CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM

Final Report

January 1, 2011 – December 31, 2013

A. Project Title: Irrigation and Nitrogen Management Web-based Software for Lettuce Production

CDFA contract number: 10-0013-SA

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A. Objectives

The overall goal of this project is to develop a web-based software tool that will aid growers in optimizing water and nitrogen fertilizer applications in lettuce, thereby saving production costs and minimizing water quality impacts. Specific objectives of the project are to:

1. Develop irrigation and nitrogen management software.
2. Evaluate irrigation and nitrogen management software in commercial lettuce fields.
3. Conduct educational trainings and develop a user guide for the software.

B. Abstract:

Commercial lettuce production requires significant inputs of water and nitrogen fertilizer to maximize yield and quality. Proposed changes in water quality regulations on the Central Coast and higher fertilizer prices in recent years have prompted grower interest in increasing efficiency of nitrogen fertilizer use in lettuce. By improving water management and matching nitrogen applications to the uptake pattern of the crop, growers could potentially reduce fertilizer use and address water quality concerns. Two tools available to growers, the quick nitrate test and CIMIS evapotranspiration data, could help lettuce producers better manage water and fertilizer nitrogen. However, adoption of these practices has not been wide spread. One reason is that these techniques can be time consuming to use, and many farm managers have several hundred fields to keep track of for irrigation, fertilization, and pest control during a single season. The overall

goal of this project was to develop a web-based software tool that will aid growers in optimizing water and nitrogen fertilizer applications in lettuce. In collaboration with UC Agriculture and Natural Resources (UCANR), Communication Services personnel, we launched a preliminary version of a web-based software program for managing nitrogen and water in lettuce production on Sept 1, 2011. The software application, named CropManage (ucanr.org/cropmanage), is hosted and maintained on the UCANR Communications server in Davis, CA. Using a web browser, users can access the software through smart phones, tablet and desktop computers. CropManage was designed to be intuitive for growers and farm managers to use. The user interface and menu structure were designed and developed under the oversight of collaborating growers, and follows common practices that they use to maintain records of fertilizers, soil tests, and irrigation. The software employs established guidelines to recommend the amount of fertilizer and water to apply during upcoming irrigation and fertilizer applications.

The software automatically updates water requirements for each of the growers' fields using evapotranspiration data from regional weather stations and measurements of applied water derived from in-field flow meters. The evapotranspiration data is automatically downloaded from the California Irrigation Management and Information System (CIMIS), operated by the Cal. Dept. of Water Resources. Flow meter data from individual fields is uploaded using cell phone communication. A nitrogen uptake module included in the software provides information on the amount of nitrogen needed for upcoming fertilizer applications.

In addition to software development, we are evaluating the accuracy of the decision support modules of the software. During the 2012-13 seasons, we conducted 6 unreplicated strip trials in commercial fields to compare lettuce yield using the grower standard management and the software recommended irrigation and N fertilizer management, and to compare potential savings in N fertilizer, water, and nitrate leaching. Yields under the CropManage practice averaged 4.5% higher than the Grower standard practice despite reducing N fertilizer by 33%. Applied water during the drip phase of the lettuce crop was reduced under the CropManage treatment by 23% at one trial compared to the grower standard but increased by 21% at another trial to compensate for low soil moisture conditions.

We anticipate that this project will lead to the implementation of better fertilizer and water management practices in lettuce production, thereby assisting growers to reduce production and management costs and maintain or even improve crop yields while at the same time achieving water quality targets for ground and surface water supplies on the central coast. This project would also help growers address proposed regulations to limit nitrate discharges to ground and surface waters on the central coast. Improved water management would also help conserve ground water, and minimize the risk of sea water intrusion into the coastal aquifer.

Information developed in this project is being extended through seminar meetings, bulletins, and newsletters. The target audiences for the project are vegetable growers and farm managers, produce company personnel, NRCS and RCD personnel, and crop consultants.

C. Introduction

The largest region of cool season vegetable production in the United States is along the central coast of California. California produced more than 350,000 acres of lettuce and broccoli (80% of US production) valued at $2.2 billion in 2007. The intensive production of these commodities requires high inputs of fertilizer, irrigation water, tillage, and pesticides. Agricultural run-off from this region has impacted the quality of surface water, and leached nitrate has contaminated ground water supplies.

Commercial lettuce production traditionally uses high inputs of nitrogen (N) fertilizer (100 to 250 lbs N/acre per crop) and irrigation water (6 to 18 inches per crop) to maximize yield and quality (Heinrich et al. 2013). Changes in water quality regulations on the Central Coast and spikes in fertilizer prices in recent years have prompted grower interest in increasing efficiency of nitrogen fertilizer. Vegetable growers could potentially use less N fertilizer and address water quality concerns by improving water management and matching nitrogen applications to the N uptake pattern of the crop. Two tools available to growers, the soil nitrate quick test (SNQT) and evapotranspiration (ET) data from the California Irrigation Management Information System (CIMIS), have been shown to help better manage water and fertilizer nitrogen in lettuce production (Cahn and Smith 2012, Hartz et al. 2000). However, adoption of these practices has not been wide spread.

One reason is that these techniques can be time consuming to use, and coastal growers have many small fields for which they make daily decisions on fertilization, irrigation, pest control, harvest, and tillage operations. Scheduling irrigations based on weather requires retrieving reference ET data from the CIMIS website, and determining an accurate crop coefficient that corresponds to the developmental stage of the crop. In addition, information on the soil water holding capacity and irrigation system performance is needed to determine the optimal irrigation interval and run-time. These calculations can be time consuming and often confusing for growers and consultants to integrate into an irrigation schedule.

The SNQT also requires an investment in time, entailing collecting a representative soil sample, extracting the sample, and calculating soil mineral N concentration. When deciding on an appropriate N fertilizer rate, growers also need to consider the N uptake rate of the crop, and mineral N contributions from soil and previous crop residues.

To address many of the time constraints in managing water and fertilizer in coastal row crops, we developed an online tool that assists growers and farm managers with determining appropriate water and nitrogen fertilizer applications on a field-by-field basis. The software automates steps required to calculate crop water needs from CIMIS ET data, and estimates fertilizer N needs using quick N test data and models of crop N uptake. The web application also helps growers track irrigation schedules and nitrogen fertilizer applications on multiple fields and allows users from the same farming operations to view and share records.

D. Work Description and Results (F): January 2011 – December 2013

Task 1. Develop irrigation and nitrogen management software (completed December 2012)

Sub-task 1.1. Develop and modify algorithms for decision module of software.
Sub-task 1.2. Grower oversight of software development.
Sub-task 1.3. Develop user interface module of software
Sub-task 1.4. Develop software database
Sub-task 1.5. Develop modules to import external data
Sub-task 1.6. Report to FREP

Sub-tasks 1.1,1.3, and 1.4: Software development

In collaboration with UC Agriculture and Natural Resources (UCANR), Communication Services, we launched a preliminary version of a web-based application for managing nitrogen and water in lettuce production on Sept 1, 2011. The software application, named CropManage (ucanr.edu/cropmanage), is hosted and maintained on the UCANR Communications server in Davis, CA. The software was revised and updated in March 2012 and in March 2013 to integrate user suggestions, improve the response time of the software, and to add new capabilities. Users can access the software through a web browser on their smart phones, tablet and desktop computers.

CropManage (CM) was designed to be intuitive for growers and farm managers to navigate. The user interface and menu structure were designed with oversight from collaborating growers (subtask 1.2) and is organized following similar practices that they currently use to maintain records of fertilizers, soil tests, and irrigation.

The web application uses a secure login procedure so that only individuals with permission can view and/or edit water and nitrogen fertilizer records of a particular farming operation. After logging on, a screen displays a list of ranches/farms that the user has permission to access. By following the hyperlink for an individual ranch, the user can view a list of all active and/or past plantings associated with the ranch (Fig. 1).

A database manages information associated with ranches, fields and plantings, which are used to drive the irrigation and N fertilizer models. The database facilitates organizing and displaying data from different sources, such as from user entries, the CIMIS website, and field sensors. By associating ranch and crop background data with specific plantings, the database streamlines data entry steps for determining irrigation and N management recommendations. To establish a new ranch, the user is guided to enter information about the ranch, including lists of field names, associated acres and soil types, as well as a list of nearest CIMIS stations. To add a planting (new crop) to a ranch, one selects the appropriate field, and enters crop information, such as the crop type, planting/harvest dates, planted acres, bed spacing, and irrigation system characteristics. The planting “home” screen displays summary tables of soil tests, fertilizer applications, and watering schedules. When the user enters intended dates to fertilize and/or irrigate, the summary tables are updated with recommended fertilizer N rates (Table 1) and water volumes (Table 2). Data in tables can be exported into an excel spreadsheet file.

Plantings

Showing ALL Plantings

Planting	Wet Date	Harvest Date	Lot	Action
FREP Ambient N Lettuce II 110%	8/14/2013	10/31/2013	4N	View / View Details / Edit
FREP Ambient N Lettuce II 150%	8/14/2013	10/31/2013	4N	View / View Details / Edit
Broccoli 5N CSUMB	7/25/2013	11/1/2013	5N	View / View Details / Edit
broccoli 5N GRW	7/25/2013	11/1/2013	5N	View / View Details / Edit
Broccoli 5N UCCE	7/25/2013	11/1/2013	5N	View / View Details / Edit
Nitrification Inhibitor	6/14/2013	8/15/2013	5N	View / View Details / Edit
Dought II low	8/1/2013	10/10/2013	6N	View / View Details / Edit
Drought II high	8/1/2013	10/10/2013	6N	View / View Details / Edit

Figure 1. Planting list in CropManage for a ranch

Soil Summary

Show / Hide Columns

Sample Date	Sample Reading (ppm)	Crop Stage	Sample Depth (ft)	Sample Analysis	Soil Nitrate-N (ppm)	Soil Mineral N (lb/acre)
6/16/13	25	Pre-thinning	1	Quick Nitrate Strip	10.42	45.23
6/20/13	30	1st sidedress	1	Quick Nitrate Strip	12.50	54.27
6/28/13	35	2nd sidedress	1	Quick Nitrate Strip	14.58	63.32

New Soil Sample View all Nutrients First Previous 1 Next Last Show 5 Rows

Fertilizer Summary

Show / Hide Columns

Fertilizer Date	Soil NO_3-N (ppm)	Crop Stage	Fertilizer N Recommended (lb N/acre)	Cumulative N Uptake	Fertilizer	Applied N (lb N/acre)	Applied Fertilizer
6/22/13	12.50	1st sidedress	27.3	0.99	UAN28	29.8	10.0 gal/acre
7/5/13	14.58	2nd sidedress	41.0	5.44	UAN28	41.8	14.0 gal/acre
Totals			68.3			71.6	

New Fertilizing First Previous 1 Next Last Show 5 Rows

Figure 2. Fertilization and soil summary tables displayed in CropManage.

Irrigation Summary

Show / Hide Columns | Reset Column Order | Show Previous Columns | Show Next Columns

Water Date	Irrigation Method	Recommended Irrigation Interval (days)	Recommended Irrigation Amount (inches)	Recommended Irrigation Time (hours)	Irrigation Water Applied (inches)	Kc	Canopy Cover (%)	Average Reference ET (inches/day)	Total Crop ET (inches)
6/4/13	Germination Sprinkler	N/A	N/A	N/A	0.75 in	0.00	0	0.00	0.00
6/5/13	Germination Sprinkler	1.6	0.22 in	0.72 hrs	0.45 in	1.00	0	0.14	0.14
6/7/13	Germination Sprinkler	1.9	0.36 in	1.18 hrs	0.30 in	0.70	0	0.17	0.23
6/9/13	Germination Sprinkler	1.7	0.39 in	1.29 hrs	0.45 in	0.70	0	0.18	0.25
6/12/13	Sprinkler	3.1	0.28 in	0.95 hrs	0.30 in	0.48	1	0.15	0.21
6/16/13	Sprinkler	2.9	0.40 in	1.33 hrs	0.45 in	0.37	1	0.20	0.30
Totals			1.64 in	5.47 hrs	2.70 in				1.13 in

New Watering | View Rainfall Data | First Previous 1 Next Last | Show All Rows

Figure 3. Irrigation summary table displayed in CropManage.

Nitrogen and Water Management Algorithms

In addition to storing and sharing records of soil tests, irrigations, and fertilizations, the software algorithms recommend N fertilizer rates and water applications appropriate for the development stage of crop. The N fertilizer algorithm develops recommendations based on an N uptake curve for the crop, soil mineral N status (soil nitrate quick test data), as well as estimates of N mineralization contributed from the residue of the previous crop, and soil. The user must enter a fertilization date, a soil N test value, and an estimate of days until the next fertilization event. Future work will account for nitrogen concentration in the irrigation water in developing the N fertilizer recommendation. The crop N uptake curve follows a sigmoidal shape as shown in Fig. 4:

$$\text{N uptake (lbs/acre)} = M \times Nmax/(1+\exp[\,(-(day/Maxday)-Yo)/b]\,) \qquad (1)$$

Where *Nmax* is the maximum amount of N (lbs/acre) that the crop takes up by harvest, *b, M,* and *Yo* are fitted parameters, *day* is the number of days after planting and *Maxday* is the total days between planting and harvest. Parameters for this model have been determined for iceberg and romaine lettuce types grown on 40 and 80-inch wide beds by collecting weekly biomass samples which were analyzed for total N content (Table 1).

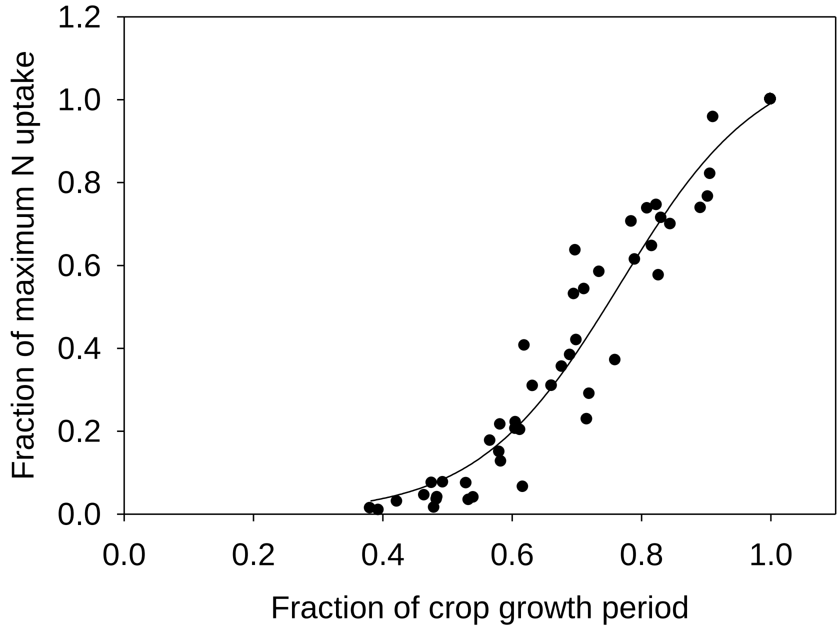

Figure 4. N uptake pattern of iceberg lettuce grown on 40-inch wide beds normalized for maximum N at harvest and number of days in crop cycle.

Table 1. Parameters for N uptake algorithm (eqn. 1) for various lettuce types and planting configurations.

Bed width	Lettuce type	Plant rows per bed	Number of sites	model coefficients Nmax	M	b	Yo	R^2
inches				lbs N/acre				
40	Iceberg	2	15	130	1.109	0.110	0.767	0.96
80	Iceberg	5 or 6	6	150	1.017	0.075	0.719	0.98
40	Romaine	2	6	120	1.202	0.110	0.828	0.99
80	Romaine	5 or 6	4	145	1.116	0.114	0.763	0.94

The irrigation scheduling algorithm uses CIMIS reference ET data, crop coefficient values for lettuce, soil water holding capacity, and the application rate of the irrigation system to estimate the appropriate irrigation interval and volume of water to apply to maximize lettuce growth and minimize deep percolation. The algorithm is based on the canopy model of Gallardo et. al. (1996) for estimating evapotranspiration of lettuce:

$$\text{Canopy cover (\%)} = \text{Gmax}/(1 + \exp(A + B\times\text{day}/\text{Maxday}) \qquad (2)$$

where *Gmax* is the maximum canopy cover, *A* and *B* are fitted parameters, and *day* and *Maxday* are as described for eqn. 1. Parameters for this model were determined for iceberg and romaine lettuce types grown on 40 and 80-inch wide beds by taking overhead near-infra red canopy photos at 10 to 15 day intervals during the crop cycle (Table 2).

Canopy cover is converted to a crop coefficient (Kc) by a modified version of the equation published by Gallardo et al. (1996):

$$Kc = (0.63+1.5\,C - 0.0039C^2)/100 \qquad (3)$$

where Kc is the crop coefficient, ranging between 0 and 1.0, and C is percent canopy cover. Evaporation from the soil surface is also estimated by the method described by Gallardo et al. (1996) and used to develop the final Kc value used for estimating crop ET.

Table 2. Parameters for canopy cover algorithm (eqn. 2) for various lettuce types and planting configurations.

Bed width	Lettuce Type	plant rows per bed	number of sites	model coefficients			
				Gmax	A	B	R^2
inches				% cover			
40	Iceberg	2	7	83	6.78	-11.61	0.77
80	Iceberg	5	2	92	6.83	-12.77	0.93
80	Iceberg	6	2	89	8.23	-14.11	0.97
40	Romaine	2	2	85	3.88	-7.68	0.94
80	Romaine	5	3	86	7.07	-10.73	0.96
80	Romaine	6	7	82	7.06	-10.95	0.94

To obtain a recommended irrigation volume and interval, the user enters the irrigation date of the next irrigation and the software automatically obtains reference ET data from the nearest CIMIS weather station and uses the algorithms described above to estimate the crop coefficient.

Additions to the second version of the software permit the user to choose between spatial CIMIS reference ET data or reference data from the nearest CIMIS station. Spatial CIMIS data would presumably increase the accuracy of crop ET estimates for fields located in a different climatic zone than the closest CIMIS station.

Irrigation Interval Algorithms

Maximum soil moisture tensions, which can be set by the user, are used to optimize the recommended irrigation interval. An algorithm relating volumetric soil moisture to soil moisture tension from soil texture data was developed to determine the maximum allowable depletion between irrigations. The algorithm also considers crop rooting depth and rainfall. A rooting depth algorithm was developed to estimate the effective root zone of lettuce at various stages of development. An algorithm was also developed to relate volumetric soil moisture to soil moisture tension using texture and bulk density data using soil undisturbed cores collected from commercial vegetable fields in the Salinas Valley. The modeled relationship is presented in Fig. 5 for a 60% sand, 30% silt soil. Parameters were determined by measuring rooting depth of lettuce grown in commercial fields at weekly intervals. An algorithm was developed to determine the appropriate irrigation schedule from estimates of crop rooting depth, soil water holding capacity, crop evapotranspiration, rainfall, and characteristics of the irrigation system.

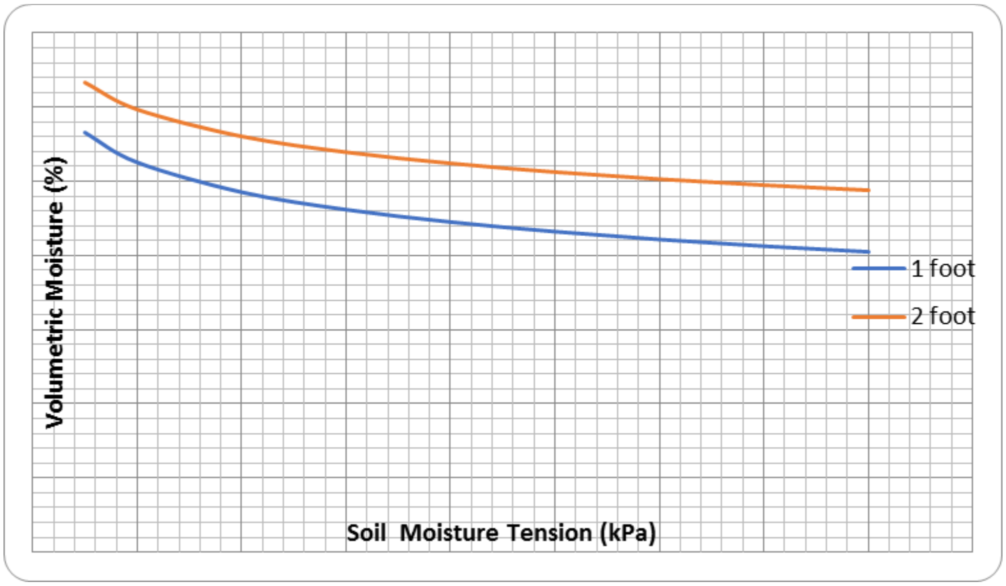

Figure 5. Example of estimated relationship between volumetric moisture and soil moisture tension for a soil with 60% sand, 30% silt texture, and bulk density of 1.3 g/cc.

Sub-task 1.5: Importing external data

Importing CIMIS data

ANR communications programmers developed a module automating importation of CIMIS reference ET and rainfall data into a database. The module can be setup to ignore rainfall information from specific CIMIS stations if the data appear faulty and use rainfall data from an alternate station. In addition, we added an option to import reference ET data from Spatial CIMIS into CropManage. Spatial CIMIS data is a useful option for attain ET data when no CIMIS weather station is located near a grower's ranch. Using the latitude and longitude of a ranch, Spatial CIMIS estimates reference ET data using satellite imagery of net radiation, and air temperature, relative humidity and windspeed data from the closest CIMIS stations. A function within CropManage allows a user to determine the latitude and longitude coordinates of the ranch of interest.

Importing Flowmeter data

CM has the option of automatically importing, analyzing, and displaying external data from a flow meter (Fig. 6), allowing growers to conveniently track the volume of water applied to their fields. Flow meters capable of producing a voltage pulse output proportional to the flow rate are interfaced with a datalogger that records flow at 2 minute intervals. The dataloggers are equipped with internet accessible cell phones, which permit flow data to be downloaded onto a computer in the Monterey County, Cooperative Extension office. The ANR server in Davis is scheduled to upload and analyze flow meter data files from the county computer at hourly intervals.

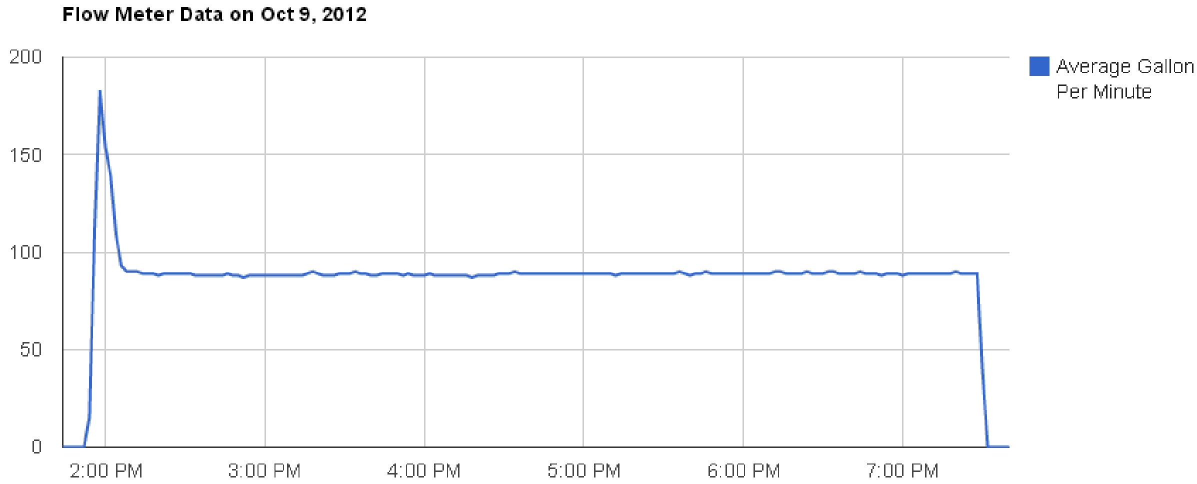

Figure 6. Flow meter data for individual plantings can be viewed on CropManage.

Sub-task 1.2: Grower Oversight

We established an advisory group of 5 major vegetable growers that are guiding the user-interface development and also beta-testing initial versions of the web application. Examples of some of the suggestions from the advisory group were:

1. Disclose UC policy on privacy of data to new users.
2. Ranch administrator should determine level at which a user can access to ranch data (read vs editing
3. Allow user to customize fertilizer list
4. Let user toggle units for entering volumes of applied water (inches, hours, gallons)
5. Let user toggle units for entering the amount of fertilizer applied (gallons, pounds/acre)
6. Improve procedures for new users to establish logins
7. Add totals at the bottom columns in the tables when appropriate
8. Allow user to enter soil test results for multiple depths.
9. Speed up loading of the tables
10. Add calculator to estimate application rate of drip and sprinkler irrigation systems
11. Improve readability of irrigation table
12. Improve procedures for adding new ranches
13. Add additional planting configurations for lettuce (42- inch wide beds)
14. Add additional vegetable crops and strawberries.
15. Allow importing of quick nitrate data for multiple fields.

We have incorporated recommendations 1-12 into the latest version of the software. Recommendations 13-14 will be accomplished when we secure additional funding.

Sub-task: 1.6 (completed February, 2014)

Interm reports were published in the 2011, 2012, and 2013 FREP conference proceedings (Cahn et al. 2011, 2012). Annual reports were submitted to FREP in 2012 and 2013. We are summary accomplishments for years 1-3 with the submission of the 2014 annual report.

Task 2. Field evaluate irrigation and nitrogen management software (completed October 2013)

Sub-task 2.1. Cooperate with a core group of growers to evaluate the irrigation and nitrogen fertilizer recommendations of software on 4 to 5 lettuce fields.

Sub-task 2.2. Interview growers and farm managers and incorporate feedback into final version.

Sub-task 2.3 Conduct strip trials comparing applied water, N fertilizer and yield between grower treatment and treatment following software

Sub-task 2.4. Report to FREP

Sub-task 2.1: Grower evaluation(completed October, 2013)

We cooperated with 6 grower/farm managers to evaluate the irrigation and N fertilizer recommendations of CropManage in a total of 10 commercial lettuce fields during the 2012 season and an additional 3 fields during the 2013 season. At each field we installed a flow meter that was interfaced with a datalogger and cell phone to record irrigation events. Either the grower or a UC staff researcher collected soil samples that were evaluated for mineral N using the quick nitrate test before fertilizer events. Growers followed their normal irrigation and fertilizer practices during the evaluations but reviewed the recommendations of CropManage. In addition, our staff and collaborating researchers used CropManage for scheduling irrigations and N fertilizer applications for 6 lettuce trials conducted at the USDA-ARS Spence research farm during the 2012 season. Their daily use of CropManage allowed us to identify and correct performance shortfalls.

Sub-task 2.2: Incorporate feedback into final version (completed October, 2013).

We have interviewed 6 grower/farm managers and 1 crop consultant on the software performance. Topics addressed included ease of use, response speed, and usefulness of decision support recommendations. We received the following feedback and recommendations for the software performance:

1. Add totals at the bottom columns in the tables when appropriate
2. Speed up loading of the tables
3. Tables load slowest when using Spatial CIMIS
4. Irrigation tables are complicated to read when too many irrigation events are included.
5. Add text messaging/emailing capabilities to send out automated notices about specific fields.

We received the following feedback and recommendations on the usefulness of the decision support:

1. Irrigation recommendations seem too low during the germination and establishment phase of the crop (weeks 0 – 3).
2. Fertilizer N recommendations seemed high in the late stages of the crop growth (weeks 5-8) and low at the early stage of growth (thinning).
3. Set a minimum and maximum N fertilizer recommendation (eg 10 lbs N/acre = minimum application rate, eg. 50 lbs N/acre = maximum rate)
4. Incorporate the contribution of N from the irrigation water into the N fertilizer recommendation.
5. Add a function to determine the appropriate leaching fraction for the salinity of the irrigation water.

We have incorporated recommendations 1-3 into the most recent version of the software. Recommendations 4-5 will require additional research and evaluation. A recent grant from FREP should allow us to determine an appropriate algorithm to estimate fertilizer N value contributed from ambient levels of nitrate in irrigation water.

<u>Sub-task 2.3: Conduct field trials in commercial fields (Completed October 2013)</u>
We conducted 6, large-scale, non-replicated trials in commercial fields comparing yield of lettuce grown under grower standard and CM recommended water and/or nitrogen management during the post-thinning phase of the crop. All crops were drip irrigated after thinning. Yield measurements were made using commercial harvesters. Approximately 33% less N fertilizer (57 lb N/Acre) was applied under the CM regime compared to the grower standard practice in 5 trials where N was managed differently among treatments (Table 3). Approximately 23% less water was applied under the CM treatment during the drip phase of the crop in trial 3, but 21% more water was applied under the CM treatment during the drip phase of trial 6, presumably because the grower standard practice was under applying water. Differences in yields between treatments for the 6 trials averaged were less than 4.5% (Table 3). The CM treatment was 2% lower than the grower standard at 2 of the trials but exceeded the grower standard at the remaining 4 trials. The CM treatment yielded almost 18% higher than the grower standard treatment at trial 6, where more water was applied under the CM irrigation regime, but N fertilizer applications were reduced by 50% compared to the standard treatment during the drip phase of the crop.

In addition to the non-replicated trials, we conducted 2 replicated trials at the USDA-ARS Spence research farm in Salinas CA to further evaluate the accuracy of the water recommendations of CropManage (Johnson et al. 2012, 2013). These trials, funded by a CDFA Specialty crop block grant, demonstrated that similar yields could be attained under the CropManage recommendations compared to the standard grower practice, using 30% to 40% less water (data not presented).

Table 3. Applied nitrogen fertilizer and water, and yield results for lettuce strip trials.

Strip Trial #	Management treatment	Applied water (post-thinning)	Fertilizer N	Final soil nitrate-N	Marketable Yield	Yield difference between treatments
		inches	lbs/acre	ppm NO_3-N	lbs/acre	%
			----------------------- iceberg cored 9/5/12 ---------------------------			
1	Grower	9.8	183	--	64307	
	CropManage	9.8	143	17.7	65713	2.2
			----------------------- romaine cored 10/17/12 -----------------------			
2	Grower	4.9	211	95.2	19114	
	CropManage	4.9	149	71.4	18760	-1.9
			----------------------- romaine cored 10/20/12 -----------------------			
3	Grower	4.9	177	26.3	17935	
	CropManage	3.8	177	26.3	18389	2.5
			----------------------- romaine cored 9/24/13 ------------------------			
4	Grower	7.6	263	87.5	15946	
	CropManage	7.6	162	22.5	15644	-1.9
			----------------------- romaine cored 9/19/13 ------------------------			
5	Grower	4.1	96	41.7	24903	
	CropManage	4.1	71	41.7	27035	8.6
			----------------------- iceberg cartons 10/18/13 -----------------------			
6	Grower	3.9	124	62.5	32765	
	CropManage	4.7	62	21.0	38434	17.3
			------------------------------ Average ----------------------------------			
	Grower	4.4[x]	175[y]	71.7[y]	29162	
	CropManage	4.2	118	34.9	30662	4.5

[x] Average of trials 3 and 6

[y] Average of trials 1,2,4,5,and 6

Sub-task 2.4: Report to FREP (completed February 2014)
Interm reports were published in the 2011, 2012, and 2013 FREP conference proceedings (Cahn et al. 2011, 2012). Annual reports were submitted to FREP in 2012 and 2013. We are summary accomplishments for years 1-3 with the submission of the 2014 annual report.

Task 3. Conduct educational trainings and develop a user guide for the software (will be completed by June 30, 2014)

Task 3 and subtasks listed below are more than completed. This task should be completed by June 2014.
Sub-task 3.1. Write user guide for irrigation and nutrient management software.
Sub-task 3.2. Conduct workshops to train participants on using the irrigation and nitrogen management software.
Sub-task 3.3. Conduct individual trainings on using irrigation and nitrogen management software.
Sub-task 3.4. Report to FREP

Sub-task 3.1: Write user guide (complete).
We have developed a CropManage blog (http://ucanr.edu/blogs/CropManage/) that provides help and guidance on using cropmanage, information on the soil nitrate quick test and weather-based irrigation scheduling, and a forum to present new information and updates about the software. A help link from CropManage connects the user to specific topics on using the software application. Examples of the help articles include "exporting data (http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=12414)", and "adding plantings to a ranch (http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=11516)." We intend to continue adding to the help menu with more in depth instructions on using the software.

Sub-task 3.2: Conduct a workshops (completed May 2013).
We conducted 4 workshops to train participants on using Cropmanage during December, 2011, and February, March and April of 2013. A total of 62 people participated in the workshops. These were workshops were intentionally designed for small groups so that participants could followed the instructions using their own laptop or tablet computer.

Sub-task 3.3: Conduct individual (completed October 2013).
We have conducted more than 10 individual trainings on using the software with participating growers and interested clientele.

Sub-task 3.4: Report to FREP (completed February 2014).
Interm reports were published in the 2011, 2012, and 2013 FREP conference proceedings (Cahn et al. 2011, 2012). Annual reports were submitted to FREP in 2012 and 2013. We summarized accomplishments for years 1-3 with the submission of the 2014 annual report.

Table 4. Hands-on training workshops for CropManage.

Date	Meeting name	Presentation Topic	Sponsors/ Co-Sponsors	Location	Attendance
12/1/2011	CropManage Workshop	Hands-on training with CropManage	UCCE	Salinas CA	12
2/26/2013	CropManage Workshop	Hands-on training with CropManage	UCCE	Salinas CA	19
3/13/2013	CropManage Workshop	Hands-on training with CropManage	UCCE	Salinas CA	15
4/2/2013	CropManage Workshop	Hands-on training with CropManage	UCCE	Salinas CA	16
Total					62

G. Conclusions

We have successfully completed all of the proposed tasks of the project which resulted in an online tool for assisting with irrigation and nitrogen of lettuce, now referred to as "CropManage." Accuracy of the software algorithms was evaluated during years 2 and 3 of the project. In addition to initial group of growers and crop consultants evaluating the performance of CropManage, more than 1000 users have established logins to access the web application. Their use of CropManage has also generated feedback for improving the application. Demand for presentations on the software and positive feedback from growers exceeded expectations with m more than 25 presentations and 4 hands-on workshops were completed from 2011-2013. A consistent comment from growers and crop consultants has been that the software should be expanded to include additional crops such as strawberry, caneberry, and other cool season vegetables. UC farm advisors in other regions of the state have also expressed interest in expanding the online software application to agronomic, row, and tree crops.

H. Project Impacts

This project resulted in the development of CropManage, an online nutrient and irrigation management decision support tool that provides growers and crop consultants with custom recommendations for fertilizer N and irrigation water. Since the release of this online tool, there has been more than 10,000 logins into CropManage by more than 900 registered users. Users have received more than 6000 fertilizer recommendations and more than 20,000 irrigation recommendations. Usage of CropManage has steadily increased since 2011 to more than 1000 recommendations per month during the peak season in May and June (Fig. 7).

We recognize that CropManage, which was developed originally for lettuce, can be adapted for other crops, including processing tomatoes, almonds, and alfalfa, thereby having further impacts on the management of water and nutrients in California.

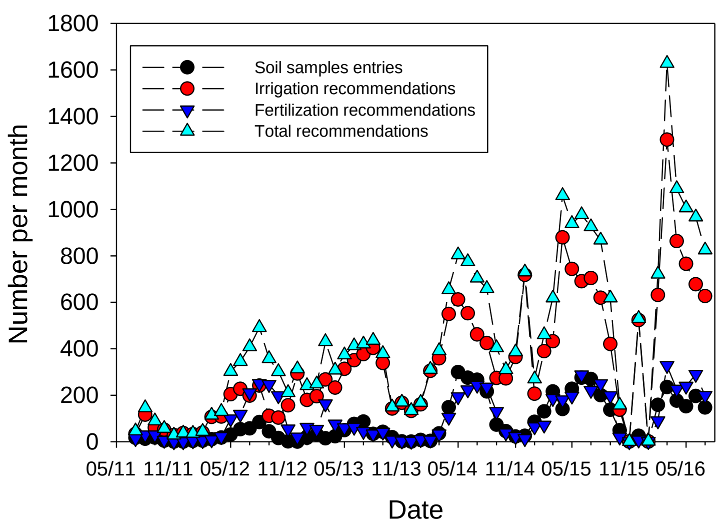

Figure 7. Monthly recommendations and soil sample entries in the CropManage database

I. Outreach Activities Summary

More than 25 presentations were made during the project to provide an overview of the irrigation and nitrogen management web-based software (Tables 5A and 5B). In total, 1344 participants attended these presentations. Additionally, 4 hand-on training workshops were conducted which had a total of 62 participants. Presentations were made about CM at 4 professional meetings (Cahn et al. 2013a, 2013b, 2013c, 2013d) and 2 FREP conferences. Articles in popular press and the ANR blog have also informed growers and industry reps about the CropManage online tool.

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CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM

Final Report

A. Project Title: Irrigation and Nitrogen Management Web-based Software for Lettuce Production (Phase 2)

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B. Objectives

The overall goal of phase 2 of this project was to demonstrate how to efficiently manage nitrogen fertilizer and irrigation water for the production of cool season vegetables using CropManage (CM), an online decision support tool. Specific objectives are:

1. Assist growers, consultants and industry representatives to implement CM on commercial vegetable operations.
2. Evaluate improvements in nitrogen and water use efficiency of cool season vegetables using the CM decision support tool.

C. Abstract:

Vegetable growers in California are under increased regulatory pressure to use nutrients and water more efficiently. This project promotes the use of two tools available to farmers for improving nitrogen and water use efficiency: 1. the soil nitrate quick test (SNQT) for monitoring soil mineral nitrogen levels and 2. Weather-based irrigation scheduling for estimating water needs of crops. We developed the web-based software application, CropManage (CM) (cropmanage.ucanr.edu), to facilitate the implementation of both tools for production of cool season vegetables. We conducted demonstrations of the CropManage tool in commercially harvested lettuce fields in the

Salinas and Imperial Valleys during 2014 and 2015. These trials provided base-line data on standard practices used by the participating growers and identified opportunities to improve water and N management. The trials continued during midseason 2014 and 2015 with the expectation that growers would use CropManage for decision support to assist with managing N and water in the production of their crops. The 2 growers participating in the project in the Salinas Valley reduced N applications to their lettuce crops by an average of 38% compared to their standard N rate. Water use was reduced by 7% compared to the amounts applied in 2014. Additionally, we conducted workshops to cross-train growers, consultants, agency personnel, and personnel from commercial companies on how to use CropManage for decision support on fertilizer and water management.

D. Introduction:

Vegetable growers on the central coast of California are under regulatory pressure to reduce nitrate loading to ground water supplies. Additionally, over pumping of ground water for agricultural production has contributed to seawater intrusion into coastal aquifers, which may be accelerated during the current drought. Two tools available to farmers for improving nitrogen and water use efficiency are the soil nitrate quick test (SNQT) (Hartz et al. 2000) for monitoring soil mineral nitrogen levels and weather-based irrigation scheduling for estimating water needs of crops (Cahn and Smith, 2012, Johnson et al. 2013). Under a previously awarded CDFA FREP grant we developed the web-based software application, CropManage (CM) (cropmanage.ucanr.edu), to facilitate the implementation of both tools for lettuce, and subsequently through additional CDFA-FREP funding, for cole crops and leafy greens (Cahn and Hartz, 2012, Cahn et al. 2013a, 2013b, 2013c, 2014d). Users can access the software through a web browser on their smart phones, tablet and desktop computers. The software allows growers to quickly determine a fertilizer N rate based on the SNQT and N uptake curves for cool season vegetables. In addition, the software estimates the water requirement of the crop using evapotranspiration data from the California Irrigation Management Information System (CIMIS) and models of canopy development. Preliminary field testing of the software in commercial fields indicated that growers can significantly reduce N fertilizer and water use without reducing crop quality and yield. Large-scale field trials comparing the CM fertilizer N recommendation with grower standard practices resulted in similar yields using an average of 32% less N fertilizer. Replicated trials resulted in a 25% to 40% savings in water by following the irrigation schedule of the online tool compared to the grower standard practice, and equal commercial yields between treatments (Johnson et al. 2013).

Since CM was first developed in 2011, the decision support tool has more than 900 registered users and more than 500 registered ranches. Some of these users represent large vegetable and berry farming companies on the central coast who are interested to adapt CM practices for their operations. Despite recognition by these growers that CM can help them efficiently use nitrogen fertilizer and water for their crops, they have been challenged to integrate the CM tool into their daily farming practices. Many growing operations needed to hire and train new personnel to sample fields and to test soil nitrate levels before applying fertilizer, and to record and to monitor irrigation applications, as well as to oversee the input of data into CM. Growers have also invested in tools such as soil moisture sensors and flow meters, to verify that changes made in their management are not risking yield and quality of their crops.

This project proposes to support efforts of growers and the agriculture industry representatives to implement CropManage into commercial farming operations by providing training, and for monitoring that changes in management improve the efficiency of nitrogen and water management while sustaining yield and quality of crops. Our approach will be to work with growers currently implementing CM into their farming operations, and provide one-on-one consulting and small group training. We will also provide field support for monitoring commercial fields and to document improvements in management. Finally, we will provide cross-training to consultants, agency personnel, and commercial companies interested in building capacity to help growers integrate CM practices into their operations.

E. Work Description

Task 1. Identify participating growers and provide trainings on CM to Agricultural Industry (Year 1)

In collaboration with major vegetable shipping operations (eg. Dole, FreshExpress, Taylor Farms) we identified 2 growers that were implementing best management practices (BMPs) for nitrogen and water in their farming operations using CM. We provided training for personnel who participated in the project including, grower operators, farm managers, farm management staff, and associated consultants. Additionally, we provided general training on CM through a hands-on workshop during the spring of 2015. Details of the workshop are provided in Task 5. This task was completed by April 15, 2015.

Task 2. Establish field sites for monitoring grower standard practices for managing water and nitrogen management (Year 1).

This task is completed. We identified 6 commercial lettuce fields to monitor in 2014 (Fig. 8) and 1 field in 2015. Each field was equipped with a flowmeter (Fig. 9) for recording applied water volumes and sensors for monitoring soil moisture (Fig. 10). Data were automatically updated in CM using cell phone and radio modem communications. Fields were evaluated for residual soil nitrogen at planting, before each fertilizer N application, and after harvest. All collected information was maintained using the online CM decision support tool. Biomass was sampled near harvest to estimate total N uptake of the crop. Participating growers provided commercial yield data for the fields. Opportunities to improve management were identified by comparing the amount of N fertilizer and water applied to the CM recommended amounts. These first sets of fields also provided an opportunity to train and coach staff of participating farming operations so that they could develop skills for better managing nitrogen and water, and learn to effectively use the CM as a decision support tool. This task was completed by November 2014.

Task 3. Establish field sites to evaluate management of water and nitrogen fertilizer following CM recommendations (Years 1 and 2).

This task was completed. Participating growers identified 2 to 3 vegetable fields of the same commodity (either lettuce, broccoli, cabbage, or cauliflower) for evaluating CM recommendations for nitrogen and water applications. One grower identified 3 fields to follow CropManage recommendations in iceberg lettuce in 2014. The same grower identified 3 additional lettuce fields in 2015, with the purpose of also comparing water use among drip, furrow, and sprinkler irrigation. An additional grower used CM to improve water and N use of 2 iceberg lettuce fields during the 2015 season. The same procedures were followed in Task 2, with the exception that the CM recommendations for nitrogen fertilizer and water were followed as closely as the grower could practically accomplish. In cases where the grower was not comfortable with managing the entire field following the CM recommendations, a strip of the field was managed following the CM recommendations. Applied water, N fertilizer, and residual soil nitrate data were maintained using the online CM decision support tool. Biomass was sampled near harvest to estimate total N uptake of the crop and the grower will provide commercial yield data. Results were compared with the recommended values to estimate the improved efficiency for nitrogen and water management. This task was completed by November 2015.

Task 4. Introduce CM for winter vegetable producers in Imperial County (Years 1 and 2). This task was completed. We provided support to a vegetable grower in Imperial County interested in evaluating CM in a lettuce field during the 2014-2015 winter. Procedures in task 2 were followed to determine the current water and N management practices and to identify opportunities to improve management. All data were collected and stored using the CM on-line tool. We also conducted a hands-on workshop to introduce growers in Imperial County to CM for winter lettuce and broccoli production (refer to Task 5 for details of the workshop).

Task 5. Introduce CM to vegetable producers in Santa Barbara and Ventura Counties (Year 2)

This task was completed. In collaboration with local Farm advisors we conducted hands-on workshops in Santa Barbara and Ventura Counties to introduce growers to using CM for lettuce, strawberry, and Cole crop production (Table 5). Workshops provided background on the purpose of the CM online software and hands-on training on how to set up a ranch or farm on the software tool and determine irrigation and nitrogen fertilization recommendations. In addition, participants learned about the rationale of the recommendations and how to integrate CM into their growing operations.

Task 6. Report on project results (Years 1 and 2).

This task is completed. We submitted interim and interpretive summaries in 2014 and 2015. With this report, we will have completed the second annual report to FREP. Results will be summarized and extended in newsletters, trade journal articles, and at educational meetings such as the annual UCCE Irrigation and Nutrient Management Meeting held in Salinas, CA.

F. Results

Salinas Valley demonstrations

Two growers were identified who were interested to implement CM decision support for their vegetable farming operations (Fig. 8) in the Salinas Valley. Each growing operation annually farms between 1500 and 3000 acres of vegetables. Growers selected 3 lettuce fields for monitoring current nitrogen and water management practices in 2014 (Table 5). Fields were equipped with a flowmeter for recording applied water volumes and sensors for monitoring soil moisture (Figs. 9 and 10). Data were automatically updated in CM using cell phone and radio modem communications. Soil was evaluated for mineral nitrogen at planting, before each fertilizer N application, and after harvest. All collected information was maintained using the online CM decision support tool. Biomass was sampled near harvest to estimate total N uptake of the crop. Marketable yield data was also collected for each field using commercial harvesting equipment.

Opportunities to improve management were identified by comparing the amounts of N fertilizer and water applied by the grower with the CM recommended amounts. An N budget for each crop was estimated from the initial and final soil nitrate concentrations in the 1 and 2 foot depths and measured N in biomass near harvest.

Baseline N use: Average applied N was 266 lbs/acre for the base-line fields monitored in Monterey and Imperial Counties in 2014 (Table 7). The average amount applied in the fields monitored in Monterey County was 272 lbs N/acre. Grower 1 applied an average of 320 lbs. N/acre to his 3 fields, which was close to his standard rate of 307 lbs. N/acre. Grower 2 applied an average of 223 lbs. N/acre. However, he stated that his standard rate was 292 lbs. N/acre, and reduced his standard rate of fertilizer N in the fields that we monitored. Average crop uptake of N was 154 lbs. N/acre in all the baseline fields monitored in 2014. Average crop N uptake (106 lbs. N/acre) was lowest in Grower 2 fields, where 40-inch wide beds were used.

Reducing N use: Cooperating Growers 1 and 2 identified a total of 8 lettuce fields in the Salinas Valley (Monterey County) during the late summer of 2014 and the 2015 season where they wanted to experiment with reducing N fertilizer rates using CropManage guidelines which are based on the soil nitrate quick test and improved water management (Table 6). The participating growers were able to reduce fertilizer N by an average of 104 lbs N/acre, or a 38% reduction compared to their average baseline N rate. Grower 1 reduce N use by 23% or 73 lbs N/acre. Grower 2 was able to reduce N fertilizer rates by an average of 37% or 82 lbs N/acre compared to his standard rate used in 2014, and by 51% compared to his stated standard rate of 292 lbs N/acre. Both growers stated that they also reduced fertilizer rates in their other lettuce fields. For example, Grower 1 used CropManage for decision support in managing N on approximately 2700 acres of iceberg lettuce during 2015 and was able to reduce N rates by an average of 73 lbs N/acre. Neither grower reported yield losses due to changes in management of N fertilizer and water.

Crop N uptake: Average crop uptake of N was 124 lbs N/acre in the fields evaluated under the CM regime (Table 8). The lower crop N uptake measured under CropManage was likely due to the inclusion of more 2 row, 40-inch wide bed fields than during the baseline evaluations. Based on soil mineral N levels and estimates of crop N uptake, the average amount of N fertilizer recommended for Growers 1 and 2 under the CropManage regime was 116 lbs N/acre (Table 8), Hence, both Growers could have potentially reduced N applications by additional amounts.

Water use: Although the 2 participating Growers made significant reductions in N fertilizer applications, less progress was made in reducing water applications. The average amount of water reduced between the base-line evaluations and following the CM recommendations was less than 1.3 inches, or a 7% reduction. In comparison to crop water requirement, average water applied was reduced from 177% to 161% of crop ET, suggesting that a significant amount of water likely percolated below the root zone and contributed to N losses. Grower 2 made the most progress in reducing water use, reducing applied water from 182% of crop ET under the baseline monitoring to 151% under the CM regime (Tables 7 and 8).

Imperial County demonstration

Grower 3 farms a ranch located near Bard CA, in Imperial County, and participated in a demonstration trial with CropManage to become familiar with the online decision support tool and to understand his baseline use of water and N fertilizer (Tables 5). Iceberg lettuce was planted in 3 rows on 42-inch wide beds in late October, 2014. The crop was germinated with sprinkler and later irrigated by furrow. All procedures used for demonstration fields in the Salinas Valley were followed in this field, including beginning and ending soil nitrate levels. Additionally, canopy cover was estimated using a multi-spectral camera because the crop was planted in a configuration that is different than in the Salinas Valley. The grower applied 233 lbs. N/acre and 13.1 inches of water during the season (Table 7). We determined that the grower applied a majority of the water during the sprinkler phase (9.5 inches) which greatly exceeded the water demand of the crop and likely leached a substantial portion of the residual soil nitrogen below the root zone.

Table 5. Field and crop summary of CropManage demonstrations monitoring grower standard practices.

Grower	Field	County	Soil Texture	Crop	Irrigation Method	Wet Date	Harvest Date
1	1	Monterey	loam	Iceberg 80 in, 6 row	Sprinkler/Drip	3/27/14	6/5/14
1	2	Monterey	v. f. sandy loam	Iceberg 80 in, 6 row	Sprinkler/Drip	4/11/14	6/20/14
1	3	Monterey	loam	Iceberg 80 in, 5 row	Sprinkler/Drip	6/8/14	8/11/14
2	4	Monterey	silty clay	Iceberg 40 in, 2 row	Sprinkler	4/14/14	6/25/14
2	5	Monterey	silt loam	Iceberg 40 in, 2 row	Sprinkler/Drip	4/18/2014	6/25/2014
2	6	Monterey	silty clay	Iceberg 40 in, 2 row	Sprinkler	4/24/14	7/3/14
3	7	Imperial	loam	Iceberg lettuce 42 in, 3 row	Sprinkler/furrow	10/23/14	1/31/15

Table 6. Field and crop summary of CropManage demonstrations following CM recommendations (growers 1 and 2).

Grower	Field	County	Soil Texture	Crop	Irrigation Method	Wet Date	Harvest Date
2	8	Monterey	clay loam	Iceberg 40 in, 2 row	Sprinkler/Drip	6/18/14	8/18/14
2	9	Monterey	silt loam	Iceberg 40 in, 2 row	Sprinkler/Furrow	6/25/14	8/30/14
2	10	Monterey	silt loam	Iceberg 40 in, 2 row	Sprinkler/Furrow	6/30/14	9/3/14
1	11	Monterey	loam	Iceberg 80 in, 6 row	Sprinkler/Drip	3/20/15	6/1/15
2	12	Monterey	clay loam	Iceberg 40-in, 2 row	Sprinkler/Drip	4/16/2015	6/29/2015
2	13	Monterey	clay loam	Iceberg 40-in, 2 row	Sprinkler/Furrow	4/24/2015	7/11/2015
2	14	Monterey	clay loam	Iceberg 40-in, 2 row	Sprinkler	4/30/2015	7/14/2015
1	15	Monterey	loam	Iceberg 80 in, 6 row	Sprinkler/Drip	6/28/15	8/27/15

Table 7. Applied and recommended amounts of water and nitrogen of demonstration trials monitoring grower standard practices.

Grower	Field	Applied Water	Recom. Water	Fertilizer N	Estimated Crop N uptake	CropManage Recom.	Initial Soil NO_3-N	Final Soil NO_3-N	Average Soil NO_3-N
		------ inches -------		------------- lbs/acre --------------			----------------- ppm -----------------		
1	1	14.4	8.6	361	206	151	50	48	27
1	2	14.7	7.8	243	214	164	30	29	20
1	3	14.0	8.6	355	188	99	21	31	25
2	4	--	--	193	130	145	--	--	18
2	5	20.1	11.0	250	85	53	29	26	20
2	6	26.9	14.9	227	103	147	132	26	27
3	7	13.1	8.0	233	150	179	24	24	14
Grower 1 avg		14.4	8.3	320	203	138	34	36	24
Grower 2 avg		23.5	12.9	223	106	115	80	26	22
Monterey Avg		18.0	10.2	272	154	126	52	32	23

Table 8. Applied and recommended amounts of water and nitrogen of demonstration trials following CM recommendations (Growers 1 and 2).

Grower	Field	Applied Water	Recom. Water	Fertilizer N	Estimated Crop N uptake	CropManage Recom.	Initial Soil NO_3-N	Final Soil NO_3-N	Average Soil NO_3-N
2	8	13.2	10.9	173	121	78	--	25	43
2	9	17.3	11.5	160	118	136	19	13	32
2	10	18.2	11.9	150	102	103	23	26	26
1	11	10.6	5.7	241	186	197	12	10	14
2	12	15.9	11.2	155	95	104	13	20	29
2	13	22.2	12.9	106	82	60	13	13	15
2	14	22.5	13.9	106	105	60	13	10	15
1	15	14.3	5.2	252	180	190	24	24	18
Grower 1 Avg		12.5	5.5	247	183	194	18	17	16
Grower 2 Avg		18.2	12.1	142	104	90	16	18	27
Monterey Avg		16.8	10.4	168	124	116	16	18	24

Survey of grower participants

We interviewed participating growers to identify ways to improve CM. Growers suggested ways to reduce time needed for entering information, improve the viewing results, and making CM more relevant to their crop production systems. Examples of these suggestions included: 1. adding furrow as an irrigation option, 2. displaying water use, fertilizer use, and soil nitrate values in the same table (currently they are displayed in separate tables), 3. Identifying the user who made a data entry for a planting. 4. Allowing multiple fertilizer entries on the same date, and 5. Providing different N recommendations for tractor applied fertilizer applications and fertigation applications. 6. Allow multiple ranch owners.

Another suggestion from participating growers was to add an *application protocol interface* (API) to CM so that other software can automatically upload data and/or export CM recommendations. Many large vegetable growing operations already use business software databases that track inputs used for growing crops for food safety, pesticide reporting, accounting, and other regulatory purposes. These operations provide tablet computers to their irrigators and foremen for recording fertilizer and irrigation applications. The API would permit these data entries to be uploaded directly into CM, allowing farm and production managers to focus on making fertilizer and irrigation decisions rather than data entry.

G. Conclusions

This project assisted 3 large vegetable growing operations to identify strategies to reduce N fertilizer inputs by minimizing losses due to leaching. Improving both water management and monitoring soil nitrate levels during the cropping cycles seem to be the best approach to using fertilizer N more efficiently. The online decision support tool, CropManage, was an efficient method to maintain records of fertilizer and water use patterns, and to quickly determine appropriate amounts of water and fertilizer to apply to their crops on a field-by-field basis. We incorporated many of the recommendations of the participating growers when the CropManage online program was updated between September 2015 and January 2016.

H. Impacts

This project helped 2 large scale vegetable growing operations in the Salinas Valley reduce the use of fertilizer N by an average of 38% without impacting commercial yield of lettuce. Participating growers applied practices learned from this project to more than 2700 acres in 2015. The project also resulted in 22 presentations and training on CropManage to more than 880 growers, crop consultants and industry reps. Use of the CropManage online software increased to more than 5000 water and fertilizer recommendations per year during 2014 and 2015.

I. Presentations and outreach

Growers participating in the demonstrations received continuing support on using the CM decision support tool either weekly or biweekly. We assisted these growers in navigating and learning to use CM as well as with interpreting recommendations.

Additionally, we presented on CM at various educational meetings, including at industry meetings, hands-on workshops, and academic/professional meetings (Table 9).

J. **Fact Sheet** (following pages)

Irrigation and Nitrogen Management Web-based Software for Lettuce Production

CDFA Grant Agreement Number 10-0013-SA

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Project period: 2014-2016.

Locations: Imperial, Monterey, and Ventura Counties

Highlights

- CropManage, an online decision support program, was developed for lettuce to assist growers in reducing nitrogen fertilizer and water applications.
- Growers participating in on-farm demonstrations were able to reduce N fertilizer rates in lettuce by an average of 38% compared to their standard practice.
- CropManage was widely extended to the agriculture industry through a total of 26 presentations and hands-on workshops, with approximately 882 participants.
- Parallel projects were funded by FREP to expand CropManage to additional vegetable commodities.

Introduction

Vegetable growers on the central coast of California are under regulatory pressure to reduce nitrate loading to ground water supplies. Additionally, over pumping of ground water for agricultural production has contributed to seawater intrusion into coastal aquifers, which may be accelerated during the current drought. Two tools available to

farmers for improving nitrogen and water use efficiency are the soil nitrate quick test (SNQT) for monitoring soil mineral nitrogen levels and weather-based irrigation scheduling for estimating water needs of crops.
Under a previously awarded CDFA FREP grant we developed the web-based software application, CropManage (CM) (cropmanage.ucanr.edu), to facilitate the implementation of both tools for lettuce, and subsequently through additional CDFA-FREP funding, for cole crops and leafy greens. Users can access the software through a web browser on their smart phones, tablet and desktop computers. The software allows growers to quickly determine a fertilizer N rate based on the SNQT and N uptake curves for cool season vegetables. In addition, the software estimates the water requirement of crops using evapotranspiration data from the California Irrigation Management Information System (CIMIS) and models of canopy development. Preliminary field testing of the software in commercial fields indicated that growers can significantly reduce N fertilizer and water use without reducing crop quality and yield.

Methods/Management

The first version of CropManage was developed by UCANR computer services staff during 2010 and 2011. During the following 2 years, the software was augmented to provide a better user interface and improve calculation speeds. Six on-farm trials were conducted in lettuce to validate the nitrogen and irrigation recommendation algorithms. We conducted demonstrations of the CropManage tool in commercially harvested lettuce fields in the Salinas and Imperial Valleys during 2014 and 2015. These trials provided base-line data on standard practices used by the participating growers and identified opportunities to improve water and N management We conducted 22 trainings/workshops on CropManage with growers, crop consultants, and industry representatives during 2014, 2015 and 2016.

Findings

The online CropManage decision support software assists growers in managing water and nitrogen fertilizer on a field-by-field basis. CropManage was also an effective method to maintain records of fertilizer and water use patterns. Both the demonstration and on-farm trials showed that growers can often reduce nitrogen fertilizer inputs by more than 30% without reducing yields. The second phase of the project assisted 3 large vegetable growing operations to identify strategies to reduce N fertilizer inputs and minimize N losses due to leaching. Improving both water management and monitoring soil nitrate levels seem to be the best approach to using fertilizer N more efficiently. Participating growers were able to reduce N fertilizer rates in lettuce by an average of 38% compared to their standard practice. These growers also applied these improvements in nitrogen management to their other commercial lettuce fields. Compared to management of fertilizer, participating growers were less successful in reducing water use. Reductions in applied water averaged about 7% compared to their base-line use. By continuing to work on improving water management these growers could potentially save additional nitrogen fertilizer.

K. Copy of the Product/Result

CropManage online nutrient management decision support software can be accessed at:
http://cropmanage.ucanr.edu

A copy of the powerpoint presentation for the CropManage Workshops is available for download from the UCCE Monterey website:
http://cemonterey.ucanr.edu/Custom_Program567/

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Table 9. Presentations and workshops on CropManage between 2014 and 2016.

Date	Event	Title	Meeting Sponsor	Location	Attendance
5/1/2014	CropManage Workshop	CropManage Hands-on Training	UCCE Monterey	Salinas CA	20
5/20/2014	Drought Talks	CropManage: On-line Decision Support Tool for Managing Water and Nitrogen of Vegetables	UC Water Resources Institute	Davis CA	online presentation
11/7/2014	Driscolls grower meeting	Using cropmanage for strawberry	Driscolls	Pajaro CA	14
11/10/2014	CropManage Workshop for Alfalfa	CropManage overview	UC Davis LAWR	Davis CA	28
12/4/2014	Washington small fruit conference	Precision irrigation and nutrient management of strawberry and canberries	Washington State University	Lynden WA	40
12/9/2014	Vegetable crop continuing conference	Update on CropManage: web-based irrigation and N management tool	UC Davis VRIC	Davis CA	45
1/8/2015	Sacramento Valley Processing Tomato Meeting	CropManage: an online tool for irrigation and fertilizer management	UCCE Yolo County	Woodland CA	50
3/5/2015	Western Nutrient Management Seminar	CropManage: an online decision support tool for irrigation and nutrient management	International plant nutrient institute	Reno NV	110
3/17/2015	Agronomic crop workgroup meeting	CropManage: an online decision support tool for irrigation and nutrient management	UC ANR	Davis CA	35
3/20/2015	Fresno County Vegetable crop seminar	CropManage: an online decision support tool for irrigation and nutrient management	UCCE Fresno	Westside CA	33
3/24/2015	Tree crop workgroup meeting	CropManage: an online decision support tool for irrigation and nutrient management	UC ANR	Davis CA	25
4/2/2015	CropManage Hands-on training workshop	Hands on training on using cropmanage	UCCE Monterey	Salinas CA	48
4/15/2015	CropManage Hands-on training workshop	Hands on training on using cropmanage	UCCE Imperial	Holtville CA	10
7/28/2015	CAPCA's Nutrient Management Seminar	CropManage: an online decision support tool for irrigation and nutrient management	CAPCA	Atascadero CA	60
7/31/2015	CropManage workshop	Hands on training on using cropmanage	UCCE Ventura/UCCE Monterey	Ventura CA	12
9/3/2015	INOVAGRI international irrigaiton conference	CropManage: an online irrigation and nitrogen management decision support tool	INOVAGRI	Fortaleza Brazil	70
9/24/2015	CropManage Hands-on training workshop	Hands on training on using cropmanage	UCCE San Luis Obispo	Santa Maria CA	13
11/16/2015	Sustainable Ag Expo	CropManage: an online approach to irrigating scheduling of row crops	Sustainable Vineyard Team	San Luis Obispo C/	45
12/8/2015	Helena Chemical Agronomy Meeting	CropManage: an online tool for irrigation and fertilizer management	Helena Chemical	Pismo Beach CA	45
1/26/2016	CropManage workshop	CropManage Hands-on Training	Pajaro Valley Water Management Agency	Watsonville CA	35
2/11/2016	San Benito Irrigation and nutrient meeting	CropManage: an online decision support tool for irrigation and nutrient management	San Benito Water Distict	Hollister CA	40
3/31/2016	CropManage workshop	CropManage Hands-on Training	UCCE Monterey	Salinas CA	40

Figure 8. Example of a commercial iceberg lettuce field included in the project during the 2015 season.

Figure 9. Water applications were automatically recorded using flow meters and uploaded to CropManage so that growers could compare their water management practices to recommendations based on crop evapotranspiration estimates.

Figure 10. Tensiometers readings were automatically recorded to a datalogger and uploaded to CropManage through radio and cell phone communications.