CROPMANAGE DECISION SUPPORT TOOL FOR IMPROVING IRRIGATION AND NUTRIENT EFFICIENCY OF COOL SEASON VEGETABLES IN CALIFORNIA: A DECADE OF FIELD DEMONSTRATIONS AND OUTREACH

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ABSTRACT

Vegetable growers on the central coast of California are under regulatory pressure to reduce nitrate loading to ground and surface water supplies. California is also implementing the Sustainable Groundwater Management Act (SGMA) which may limit agricultural pumping in regions such as the central coast where the aquifer has been over-extracted for irrigation of crops. Growers could potentially use less N fertilizer, address water quality concerns, and conserve water by improving water management and matching nitrogen applications to the N uptake pattern of their crops. Two tools available to growers, the soil nitrate quick test (SNQT) and reference evapotranspiration (ETo) data from the California Irrigation Management Information System (CIMIS), have been shown to help better manage water and fertilizer nitrogen in vegetable production systems. However, the adoption of these practices has not been widespread. One reason may be that these techniques can be time-consuming to use, and vegetable growers have many crops for which they make daily decisions on fertilization, irrigation, pest control, and tillage. To address the time constraints in managing water and fertilizer on a field-by-field basis, a web-based software application, called CropManage (CM) (cropmanage.ucanr.edu) was developed to facilitate the implementation of the SNQT and ET-based irrigation scheduling in 2011. Additionally, CM enables growers to quickly estimate the N fertilizer contribution from background levels of nitrate in their irrigation water. Since launching CM, trials were conducted in commercial vegetable fields on the central coast to evaluate the accuracy of the fertilizer and irrigation recommendations and provide outreach on irrigation and nitrogen management to growers, farm managers, and irrigators. The main crops evaluated were head and romaine lettuce, and broccoli. The results of these trials demonstrated that in many situations significant savings in water and fertilizer could be attained compared with the grower standard practice by following the CropManage recommendations without jeopardizing yield or quality.

INTRODUCTION

The central coast of California, which has a mild Mediterranean climate, is a major producer of vegetables consumed in the US. Inputs for the production of vegetables in this region are intensive. Most medium to large vegetable production operations produce two to three crops per field each season in small plantings ranging from 5 to 15 acres. Due to their high value and the importance of quality, cool-season vegetables are typically fertilized and irrigated to achieve maximum yield. Because only a portion of the N taken up by these crops is removed in the harvested product, crop residues incorporated into the soil typically breakdown rapidly and mineralize significant amounts of nitrate-N, which can easily be leached during irrigations. As a result of intensively producing vegetables over many decades, much of the groundwater underlying these valleys have nitrate concentrations greater than the US EPA drinking water standard of 10 ppm N. Additionally, over-extraction of groundwater for irrigation has led to saltwater intrusion into the aquifers near the coast.

Growers on the central coast currently face water quality regulations that will restrict the use of nitrogen fertilizer. The Agriculture Order adopted by the Central Coast Regional Water Quality Control Board (CCRWQCB) in 2021 requires that growers estimate nitrogen loading to groundwater through annual reports of applied nitrogen and nitrogen removed in the harvested product. The Ag. Order sets limits on how much loading of nitrate to the groundwater will be allowed in the future. Additionally, the Sustainable Groundwater Management Act (SGMA), passed by the state legislature after the drought in 2014, will limit pumping in basins where groundwater has been severely depleted.

Growers could potentially use less N fertilizer, address water quality concerns, and conserve water by improving water management and matching nitrogen applications to the N uptake pattern of their crops. Two tools available to growers, the soil nitrate quick test (SNQT) and reference evapotranspiration (ETo) data from the California Irrigation Management Information System (CIMIS), have been shown to help better manage water and fertilizer nitrogen in vegetable production systems. The SNQT was introduced to central coast vegetable growers in the early 2000s (Hartz et al., 2000) and ET-based scheduling of irrigations was made possible on the central coast with the establishment of a network of CIMIS weather stations in the 1990s. However, the implementation of these tools by vegetable growers has not been widespread. One reason may be that these techniques can be time-consuming to use, and vegetable growers typically have many crops for which they make daily decisions on fertilization, irrigation, pest control, and tillage. To address the time constraints in managing water and fertilizer on a field-by-field basis, a web-based decision support tool, called CropManage (CM) (cropmanage.ucanr.edu) was developed to facilitate the implementation of the SNQT and ET-based irrigation scheduling in 2011 (Cahn et al., 2015, 2022). Additionally, CM enables growers to quickly estimate the N fertilizer contribution from background levels of nitrate in their irrigation water and maintain records of water and fertilizer applications for regulatory compliance.

Since the initial release of CM, outreach efforts combined with the expansion of supported crop types and improved model accuracy have helped widen the acceptance of CM as a decision support tool. This paper presents the results of trials conducted in commercial broccoli, head and romaine lettuce fields where fertilizer N and/or water applications were guided by CM and compared with a grower standard practice.

METHODS

Software description

CropManage is a database-driven web application hosted on Amazon Web Service. It was first launched to the public in 2011 and has since undergone several major updates to stay current with changes in online software technology. Users can access CM through a web browser on their smartphone, tablet, laptop, or desktop computer. The user interface was developed in concert with collaborating growers and designed to be intuitive for users to navigate. To begin using CM, growers follow an onboarding routine to enter information about their ranches or farms, such as locations of fields, soil types, fertilizer types, and source of weather data. CM uses web tools, such as Google Maps and UC Davis SoilWeb to facilitate this process. A structured query language (SQL) database manages information associated with ranches, fields and plantings within fields, which are used to drive the irrigation and N fertilizer decision support models. The database minimizes the necessity for the reentry of information each time an irrigation or fertilizer application is made. CM is designed so that multiple users from the same farming operation can view ranch and crop information.

CM automatically retrieves reference ET data from CIMIS, and uses a crop coefficient model based on canopy development to estimate crop water requirements. Cahn et al. (2022) summarizes the irrigation equations used in CM, which are based on Gallardo et al. (1996) and FAO56 (Allen et al 1998). Fertilizer N recommendations are based on comparing soil nitrate test values with a threshold for optimal growth and by estimating future crop N needs using N uptake demand curves. Crop N uptake of many cool season vegetables has been intensely researched during the past decade through field sampling of commercially grown crops (Bottoms et al. 2012, Smith et al. 2016). The N fertilizer recommendation is also adjusted by crediting for N available in irrigation water, and N mineralization from soil organic matter and crop residues.

Outreach

CropManage has been extended to the vegetable industry through various approaches, including presentations at industry meetings, hands-on trainings, and field demonstrations. Presentations at industry meetings introduce the decision support tool to growers, consultants, and farm managers, and demonstrate the potential benefits of the application for improving water and nutrient management on a field-by-field basis using site-specific data about the crop, soil type, and weather. Hands-on training provides an opportunity for clientele to receive intensive instruction on how to use the online tool, and adapt it to their farming operation. During three to four-hour trainings, participants learn how to set up their farm on CM, create and customize plantings, and retrieve recommendations on water and fertilizer applications. Participants are encouraged to bring a tablet or laptop computer to complete a series of exercises during the training. Local trainings are conducted in groups of 20 to 30 participants, or on-site with a small group from a farming operation.

Commercial field trial demonstrations have been conducted to compare the irrigation schedule and fertilizer management of the grower with CM recommendations. At most field sites, a flow meter interfaced with a datalogger was installed on the mainline of the irrigation system to automatically retrieve and post irrigation events in CM. Soil moisture sensors, such as tensiometers or volumetric sensors, were sometimes installed in demonstration fields to verify that the crop received adequate soil moisture. The SNQT was used to monitor nitrate concentration in the root zone of the crops. Field demonstrations offered an opportunity to train staff on how to make decisions on irrigation and N fertilizer applications using CM. In many cases, growers were also interested to experiment with reducing water and/or N fertilizer applications during the trial by following CM recommendations, or an intermediate level between the CM recommendation and the grower's standard practice.

Commercial scale field trials

Twenty-six field trials were conducted in commercial broccoli, head and romaine lettuce fields across 16 farms in the Salinas Valley between 2012 and 2019. These trials served to both validate the CM algorithms and to demonstrate potential savings in nitrogen fertilizer and/or water. The trials presented in this paper were conducted in large plots (0.25 to 1-acre areas), where treatments were not replicated. Both the CM and standard treatment plots were established adjacent to each other in the same field and were usually more than 30 ft wide and the length of the field to accommodate an evaluation of yield using commercial equipment and professional harvest crews. Water and nitrogen fertilizer applications were applied to the plots separately. Applied water volumes were monitored using flowmeters. All irrigation and fertilizer applications and soil test results for the treatments were archived in CM. Irrigation methods included sprinkler, drip, and furrow, but at most sites, the crops were established with sprinklers and irrigated by drip thereafter. Soil textures varied from sandy loam to clay loam among field sites. Relative yield was calculated for the CM treatment relative to the grower standard. Yield and relative yield data for the CM and grower standard practice were statistically compared using SAS general linear means procedure, where each site was considered a replication of the CM and grower standard treatments.

RESULTS AND DISCUSSION

Approximately 60 introductory presentations on the decision support tool have been made at industry meetings to date, and 42 hands-on trainings have been conducted throughout California. Approximately 280 field demonstrations were conducted in commercial vegetable fields during this period by UC advisors, crop consultants, resource conservation district staff and vegetable industry staff. More than 3,300 users created CM accounts, and the online tool has provided more than 63,000 irrigation and 20,000 fertilizer recommendations to users during the past decade. Users entered almost 15,000 SNQT values into the decision support tool.

Field trial results comparing CM and standard practices demonstrated that the CM decision support tool can save substantial amounts of nitrogen fertilizer and water without jeopardizing yield. Total water savings averaged 27% relative to the grower standard across the 5 broccoli field trials (Table 1). Water savings averaged 34% relative to the grower standard practice during the period after crop establishment, which was when CM recommendations could be implemented. Nitrogen fertilizer savings in the 3 broccoli trials where N management was an objective were 24% relative to the standard. Broccoli yields were not statistically different between treatments with the CM plots averaging 98% of the yield of the grower standard.

The trials demonstrated an average of 31% savings in fertilizer N relative to the standard practice, where the CM treatment and grower standard averaged 104 and 151 lbs N acre^{-1}, respectively (Table 2). Fertilizer savings were mainly achieved by crediting for residual mineral N in the root zone of the soil and N available from irrigation water. For some trials (sites 8,9,12,13, and 18), the fertilizer N rate of the standard practice may have been lower than is typically used because the growers were experimenting with reducing fertilizer N applications. The average N fertilizer rate for lettuce reported to the CCRWQCB by growers on the central coast for years 2014 – 2017 was 183 lbs N acre^{-1}. Hence potential N savings following the CM recommendations could be as high as 43%.

Water management was an objective for only 6 of the 15 lettuce trials and on average applied water volumes were similar between CM and grower treatments. This result is likely because lettuce is usually over-irrigated during germination (crop establishment) and often under-irrigated later in the season. CM recommendations were only implemented after plants were established in these trials. In some of these trials (sites 11,12,14, and 16) water was reduced under the CM treatment by an average of 15% after establishment, but in the other trials (sites 13 and 15), the grower standard irrigated less than the CM treatment.

Across all sites yields of lettuce under the CM treatment were generally equal to or higher than the grower standard (averaging 107% of the yield of the grower standard), and were not significantly different between the two management regimes.

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Table 1. Applied water, N fertilizer, and yields of large-scale commercial field trials in broccoli comparing CropManage (CM) recommendations with a grower (Grower) standard practice. Trial objectives are noted as nitrogen management (N), water management (Water) or both (Water/N)

Site #	Objective	Year	Crop	Treatment	Applied water Total	Applied water Post Establishment	Applied N	Commerial Yield	Relative Yield
					------- inches -------		----- lbs/acre ----		%
1	Water	2013	broccoli	CM	20.4	12.9	166	14741	105
				Grower	33.5	26.1	166	14006	100
2	Water	2013	broccoli	CM	19.6	15.2	187	20382	97
				Grower	35.4	31.0	187	20930	100
3	Water/N	2015	broccoli	CM	20.4	16.2	154	12897	93
				Grower	23.1	18.9	169	13934	100
4	Water/N	2015	broccoli	CM	16.0	11.2	118	7746	96
				Grower	15.5	10.7	206	8068	100
5	Water/N	2017	broccoli	CM	12.7	9.6	165	13067	97
				Grower	15.0	12.3	199	13472	100
Average				CM	17.8	13.0	158	13766	98
				Grower	24.5	19.8	185	14082	100

Table 2. Applied water, N fertilizer, and yields of large-scale commercial field trials in lettuce comparing CropManage (CM) recommendations with a grower (Grower) standard practice. Trial objectives are noted as nitrogen management (N), water management (Water) or both (Water/N)

					Applied water				
Site #	Objective	Year	Lettuce Type	Treatment	Total	Post Establishment	Applied N	Commerial Yield	Relative Yield
					------- inches -------		----- lbs/acre ----		%
6	N	2012	head	CM	20.1	9.8	143	65713	102
				Grower	20.1	9.8	183	64307	100
7	N	2012	head	CM	8.0	4.9	149	18760	98
				Grower	8.0	4.9	211	19114	100
8	N	2013	head	CM	13.6	4.3	62	38434	117
				Grower	13.2	3.9	124	32765	100
9	N	2014	head	CM	4.8	2.3	27	20655	107
				Grower	4.8	2.3	54	19364	100
10	N	2014	head	CM	20.1	11.6	118	11334	128
				Grower	20.1	11.6	250	8861	100
11	Water/N	2016	head	CM	7.5	5.0	140	54692	102
				Grower	8.4	6.2	154	53573	100
12	Water/N	2016	head	CM	14.8	5.3	32	41928	99
				Grower	15.8	6.3	62	42387	100
13	Water/N	2017	head	CM	9.1	5.0	7	44758	108
				Grower	7.9	3.8	63	41526	100
14	Water/N	2017	head	CM	17.0	8.1	118	27185	121
				Grower	17.7	8.9	155	22511	100
15	Water/N	2018	head	CM	23.5	9.7	92	40014	96
				Grower	21.5	7.7	155	41496	100
16	Water/N	2012	romaine	CM	9.2	3.8	177	18389	103
				Grower	11.1	4.9	177	17935	100
17	N	2013	romaine	CM	14.6	7.6	162	15644	98
				Grower	14.6	7.6	263	15946	100
18	N	2017	romaine	CM	10.1	4.1	71	27035	109
				Grower	10.1	4.1	96	24903	100
19	N	2017	romaine	CM	8.4	4.4	128	40515	110
				Grower	8.6	4.6	120	36832	100
20	N	2019	romaine	CM	7.2	3.8	129	27177	105
				Grower	6.9	3.3	191	25789	100
Average				CM	12.5	6.0	104	32816	107
				Grower	12.6	6.0	151	31154	100