A WEATHER-BASED IRRIGATION SCHEDULING TOOL FOR STRAWBERRY PRODUCTION IN THE PAJARO VALLEY, CALIFORNIA

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ABSTRACT

Strawberries are one of the most important crops in Santa Cruz County and strawberry production relies on groundwater. As part of a water conservation program, the Resource Conservation District of Santa Cruz County produced a weather-based irrigation tool consisting of irrigation scheduling tables that indicate the irrigation system run times for strawberry production for each week of the year and for the most common irrigation system configurations. Daily ETo obtained from the Pajaro CIMIS station (#129) was aggregated to calculate weekly ETo for the whole 22-year time series. For each week, a maximum and an average ETo was calculated across the years and multiplied a the crop coefficient to obtain weekly crop evapotranspiration (ETc). Finally, irrigation system run times were obtained by dividing ETc by the application rates of each irrigation system configuration. The results from the table were compared about the recommendations of Crop Manage, an on-line decision support tool developed by the University of California. In five out of six ranches where applied irrigation water data were collected, the recommendations of the irrigation scheduling tables deviated from the Crop Manage recommendations less than 4 inches of seasonal irrigation water, and grower applied water always deviated more from the Crop Manage recommendations. Therefore, substantial potential for conservation is to be expected from the adoption of the tables. However, the table recommendations appeared to be less accurate for organic ranches with 48 inch beds and for ranches located further than five miles from the CIMIS station.

Keywords: Irrigation scheduling, strawberry, evapotranspiration.

INTRODUCTION

Strawberries are one of the most important crops in Santa Cruz County. In 2016 they accounted for 36% of the total agricultural value produced in the county, or $229,107,000 (Santa Cruz County Crop Report 2016). Strawberries require high soil moisture to achieve commercial yield and high-quality production. Additionally, in the Pajaro Valley, the entire agricultural industry relies on groundwater to irrigate crops. As a result, the Pajaro watershed is currently over drafted and seawater intrusion is common, particularly in areas close to the coastline. Water conservation in agriculture is one of the strategies that is being applied in order to bring the aquifer in to balance. As part of this effort, the University of California Cooperative Extension (UCCE) developed an online irrigation scheduling application called Crop Manage to aid growers and ranch managers in irrigation scheduling decisions. However, in some cases irrigation decisions are made in the field by irrigators with limited access to internet or with few

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technical skills to apply the recommendations. The Resource Conservation District of Santa Cruz County produced a weather-based irrigation tool consisting of tabulated data that indicate the irrigation system run times for each week of the year and for the most common irrigation system configurations. In this paper this irrigation scheduling tables are presented and their performance is evaluated against CropManage recommendations. The strength and limitations of the tables are presented and suggestions are offered to produce similar tables for other crops.

MATERIALS AND METHODS

Reference Evapotranspiration

Daily reference evapotranspiration (ETo) data were obtained from CIMIS station # 129 located in Pajaro, CA (http://cimis.water.ca.gov) for the period between January 1st 1995 and December 31st 2016.

Crop Coefficients

Crop coefficients were obtained for strawberry grown in the Watsonville-Salinas area, for bed width 48 and 52 inches from the blog of Dr. Mike Cahn of the UCCE of Monterey County http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=6934.

Irrigation run times

Daily ETo was aggregated to calculate weekly ETo for the whole 11-year time series. For each week, a maximum and an average value was calculated across the years. Then, the weekly average and maximum ETo was multiplied by the crop coefficient to obtain weekly crop evapotranspiration (ETc) for each bed width. The application rate of the most common irrigation system configurations was calculated, for 48 inch beds with one and two driplines per bed and for 52 inch beds with two driplines per bed. For each configuration, a different application rate was obtained for the most common driptape flow rates: 0.4, 0.5 and 0.67 gpm/100 ft. Run times were obtained by dividing ETcby the application rates and were reported in three tables, one for each irrigation system configuration. Each table has a row for each week of the year and a column for each driptape flow rate. From the corresponding cell in the table, growers can obtain the weekly average and maximum run time for each week of the year. It is recommended that the grower divides the weekly requirement into three to four irrigations per week.

Average values are intended for use by growers under normal circumstances. Maximum values should only be used during exceptionally windy or hot weeks and provide an upper limit that growers should never exceed.

Strawberry is an annual crop with a very consistent yearly schedule with transplanting of all acreage happening within 2-3 weeks at the beginning of November. As a result, most strawberry planting in the area are synchronized, and little error results from basing irrigation recommendations on the week of the year instead of weeks from planting.

Table validation

Irrigation scheduling recommendation data from real plantings were downloaded from Crop Manage for ranches with 48 and 52 inch beds and for conventional and organic production. The data obtained from Crop Manage was aggregated by week and used to validate the tables.

RESULTS

Weekly ETo ranged from less than 0.2 inches per week during winter months, to up to 1.65 inches per week in June. Although all years showed the same pattern for weekly ETo, for any given week across the years weekly ETo ranged about 1 inch. Maximum ETo was always higher than average ETo for each week, with maximum ETo being about 0.5 inches higher than average ETo (Figure 1).

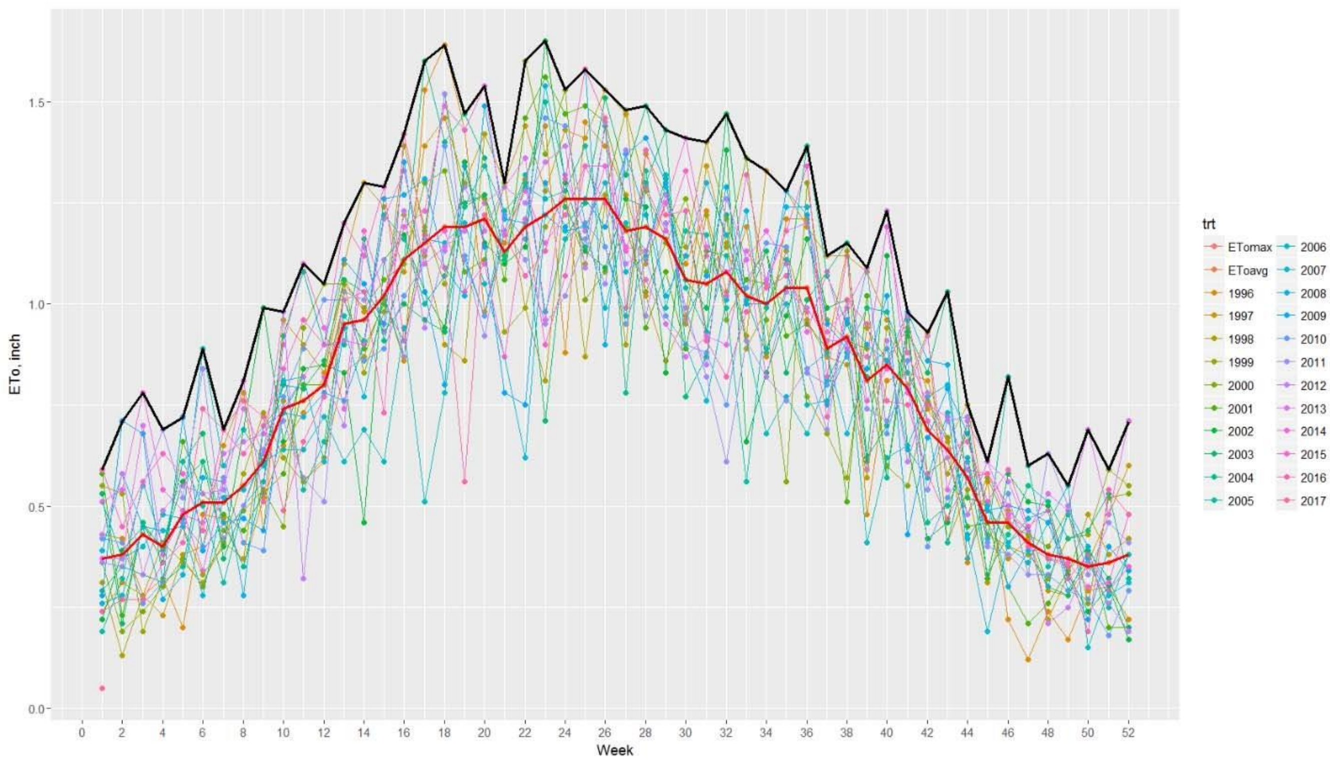

Figure 1. Reference ET obtained from the CIMIS station "Pajaro" for the period 1996-2017. The black line indicates the maximum ETo for each week and the red line indicates the average ETo for each week across all years.

Cumulative ETo showed little variability across the years, and the total cumulated ETo for all years ranged from 38.3 to 47.1 inches. The average cumulative ETo for the year was 42.8 inches. The highest and the lowest cumulative ETo were both within 5 inches of the average (Figure 2).

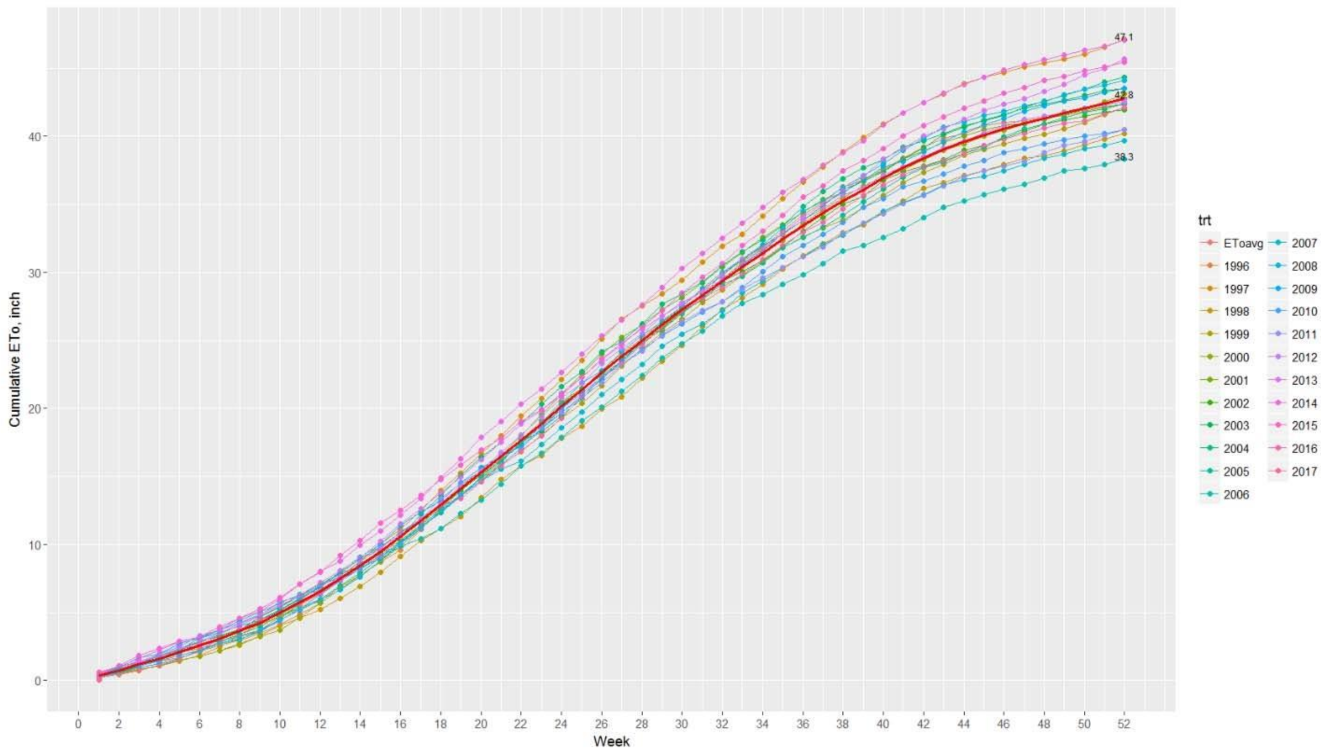

Figure 2. Cumulative reference ET for each year between 1996 and 2017. All data obtained from the CIMIS station "Pajaro".

The irrigation scheduling tables provide irrigation recommendations expressed in irrigation system run times (Figure 3). The additional data presented in this study are expressed in inches, in order to compare them with the recommendations obtained from CropManage**.**

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Weekly Irrigation Requirements for Strawberries in the Pajaro Valley*

		52-inch beds, 2 drip lines per bed					
		0.4 gpm/100 ft flowrate		0.5 gpm/100 ft flowrate		0.67 gpm/100 ft flowrate	
Week	Month	Average	Maximum	Average	Maximum	Average	Maximum
1	Jan	--- 10 min	--- 15 min	--- 10 min	--- 10 min	--- 5 min	--- 10 min
2		--- 10 min	--- 20 min	--- 10 min	--- 15 min	--- 5 min	--- 10 min
3		--- 15 min	--- 25 min	--- 10 min	--- 20 min	--- 10 min	--- 15 min
4		--- 15 min	--- 25 min	--- 10 min	--- 20 min	--- 10 min	--- 15 min
5	Feb	--- 20 min	--- 30 min	--- 15 min	--- 25 min	--- 15 min	--- 20 min
6		--- 20 min	--- 40 min	--- 20 min	--- 35 min	--- 15 min	--- 25 min
7		--- 25 min	--- 40 min	--- 20 min	--- 30 min	--- 15 min	--- 25 min
8		--- 30 min	--- 50 min	--- 25 min	--- 40 min	--- 20 min	--- 30 min
9	Mar	--- 45 min	1 hrs 15 min	--- 35 min	1 hrs	--- 25 min	--- 45 min
10		1 hrs	1 hrs 25 min	--- 50 min	1 hrs 5 min	--- 35 min	--- 50 min
11		1 hrs 10 min	1 hrs 45 min	--- 55 min	1 hrs 25 min	--- 45 min	1 hrs 5 min
12		1 hrs 25 min	2 hrs	1 hrs 10 min	1 hrs 35 min	--- 55 min	1 hrs 10 min
13		1 hrs 55 min	2 hrs 35 min	1 hrs 30 min	2 hrs 5 min	1 hrs 10 min	1 hrs 35 min
14	Apr	2 hrs 10 min	3 hrs 10 min	1 hrs 45 min	2 hrs 30 min	1 hrs 20 min	1 hrs 55 min
15		2 hrs 40 min	3 hrs 25 min	2 hrs 5 min	2 hrs 45 min	1 hrs 35 min	2 hrs 5 min
16		3 hrs 5 min	4 hrs 5 min	2 hrs 25 min	3 hrs 15 min	1 hrs 50 min	2 hrs 25 min
17		3 hrs 35 min	5 hrs 15 min	2 hrs 50 min	4 hrs 10 min	2 hrs 10 min	3 hrs 10 min
18	May	4 hrs	5 hrs 45 min	3 hrs 15 min	4 hrs 40 min	2 hrs 25 min	3 hrs 30 min
19		4 hrs 25 min	5 hrs 35 min	3 hrs 30 min	4 hrs 30 min	2 hrs 40 min	3 hrs 20 min
20		4 hrs 40 min	6 hrs 15 min	3 hrs 45 min	5 hrs	2 hrs 45 min	3 hrs 45 min
21		4 hrs 40 min	5 hrs 40 min	3 hrs 40 min	4 hrs 30 min	2 hrs 45 min	3 hrs 20 min
22	Jun	5 hrs 15 min	7 hrs 20 min	4 hrs 10 min	5 hrs 55 min	3 hrs 5 min	4 hrs 25 min
23		5 hrs 35 min	7 hrs 55 min	4 hrs 30 min	6 hrs 20 min	3 hrs 20 min	4 hrs 45 min
24		5 hrs 55 min	7 hrs 40 min	4 hrs 45 min	6 hrs 5 min	3 hrs 35 min	4 hrs 35 min
25		6 hrs	8 hrs 5 min	4 hrs 50 min	6 hrs 30 min	3 hrs 35 min	4 hrs 50 min
26		6 hrs 10 min	8 hrs	5 hrs	6 hrs 25 min	3 hrs 45 min	4 hrs 50 min
27	Jul	6 hrs 5 min	8 hrs	4 hrs 50 min	6 hrs 25 min	3 hrs 40 min	4 hrs 45 min
28		6 hrs 10 min	8 hrs 15 min	4 hrs 55 min	6 hrs 35 min	3 hrs 40 min	4 hrs 55 min
29		6 hrs 5 min	8 hrs	4 hrs 50 min	6 hrs 25 min	3 hrs 40 min	4 hrs 45 min
30		5 hrs 35 min	8 hrs	4 hrs 30 min	6 hrs 25 min	3 hrs 20 min	4 hrs 45 min
31	Aug	5 hrs 45 min	8 hrs	4 hrs 35 min	6 hrs 25 min	3 hrs 25 min	4 hrs 50 min
32		6 hrs	8 hrs 30 min	4 hrs 45 min	6 hrs 50 min	3 hrs 35 min	5 hrs 5 min
33		5 hrs 40 min	7 hrs 55 min	4 hrs 30 min	6 hrs 20 min	3 hrs 25 min	4 hrs 45 min
34		5 hrs 30 min	7 hrs 45 min	4 hrs 25 min	6 hrs 15 min	3 hrs 15 min	4 hrs 40 min
35	Sep	5 hrs 50 min	7 hrs 35 min	4 hrs 40 min	6 hrs 5 min	3 hrs 30 min	4 hrs 30 min
36		5 hrs 50 min	8 hrs 15 min	4 hrs 40 min	6 hrs 35 min	3 hrs 30 min	4 hrs 55 min
37		5 hrs 5 min	6 hrs 40 min	4 hrs 5 min	5 hrs 20 min	3 hrs 5 min	4 hrs
38		5 hrs 10 min	6 hrs 55 min	4 hrs 10 min	5 hrs 30 min	3 hrs 5 min	4 hrs 5 min
39		4 hrs 35 min	6 hrs 30 min	3 hrs 40 min	5 hrs 15 min	2 hrs 45 min	3 hrs 55 min
40	Oct	4 hrs 50 min	7 hrs 20 min	3 hrs 50 min	5 hrs 55 min	2 hrs 55 min	4 hrs 25 min
41		4 hrs 30 min	5 hrs 50 min	3 hrs 35 min	4 hrs 40 min	2 hrs 40 min	3 hrs 30 min
42		4 hrs	5 hrs 40 min	3 hrs 10 min	4 hrs 30 min	2 hrs 25 min	3 hrs 25 min
43		3 hrs 45 min	6 hrs 15 min	3 hrs	5 hrs	2 hrs 15 min	3 hrs 45 min
44		3 hrs 15 min	4 hrs 35 min	2 hrs 40 min	3 hrs 40 min	2 hrs	2 hrs 45 min
45 new crop	Nov	--- 5 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min
46		--- 5 min	--- 10 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min
47		--- 5 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min
48	Dec	--- 5 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min
49		--- 5 min	--- 10 min	--- 5 min	--- 5 min	--- 5 min	--- 5 min
50		--- 5 min	--- 10 min	--- 5 min	--- 10 min	--- 5 min	--- 5 min
51		--- 5 min	--- 10 min	--- 5 min	--- 10 min	--- 5 min	--- 10 min
52		--- 10 min	--- 15 min	--- 5 min	--- 10 min	--- 5 min	--- 10 min

Figure 3. Example of the irrigation scheduling table for 52 inch beds and 2 driplines per bed.

The recommendations obtained by the irrigation scheduling table values closely matched the recommendations obtained from Crop Manage on conventional ranches with 52 inch wide beds that were located within five miles of the CIMIS station (Figure 4, Figure 5, Table 1). In ranches with 48 inch wide beds, the deviation of the cumulative irrigation scheduling table recommendations from the Crop Manage recommendations was between three and four inches (Figure 6, Table 1). One additional ranch that was part of the study presented a deviation of 3.8 inches. The ranch distance from the CIMIS station was 9.3 miles (Table 1).

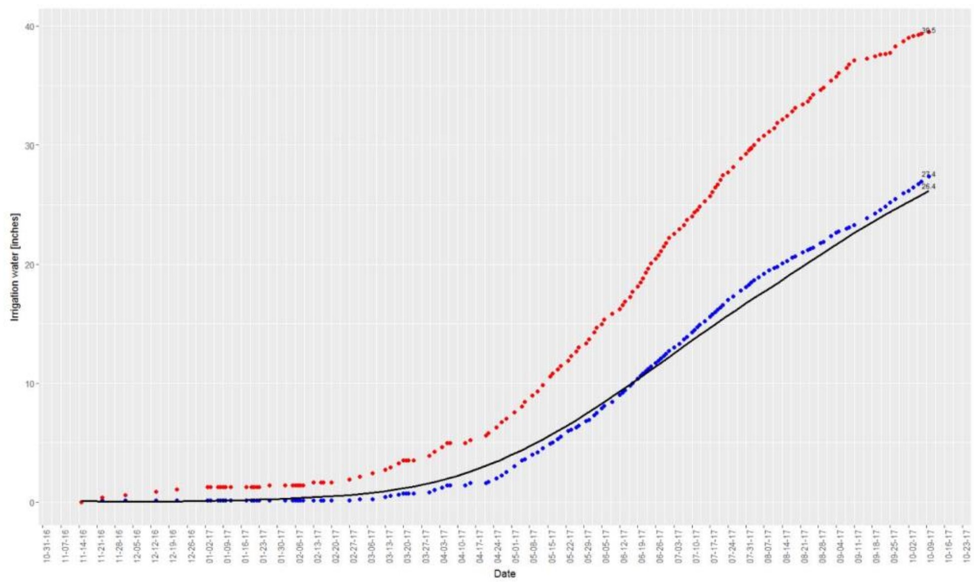

Figure 4. Cumulative water applied (red dots), recommended by Crop Manage (blue dots) and recommended by the irrigation scheduling table (black line) for a conventional ranch with 52 inch beds where substantial over-irrigation occurred.

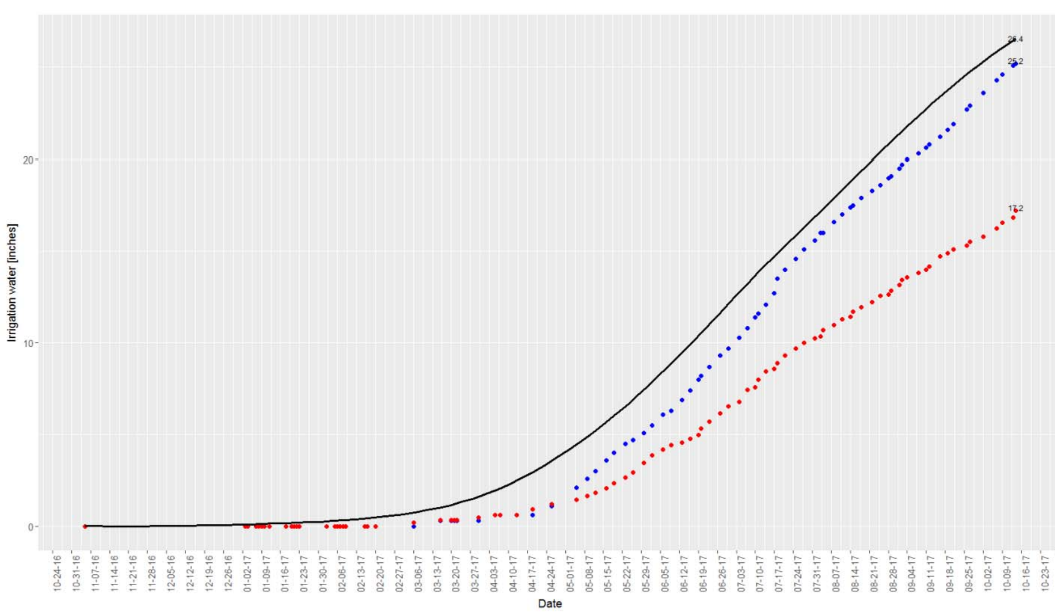

Figure 5. Cumulative water applied (red dots), recommended by CropManage (blue dots) and recommended by the irrigation scheduling table (black line) for a conventional ranch with 52 inch beds where under-irrigation occurred.

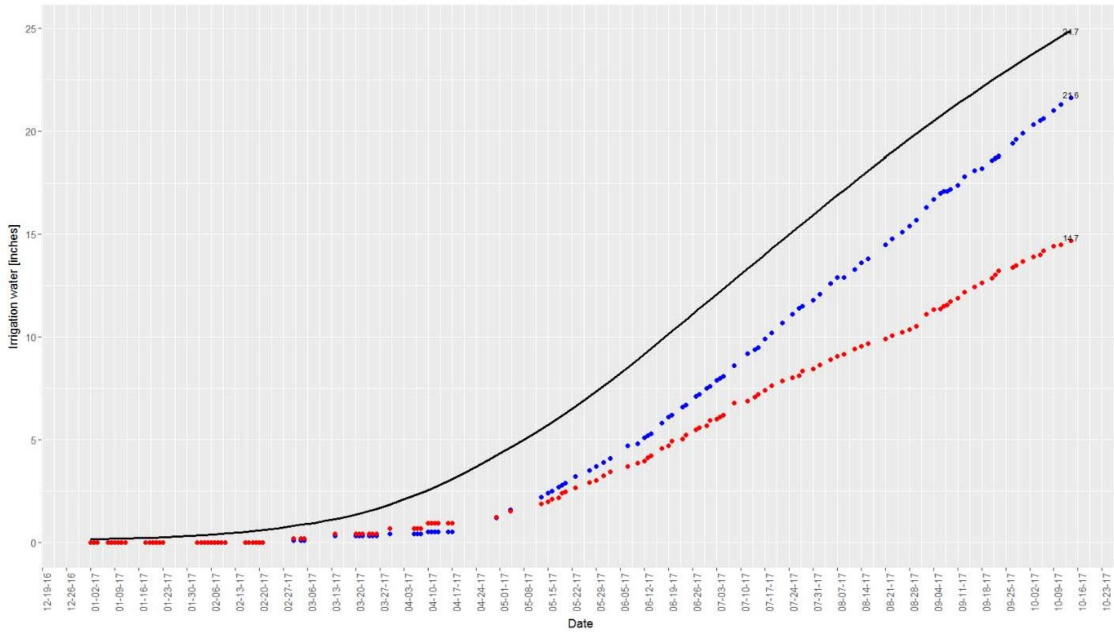

Figure 6. Cumulative water applied (red dots), recommended by Crop Manage (blue dots) and recommended by the irrigation scheduling table (black line) for an organic ranch with 48 inch beds where under-irrigation occurred

Table 1. Summary of the cumulative water recommended by CropManage, the irrigation scheduling table values, the total rainfall and the amount of water applied by growers. The table also includes the width of the beds, the week of crop termination and the distance between the ranch and the weather station from which reference ET was obtained.

Ranch code	Cumulative water recommended by CropManage, inch	Cumulative water recommended by irrigation scheduling tables, inch	Deviation, inch	Total Rainfall, inch	Cumulative water applied by grower, inch	Bed width, inch	Termination, week	Distance from CIMIS Pajaro station, miles
TR_G	22.6	26.4	3.8	20.4	19.9	52	41	9.3
BD_B	21.6	24.7	3.1	29.4	14.7	48	41	5.3

AD_P	21.2	24.7	3.5	24.3	13.4	48	39	5.9
MR_R	27.4	26.4	-1	22.9	39.5	52	42	4.9
JM_S	25.2	26.4	1.2	21.7	17.2	52	41	3.8
DS_H	19.8	26.4	6.6	26.6	30.7	48	44	1.9

The deviation from the cumulative water recommended by Crop Manage and the irrigation scheduling values was analyzed statistically to explore its association with bed width, miles from CIMIS station, termination week and total rainfall. All statistical analyses yielded non-significant results, however the slopes of the relationships were positive for rainfall and termination week and negative for distance from CIMIS staion (Table 2).

Table 2. Summary of the statistical analyses performed on the relationship between deviation from the cumulative water recommended by Crop Manage and the irrigation scheduling values and bed width, miles from CIMIS station, termination week and total rainfall

Variable	Observation (n)	Regression slope	p-value	Analysis
Bed size	6	-	0.159	ANOVA
Miles from CIMIS station	6	-0.15	0.789	Linear regression
Termination week	6	0.45	0.578	Linear regression
Total rainfall	6	0.28	0.467	Linear regression

Linear regression analyses of the relationship between the irrigation scheduling table values and the irrigation recommendations obtained from Crop Manage for each ranch yielded a slope different than zero with highly significant p-values. The slope of the relationship ranged between 0.25 and 0.45 and the adjusted R2 ranged between 0.33 and 0.54 (Figure 7, Table 3).

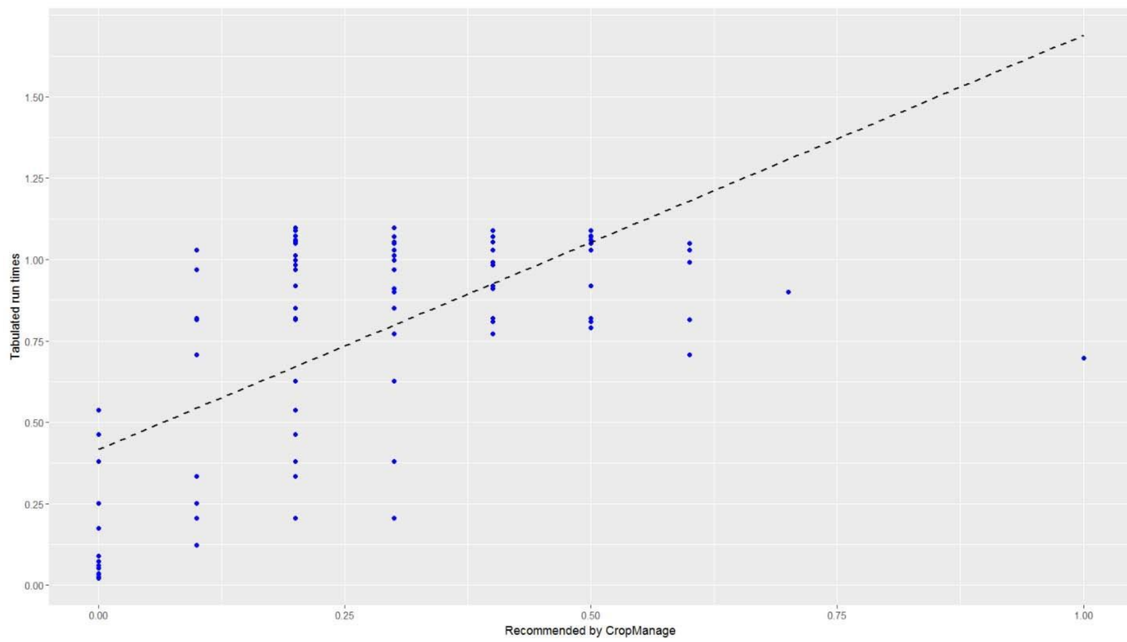

Figure 7. The linear regression of the relationship between the irrigation scheduling table values and the irrigation recommendations obtained from CropManage for the ranch MR_R.

Table 3. Linear regression analysis of the relationship between the irrigation scheduling table values and the values obtained from CropManage for all the ranches in the study.

Ranch code	Number of observations (n)	Bed width, inch	Range in water recommended, inch	Regression slope	P-value	Adjusted R^2
TR_G	125	52	0 to 0.6	0.25	4.91e-16 ***	0.41
BD_B	124	48	0 to 0.7	0.33	<2e-16 ***	0.33
AD_P	132	48	0 to 0.6	0.27	<2e-16 ***	0.47
MR_R	138	52	0 to 1	0.29	1.95e-15***	0.36
JM_S	87	52	0 to 1	0.45	<2e-16 ***	0.54
DS_H	172	48	0 to 0.6	0.17	<2e-16 ***	0.23

* = significant at the 0.05 level, ** = significant at the 0.01 level, *** = significant at the 0.001 level

DISCUSSION

The weekly ETo data obtained from the CIMIS Pajaro station was relatively variable across the 22 years considered in this study. For any given week across the years, ETo ranged up to 1 inch. However, the cumulative values were more stable and the cumulative ETo for each year was always within five inches of the cumulated weekly average. The relatively stable pattern of cumulative ETo across years suggests there is good potential for basing irrigation management strategies on average ETo. Although five inches of deviation from average ETo may seem a large number, it seems that this tool could still be useful for encouraging water conservation amongst growers, considering that one foot of over-irrigation in one cycle of strawberry is not uncommon in the area.

The values obtained from the irrigation scheduling table matched the recommendations obtained from Crop Manage within 4 inches of each other, except at DS_H. Deviations larger than 3 inches were observed in the ranch TR_G and on two organic ranches. TR_G was located almost 10 miles from the Pajaro CIMIS station and in an area with different geographical morphology than the Pajaro Valley. It appears that on ranches located further than 10 miles from the CIMIS station, the recommendations from the irrigation scheduling table values start to lose their accuracy. The other ranches where the disagreement between the cumulative recommendations obtained from Crop Manage and from the irrigation scheduling tables was larger than 3 inches were both organic ranches with 48 inch beds. This deviation is expected, since the crop coefficients used in the calculation of the irrigation scheduling tables were based on conventional strawberry canopy development, which is larger than in organic ranches; this results in larger irrigation recommendations for conventional fields. Crop Manage accounts for the development of canopy cover using satellite imagery data obtained from Landsat, this explains the lower recommendations obtained from Crop Manage for organic ranches (Cahn et al., 2015).

At the ranch DS_H a deviation of 6.6 inches between the cumulative recommendations obtained from Crop Manage and from the irrigation scheduling tables was observed. At this ranch the lowest recommendations from Crop Manage was observed (19.8 inches) due to substantial rains recorded at this site in March 2017 (2.93 inches) and April 2017 (2.63 inches). The rainfall caused a reduction in the recommendations from Crop Manage at this site, causing substantial deviation from the irrigation scheduling table values, even if the site was the closest to the Pajaro CIMIS station. However the total rainfall at the site did not differ substantially from the other sites. The regression analysis at this site is significant, however the R2 observed and the slope of the relationship was the lowest.

Water applied by the growers deviated substantially from recommendations in both directions. Some ranches showed a substantial amount of over-irrigation, while others under irrigated considerably. During the harvesting season, irrigations are limited by the need of pickers to access the fields, while some of the amount of the over-irrigations could be due to salinity management, where an additional amount of water is applied as a leaching requirement. A leaching requirement is not included in the tabulated values, and although CropManage offers a function to calculate this amount, it is not calculated by the program by default and was not used in this study. Nevertheless, the recommendations derived from the irrigation schedules were always closer to the Crop Manage recommendations than the amounts applied by the growers, indicating that there is great potential for conservation deriving from the adoption of the irrigation schedule tables.

In conclusion, the irrigation scheduling table values appeared in most cases comparable to the recommendations of Crop Manage, particularly for conventional ranches with 52 inch beds located within 5 miles of the CIMIS station. Substantial potential for conservation is to be expected from the adoption of the tables. However, it appears that the largest potential for conservation would be achieved if different tabulated sheets were produced for each strawberry production region within the Pajaro Valley, using CIMIS data from the closest station. Additionally, specific irrigation scheduling tables could be produced for organic strawberry growers, using crop coefficients specifically developed for organic production.

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