg ha^{-1}, and the relative portion of seasonal N applied preplant vs. fertigated during the growing season varies widely among growers.

There is a paucity of relevant research on efficient fertilization and irrigation management to guide grower practices. A number of researchers have reported that seasonal N rates of no more than 150 kg ha^{-1} are sufficient to maximize fruit yield in an

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There is a paucity of relevant research on efficient fertilization and irrigation management to guide grower practices. A number of researchers have reported that seasonal N rates of no more than 150 kg ha^{-1} are sufficient to maximize fruit yield in an annual strawberry system (Hochmuth et al., 1996: Kirschbaum et al., 2006; Miner et al., 1997). However, these reports came from production environments unlike central California, and described systems that produced fruit yields < 45 Mg ha^{-1}, far below California norms. Strawberry has been shown to be very sensitive to both water stress (Serrano et al., 1992) and salinity (Maas and Hoffman, 1977). Given the high value of this crop, grower irrigation management may focus on stress avoidance rather than irrigation efficiency. The objectives of this study were to monitor grower irrigation and N fertilization practices in commercial strawberry fields, document soil and plant nitrogen dynamics, and estimate NO_3-N leaching potential.

MATERIALS AND METHODS

Three commercial strawberry fields near Salinas, California, were monitored in each of the 2009-10 and 2010-11 production seasons. This area is characterized by a mild marine climate, with precipitation concentrated during the winter months (Fig. 1). Strawberry crowns of the day-neutral cultivar 'Albion' were planted between mid-October and mid-November, sprinkler irrigated for establishment, and then transitioned to drip irrigation. Water meters were installed in March in the 2009-10 fields, and measured applied drip irrigation through September; meters were installed prior to crown establishment in the 2010-11 fields, and recorded both sprinkler irrigation for crown establishment and drip irrigation through the following September.

Crop canopy coverage was estimated by infrared photography, with images taken on 4-5 week intervals beginning in March in both production seasons. Reference evapotranspiration (ET_o, modified Penman) was obtained from computerized weather stations close to the monitored fields. A canopy cover development model was fit to data collected from sites with similar varieties and bed widths, allowing canopy cover to be estimated for each day of the season. Canopy cover estimates were converted to crop coefficients by the equation from Gallardo et al. (1996) modified for strawberry:

$$K_c = (0.63+1.5\ C - 0.0039\ C^2)/100$$

where K_c is the crop coefficient, ranging between 0 and 1, and C is percent canopy cover. Daily K_c values were multiplied by ET_o to estimate crop evapotranspiration (ET_c). Evaporation from the soil surface of beds was assumed negligible since they were covered with plastic mulch. Because rainfall was minimal during the production season (April - October), evaporation from the furrows was also presumed to be insignificant.

Whole plant sampling was initiated in March and repeated on approximately monthly intervals until September to document crop N uptake in 2 of the monitored fields in each production season. Three replicate samples per field, each comprised of 4 representative whole plants, were collected on each sampling date. Fruit were removed and the vegetative tissue was dried, weighed, and analyzed for total N by combustion (Elemental Combustion System 4010, Costech Analytical Technologies Inc., Valencia, CA). Ripe fruit were similarly analyzed, and the N content of fruit harvested between sampling dates was estimated by multiplying fruit N concentration on a fresh mass basis by the marketable yields during that period. Root zone soil samples (top 30 cm) were collected concurrently with plant sampling, with at least 12 soil cores per field combined to make a composite sample; soil NO_3-N concentration was determined in 2 N KCl extracts by the method of Doane and Horwath (2003). Six suction lysimeters were installed at 60 cm depth in each field and connected to an automated vacuum pump system that maintained a constant tension of -.02 MPa over a 24-48 hour period. Soil water samples were collected from one irrigation event per week per field from June-August (2010) or May-September (2011). Weekly leaching volume was estimated as the difference between irrigation volume applied and ET_c, adjusted for any irrigation deficit the preceding week. Growers provided detailed information on N fertilization practices and marketable yields obtained.

RESULTS AND DISCUSSION

Nitrogen management in the monitored fields varied substantially, with total seasonal N application ranging from 141 to 476 kg ha^{-1} (Table 1). All fields received a preplant application of CRF, a practice that is nearly universal in the California strawberry industry. The common CRF products used are typically rated as 6-8 month nutrient release. In-season N fertigation was concentrated during the fruit production portion of the season (April - September). Marketable fruit yield, which ranged from 56 - 75 Mg ha^{-1}, was not correlated with preplant, fertigated or total seasonal N rates.

Crop N uptake showed a consistent pattern across fields (Fig. 2). Plant growth and N uptake was slow through the winter, with above-ground biomass N less than 20 kg ha^{-1} by 1 April. N uptake appeared to be linear from April to September, with biomass N increasing by approximately 1 kg ha^{-1} d^{-1} over that period. At the last sampling date (27 Aug and 13 Sept in 2010 and 2011, respectively) biomass N averaged 163 kg ha^{-1}; marketable fruit constituted 46% of biomass N. Cull fruit (estimated to average approximately 15% of total fruit mass) was not included in these measurements, but would represent an additional 13 kg ha^{-1} biomass N. Fields kept in production later in the fall would continue to take up N, although presumably at a slower rate as temperature declined and plants senesced. The similarity of crop N uptake across fields, despite large differences in seasonal N application, indicated that strawberry N requirements were modest, and luxury N uptake limited. The consistent crop N uptake rate over the entire fruiting season suggested that a program of small, uniform N fertigations throughout that time period would be an efficient practice that would minimize summer NO_3-N loss potential.

Soil NO_3-N was maintained below 10 mg kg^{-1} in the top 30 cm in most fields throughout the summer irrigation period (Fig. 3); the exception was field 6, which received by far the greatest N fertigation rate. Soil NO_3-N at crown planting was between 19-25 mg kg^{-1} in the 2010-11 fields; high soil NO_3-N at crown planting is a common occurrence in this production system, in which strawberries are typically planted following heavily fertilized vegetable crops. Soil NO_3-N declined substantially by the April sampling, despite the fact that N release from the preplant CRF (applied approximately 5 months earlier at an average of 126 kg ha^{-1} N) was undoubtedly much greater than crop N uptake over that time (< 30 kg ha^{-1}). These observations suggested that substantial movement of NO_3-N below the root zone occurred over the winter, and call into question the efficiency of the current practice of applying 30-50% of seasonal N preplant in the form of a 6-8 month release CRF.

Irrigation management varied by field (Fig. 4). In fields 1 and 4 applied water (irrigation and precipitation) closely matched estimated ET_c over the period April through September; from June through September estimated ET_c slightly exceeded irrigation. By contrast, applied water exceeded ET_c by 37 cm, or 75%, in field 3. Across fields, applied water averaged 18 cm, or 37%, more than seasonal ET_c. The vast majority of applied water was irrigation; precipitation was less than 8 cm in all fields. With the exception of field 3, the majority of the estimated leaching volume occurred by mid-June.

Soil water NO_3-N concentration at 60 cm depth, and estimated NO_3-N leaching below that depth, were functions of irrigation and N fertigation management (Fig. 5). Fields 1 and 4 had a combination of low soil water NO_3-N and a small leaching volume; estimated NO_3-N leaching loss over the monitored period was 1 and 7 kg ha^{-1}, respectively. In the other fields higher soil water NO_3-N, and greater leaching volume, led to much greater NO_3-N leaching losses, ranging from 37 kg ha^{-1} in field 5 to 67 kg ha^{-1} in field 6. Across fields, the average summer NO_3-N leaching loss was estimated at 33 kg ha^{-1}.

CONCLUSIONS

A combination of precise irrigation and moderate N fertigation can produce high strawberry yields with minimal NO_3-N leaching losses during the fruit production period (May through September). Modification of the current practice of preplant CRF application may reduce the opportunity for NO_3-N loss during the winter.

Literature Cited

Doane, T.A. and W.R. Horwath. 2003. Spectrophotometric determination of nitrate with a single reagent. Anal. Letters 36:2713-2722.

Gallardo, M., L.E. Jackson, K. Schulbach, R.L. Snyder, R.B. Thompson and L.J. Wyland. 1996. Production and water use in lettuces under variable water supply. Irrig. Sci. 16:125-137.

Hochmuth, G.J., E.E. Albregts, C.C. Chandler, J. Cornell and J. Harrison. 1996. Nitrogen fertigation requirements of drip-irrigated strawberries. J. Amer. Soc. Hort. Sci. 121:660-665.

Kirschbaum, D.S., A.M. Borquez, S.L. Quipildor, M. Correa, H. Magen and P. Imas. 2006. Nitrogen requirements of drip irrigated strawberries grown in subtropical environments. Acta Hortic. 708:93-96.

Mass, E.V. and G.J. Hoffman. 1977. Crop salt tolerance: Current assessment. J. Irrig. Drainage Div., Am. Soc. Civ. Eng. 103:115–134.

Miner, G.S., E.B. Poling, D.E. Carroll, L.A. Nelson and C.R. Campbell. 1997. Influence of fall nitrogen and spring nitrogen-potassium applications on yield and fruit quality of ‘Chandler’ strawberry. J. Amer. Soc. Hort. Sci. 122:290-295.

Serrano, L., X. Carbonell, R. Save, O. Marfa and J. Penuelas. 1992. Effects of irrigation regimes on the yield and water use of strawberry. Irrig. Sci. 13:45-48.

Tables

Table 1. Soil texture, N fertilization and marketable yield of the monitored fields.

Field	Production season	Soil texture	N applied (kg ha^{-1}) preplant	fertigated	total	Marketable fruit yield (Mg ha^{-1})
1	2009-10	loam	61	173	234	72
2	2009-10	clay loam	101	40	141	74
3	2009-10	sandy loam	88	250	338	63
4	2010-11	loam	121	175	296	75
5	2010-11	loam	121	249	360	73
6	2010-11	loam	135	341	476	56

Figures

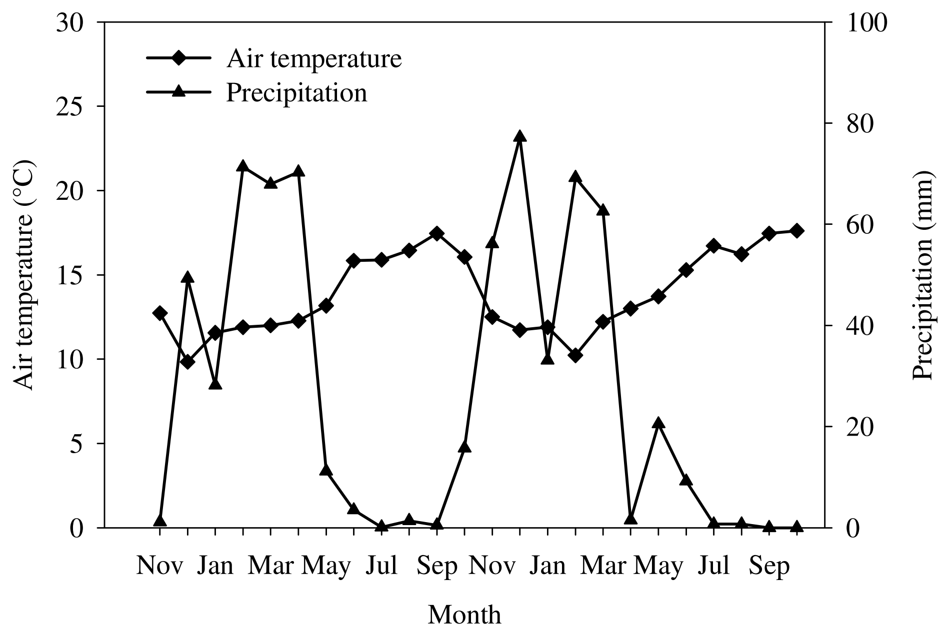

Fig. 1. Monthly precipitation and mean air temperature at Salinas, California, from November, 2009, through October, 2011.

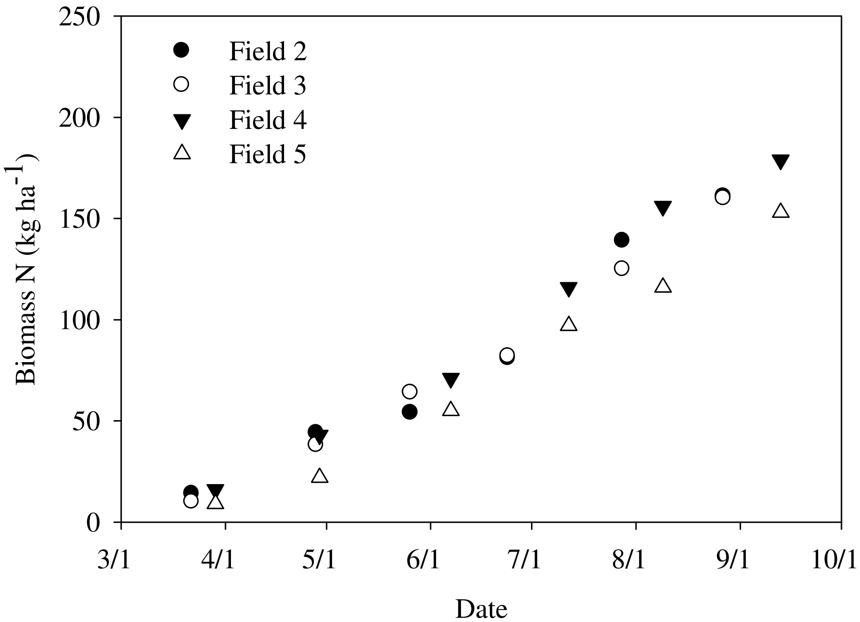

Fig. 2. Above-ground biomass N accumulation of strawberry; values include vegetative tissue and marketable fruit, but not cull fruit.

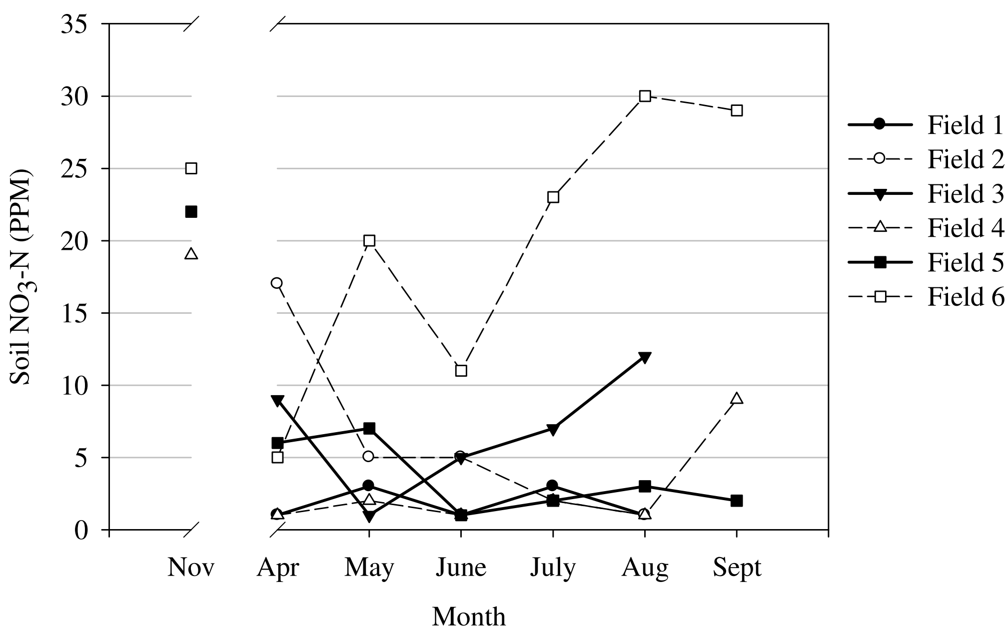

Fig. 3. Pattern of root zone soil NO_3-N (top 30 cm) in the monitored fields.

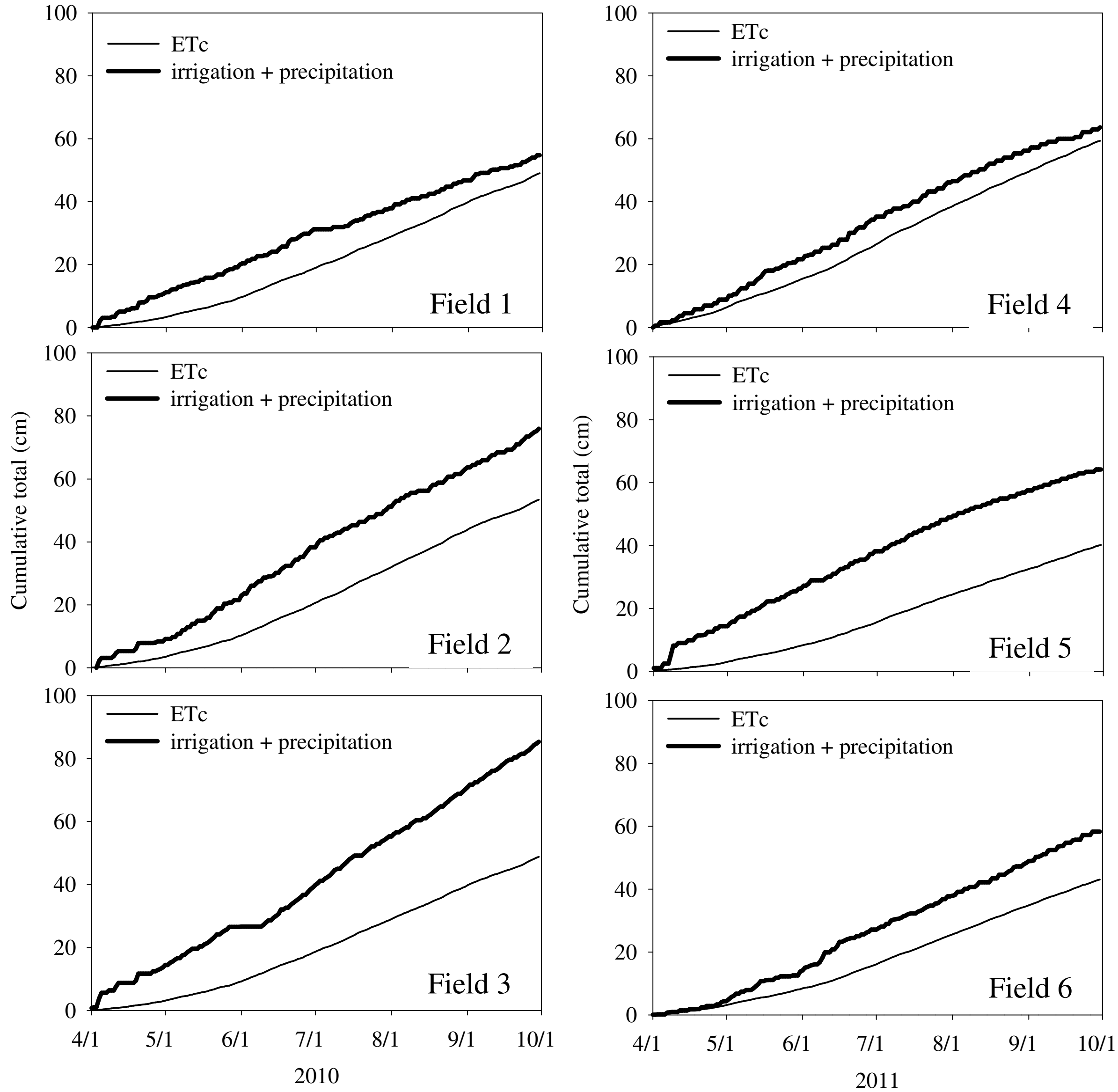

Fig. 4. Crop evapotranspiration (ET_c) and applied water (irrigation and precipitation) from 1 April through 30 September.

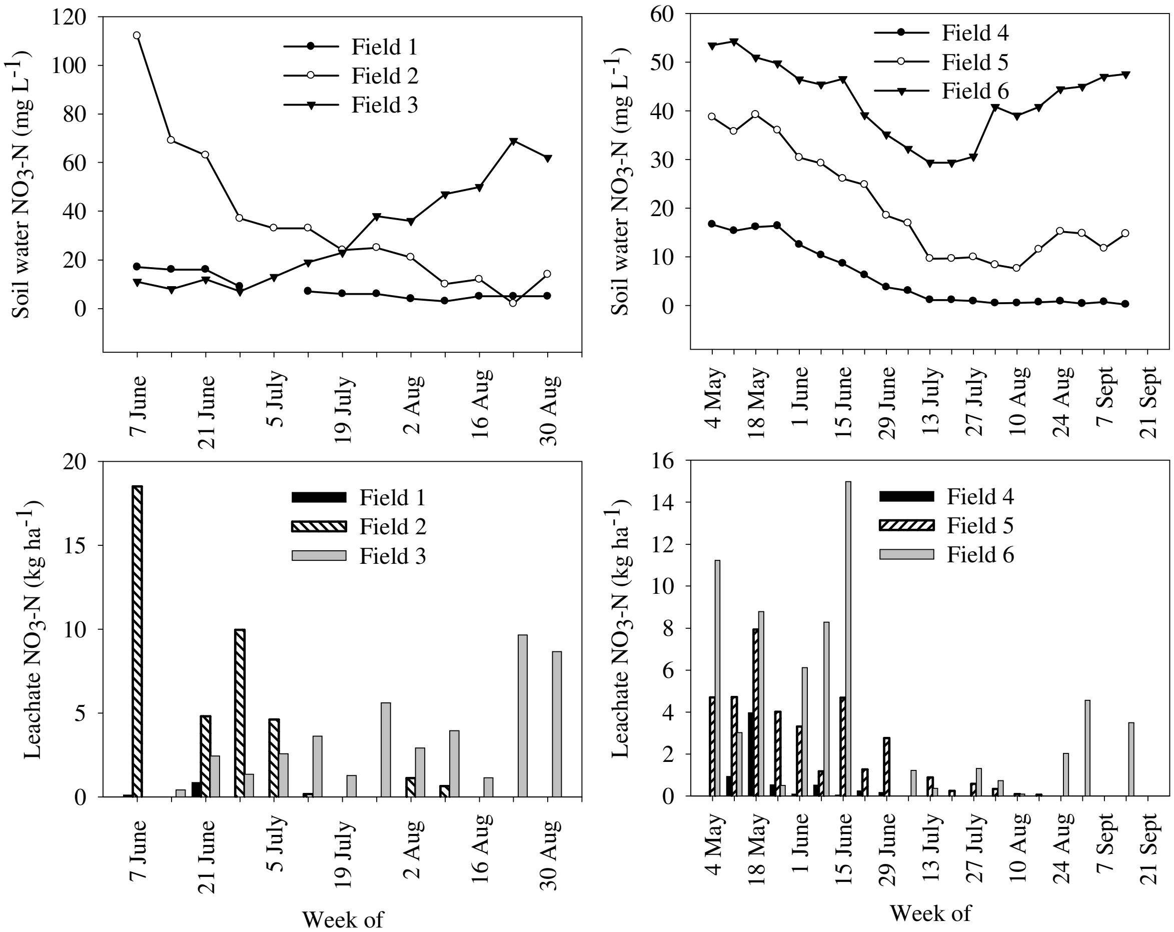

Fig. 5. Soil water NO_3-N (60 cm depth) and estimated weekly NO_3-N leaching loss.

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2012 Annual Central Coast Strawberry Meeting
February 2, 2012
Organized by University of California Cooperative Extension, Santa Cruz County
Location Change:* Kennedy Youth Center, 2401 E. Lake Avenue*: Location Change
Watsonville, CA, 95076

6:45-7:15	**Registration and Sign In. No Fee.**
7:15-7:45	**Laws and Regulations Update, 2012** **Mary Lou Nicoletti, Agriculture Commissioner**
7:45-8:05	**Central California Breeding and Cultural Practices Update 2012** **Doug Shaw, University of California, Davis**
8:05-8:25	**Costs and Returns of Second Year Strawberry Production.** **Laura Tourte and Mark Bolda, UC Cooperative Extension, Santa Cruz County**
8:25-8:45	**An Update on Strawberry Herbicides.** **Steve Fennimore, UC Cooperative Extension, Salinas**
8:45-9:10	**Research and Regulatory Update.** **Dan Legard and Rick Tomlinson, California Strawberry Commission**
9:10-9:30	**Water Use of Strawberries.** **Mike Cahn, UC Cooperative Extension, Salinas**
9:30-10:00	**Break**
10:00-10:20	**Anaerobic Soil Disinfestation.** **Carol Shennan and Joji Muramoto, University of California, Santa Cruz**
10:20-10:40	**The Challenge of Soilborne Pathogens in the Post-Fumigation Era** **Tom Gordon, UC Davis**
10:40-11:00	**Efficient Fertilization of Strawberries** **Tim Hartz, UC Davis**
11:00-11:20	**Producing Strawberries in Substrate** **Hillary Thomas, California Strawberry Commission**
11:20-11:40	**Southern California Strawberry Research Update** **Kirk Larson, University of California South Coast Research & Extension Center**
11:40-noon	**Recent Studies of Controls for Lygus** **Frank Zalom, University of California, Davis**

New for this year: All meeting participants are invited to come for breakfast, which will be served before and during the meeting.

For more information, contact Mark Bolda (831)-763-8040; 1432 Freedom Blvd., Watsonville, CA, 95076
Continuing education credits will be applied for. Please call ahead for arrangements of special needs; every effort will be made to accommodate full participation.
Spanish translation will be available.

2012 IRRIGATION TRAINING SEMINAR

When:	April 27th, 2012
Where:	Aromas Grange (Aromas, CA)
Address:	400 Rose Avenue, located near the corner of Carpenteria and Rose Avenue in Aromas, CA
Driscoll's Contacts:	Michael Babcock (831-254-9458); Ian Greene (831-254-6199)
RAC Contacts:	Kevin Healy (831-262-9135); Carlos Torres (831-750-7074

Training Seminar Agenda:

Time	Topic	Speaker
7:30 – 8:00	Breakfast	
8:00 – 8:15	Welcome and Introduction	Kevin Healy (RAC)
8:15 – 8:45	Distribution uniformity: irrigation system assessment	Tom Lockhart (UC Cooperative Extension)
9:00 – 9:30	Irrigation scheduling using CIMIS weather data and soil moisture sensors	Michael Cahn (UC Cooperative Extension)
9:45 – 10:00	Break	
10:00 – 10:45	Water quality sampling and interpretation of test results	Clifford Low (Agronomist and Fertility Consultant – Watsonville)
11:00 – 11:45	Ag Order: reviewing the irrigation section of the Farm Plan	Tim Frahm and Mary Ellen Dick (Central Coast Ag Water Quality Coalition)
12:00 – 1:00	Lunch	
1:00 – 2:00	TCR Ranch Tour: Tensiometric Triggers Trial and tensiometer installation demonstration	Ian Greene (Driscoll's)
2:00 – 3:00	Ferris Ranch Tour: Automated Strawberry Irrigation Trial	Kevin Healy (RAC)

PLEASE RSVP !!!

*The 2012 Irrigation Training Seminar is jointly-sponsored by DSA's Northern District Production Department and RAC's Northern District Knowledge and Innovation Department. For RAC growers, this seminar is part of the "2012 Grower's Expertise" training series

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University of California
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Strawberry Meeting

UCCE

Friday, May 11, 2012

Strawberry Field Day

Friday, May11, 2012
Manzanita Berry Farms, 1891 West Main, Santa Maria, CA 93458
2.0 hours of DPR and 3.5 hours of CCA CE Credits have been approved

08:30 Registration - No fee
09:00 Update on regulatory and fumigation issues
Debbie Trupe, Supervising Ag Biologist, Santa Barbara Co Ag Commissioner Office
09:15 Pesticide usage and water quality
Peter Meertens, Environmental Scientist, Central Coast Regional Water Quality Control Board
09:30 Update on reduced sprinkler irrigation and salinity management in strawberries
Stuart Styles, Professor of BioResource and Ag Engineering, Cal Poly, San Luis Obispo
10:00 Soil moisture monitoring and irrigation scheduling in strawberries
Michael Cahn, Irrigation and Water Resources Advisor, UCCE, Salinas
10:30 Nutrient management in strawberries for high productivity and efficiency
Tim Hartz, Vegetable Crops Specialist, University of California, Davis
11:00 Update on strawberry Raised Bed Trough (RaBeT) system
Hillary Thomas, Research Manager, California Strawberry Commission, Watsonville
11:30 Fumigation alternatives for strawberry disease and weed management
Carol Shennan, Professor of AgroEcology, Joji Muramoto, Associate Researcher, University of California, Santa Cruz
12:00 Field tour
12:30 Lunch

Spanish interpretation will be provided

Please pre-register by May 4, 2012 online at http://ucanr.org/strawberryfieldday **or call Ingrid Schumann at 805-781-5940 for additional information. Early registration helps w arrangements.**

Thanks to our meeting sponsors:
California Strawberry Commission and Skyplastic USA

Cachuma Resource Conservation District

Your Local Partner in Conservation

A Workshop For Strawberry Growers
Presented in Spanish

Workshop: Irrigation Management

Date: October 24, 2012
Time: 8:30 am - 12:30 pm
Place: Best Western Hotel (Heritage Room)
1725 North Broadway
Santa Maria, CA 93454

8:30 AM	Registration
9:00 AM	Drip Irrigation and Different Salts Effects on Strawberries *Oleg Daugovish–UCCE Farm Advisor Ventura County*
9:45 AM	CRCD Mobile Irrigation Lab Services Misael Sanchez–*CRCD Technical Field Advisor*
10:20 AM	Break (10 Minutes)
10:30 AM	Irrigation Effects on Nutrient Management of Strawberries *Michael Cahn–UCCE Farm Advisor Monterey County*
11:30 AM	Lunch (will be provided)

RSVP to Misael Sanchez at:
E-mail: msanchez@rcdsantabarbara.org
Phone#: (805) 868-3770

Presented by Cachuma RCD with a CDFA Specialty Crop Block Grant
for Spanish-speaking strawberry growers
Co-sponsored by University of California Cooperative Extension (UCCE)
and the Natural Resources Conversation Service (NRCS)