Irrigation management based on soil matric potential improves water use efficiency of field-grown strawberries in California

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Abstract

Faced with climate change and the intensification of crop production, water is expected to be increasingly in demand worldwide. Focus is now on increasing water use efficiency (WUE) of crops as influenced by irrigation management practices. Common methods for irrigation scheduling in open-field strawberry production are based on the estimation of crop evapotranspiration (ET) and on soil moisture measurements. Although studies have reported that tension(ψ)-based irrigation management presented a good potential of optimizing WUE, the capacity of this method to improve WUE has not always been clearly demonstrated. This study aimed at comparing WUE of two irrigation management methods, the conventional and the ψ-based approaches, in strawberry crop in California. Conventional irrigation treatments included both the standard grower procedure and managements based on evapotranspiration (ET) of the crop (50% ET, 75% ET and 100% ET). Irrigation management based on tension measurements used irrigation thresholds that varied from -8 kPa to -35 kPa. Multiple linear regressions determined using data from 5 growing seasons and 8 sites in field strawberry production in California and describing relationships between (1) marketable yield and ψ achieved before irrigations and (2) water use (WU) and ψ at irrigation initiation, considering the management method, were used. WUE was calculated as the ratio of predicted marketable yield by predicted WU values at specific ψ thresholds deduced from the regression lines. A cost-benefit analysis was also conducted to assess the economic effectiveness of increasing WUE based on a deficit irrigation strategy. Results show that tension-based irrigation management improves WUE compared to conventional irrigation management. For a same amount of water used, WUE is increased by 7.5 to 8.3%. For a same average ψ threshold achieved before irrigations, tension-based irrigation management improves WUE from 33% to 93% compared to conventional practices. This study demonstrates that (1) tension-based irrigation management improves WUE in strawberry crop in California, regardless of the production region and soil type, and that (2) water savings associated with deficit

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irrigation strategies generate little benefits compared to yield losses associated with such a practice.

Keywords: Tensiometer, fresh market yield, irrigation rate, grower practice, soil water suction

INTRODUCTION

Faced with climate change and the intensification of crop production, water is expected to be increasingly in demand worldwide. In this context, interest in producing more “crop per drop” is greatly heightened and research focuses on increasing water use efficiency (WUE) of crops as influenced by irrigation management, among other factors. In field-grown strawberry production in California, common irrigation management tools are usually based on the estimation of evapotranspiration (ET) of the crop and on soil moisture measurements.

ET-based approach is certainly widely used in strawberry production in California. Indeed, the common irrigation practice is to apply about 100% of crop ET weekly through two to three irrigation events on predetermined days. Growers’ irrigation decision may also be influenced by personal observations of plants and weather forecast. In this study, the grower standard procedure as well as the management based on estimations of crop evapotranspiration are grouped into one single category called “conventional irrigation management”, because the two approaches mainly estimate water needs based on the past water use.

Studies have reported that irrigation management based on tension presents a good potential of optimizing WUE in strawberry production compared to conventional practices (Létourneau et al., 2015; Anderson, 2015). However, the capacity of this method to improve WUE has not always been clearly demonstrated. While on a clay loam soil, tension-based management produced higher WUE than the grower practice (Létourneau et al., 2015), Anderson (2015) showed that tension-based method produced a lower WUE than the grower standard practice on a fine sandy loam. On a silty clay soil, WUE was increased with tension-based management compared to the grower procedure, and to 75% and 100% of crop ET, but was decreased compared to a deficit management at 50% of crop ET (Anderson, 2015).

Indeed, conventional scheduling may refer either to dry or to wet managements, depending on grower irrigation strategies and crop ET estimations. Several studies have reported that dry management, or deficit irrigation, can improve WUE in many crops (Kang et al., 2002; Zwart et Bastiaanssen, 2004). Thus, in order to determine which irrigation management method is the most water use efficient, the two common approaches must be compared for equivalent strategies (wet or dry management).

This study aimed at comparing the WUE of tension-based irrigation scheduling for different irrigation strategies with that of conventional irrigation procedure for strawberries grown in open-field production in California.

MATERIALS AND METHODS

Site Description

This study uses data collected over 5 growing seasons and on 8 experimental sites in field strawberry production in California (USA).

Experimental sites were located in two of the main strawberry growing regions: Southern and Northern regions. Four experiments were located in Oxnard, in the southern part of California, from 2012 to 2015. These experiments took place on a sandy loam from January/February to May/June. Short-day strawberry plants (*Fragaria × ananassa* Duch.) were planted in October. Three experiments took place in Watsonville from April to October 2011, 2013 and 2014 with day-neutral strawberry plants planted in mid-October/November of the previous year. Finally, one experiment took place in Salinas from mid-April to late June 2012. The latter four experiments were located in the northern region and were therefore characterized by similar soil types (silt clay and clay loam soils). On all 8 sites, strawberry were grown on raised beds covered with a plastic mulch according to conventional farming practices. During the harvesting period, water was supplied using drip irrigation. Both areas are experiencing a Mediterranean climate.

Experimental Design

On each site, a representative area of the field was selected to perform the experiments. This zone was irrigated independently from the rest of the farm. On all sites but one, each treatment was replicated 3 to 5 times in randomized complete block designs. Irrigation of the different treatments was managed independently. Twenty-five treatments consisted of different irrigation initiation thresholds based on soil matric potential (ψ) ranging from -8 kPa to -35 kPa. Five grower standard irrigation managements as well as three managements based on crop evapotranspiration (50% ET, 75% ET and 100% ET) were also included in the experimental setup. Tensiometers were installed at two depths (15 cm and 30 cm) in one to three blocks. The grower treatments (Control) were managed by each site's producer while evapotranspiration treatments were managed according to crop evapotranspiration; however, monitoring stations were also installed in these plots. Therefore, average ψ thresholds at irrigation initiation were measured in the Control and evapotranspiration plots, as well as total water use over the harvesting period. In tension-based treatments, irrigations were triggered when the average tension at 15 cm reached a predetermined threshold and were stopped when the tensiometer at 30 cm reached -5 kPa.

Regression models

The equation of the regression model predicting average marketable yield from ψ achieved before irrigations (ψ = -kPa) is presented below, as obtained from Gendron (2016).

$$\hat{Y} = \beta_m - m * \psi \text{ v}$$

$$Marketable\,Yield\left(\frac{kg}{ha}\right) = 55{,}465.96 - 289.45 * \psi \text{ v}$$

Table 1. Basic descriptive statistic of the first regression model

Correlation Coefficients	
$R^2_{adjusted}$	0.86

Equations of the regression models predicting average water use from the ψ achieved before irrigation events (ψ = -kPa) and the preferred common irrigation management method are presented below, as obtained from Gendron (2016).

$$\hat{Y} = \beta_m + \beta_n * irrigation_{method} - m * \psi$$

$$Water\ Use_{\psi - based\ method}\left(\frac{m^3}{ha}\right) = 3962.80 - 81.69 * \psi \text{ v}$$

$$Water\ Use_{conventional\ method}\left(\frac{m^3}{ha}\right) = 4993.88 - 81.69 * \psi \text{ v}$$

Table 2. Basic descriptive statistic of the second regression model.

Correlation Coefficients	
$R^2_{adjusted}$	0.91

More details about the regression models can be found in Gendron (2016).

Water Use Efficiency Calculations

Water use efficiencies were calculated as the ratio of predicted yield by predicted water use deduced from the regression model equations, using an average intercept. Therefore, the predicted data used for calculations represent averages of all experimental sites (average yield and average water use).

Economic Analysis

A cost-benefit analysis was conducted to assess the economic effectiveness of increasing WUE based on a deficit irrigation strategy. A production area of 1 ha was considered. Water savings and yield loss ($/ha) associated with irrigations at lower ψ thresholds (irrigations triggered at -40 kPa instead of -22.4 kPa with conventional management and at -27.4 kPa instead of -10 kPa with the ψ-based management; see Table 4) were considered. Also, cost operation savings ($/ha) associated with yield loss were included in the analysis.

The cost of water is based on 2015 water costs in Watsonville area, and is higher than the estimated average cost in Oxnard area for the same period (Laurence Gendron, Personal Communication). The price of fresh strawberries is based on average yearly prices ($/100 lbs) listed by the USDA for fresh strawberries from 2004 to 2014. Operation costs represent an average of the data collected by the University of California Cooperative Extension in 2010, 2011 and 2014 in order to describe the costs to produce strawberries in the main growing regions of California.

RESULTS AND DISCUSSION

Water Use Efficiency

1. Calculated from a same average tension threshold.

At a same average tension threshold reached before irrigation, which generated a certain predicted marketable yield, conventional management used more water compared to the ψ-based method. WUE is therefore improved by 33-93% with the ψ-based management compared to the conventional management, depending on the irrigation strategy, i.e. where types of management go from -10 kPa (wet) to -35 kPa (dry). Results are presented in Table 3.

Table 3. Water use efficiencies calculated from a same average irrigation tension threshold reached before irrigations.

Average Irrigation Threshold (-kPa)	Predicted Marketable Yield ($kgha^{-1}$)	WUE ($kg_{fruit}m^{-3}_{water}$)		Increase in WUE[1] (%)
		Conventional Irrigation Management (Grower + ET_c)	ψ-based Irrigation Management	
10	52,571	12.6	16.7	32.8
15	51,124	13.6	18.7	37.7
20	49,677	14.8	21.3	44.3
25	48,230	16.3	25.1	53.7
30	46,782	18.4	30.9	68.2
35	45,335	21.2	41.1	93.4

[1]Corresponds to the increase in WUE with ψ-based management in comparison with conventional method.

1. Calculated from a same amount of water used.

For a same amount of water used, the conventional management produced less yield than the ψ-based irrigation method. Therefore, WUE was improved with the latter method, from 7.5% to 8.3%, depending on the amount of water used. Results are presented in Table 4.

Table 4. Water use efficiencies calculated from a same amount of water used.

Predicted Water Use (m^3m^{-2})	Conventional Irrigation Management (Grower + ET_c)			ψ-based Irrigation Management			Increase in WUE (%)[1]
	Average Irrigation Threshold (-kPa)	Predicted Marketable Yield ($kgha^{-1}$)	WUE ($kg_{fruit}m^{-3}_{water}$)	Average Irrigation Threshold (-kPa)	Predicted Marketable Yield ($kg\ ha^{-1}$)	WUE ($kg_{fruit}m^{-3}_{water}$)	
0.32	22.4	48,925	15.6	10.0	52,570	16.7	7.5
0.30	25.0	48,230	16.3	12.4	51,875	17.6	7.6
0.26	30.0	46,780	18.4	17.4	50,430	19.8	7.8
0.21	35.0	45,335	21.2	22.4	48,980	22.9	8.0
0.17	40.0	43,890	25.4	27.4	47,535	27.6	8.3

[1]Corresponds to the increase in WUE with ψ-based management in comparison with conventional method.

Economic Analysis

The analysis showed that money savings associated with a diminution of water use were small relative to the decrease of income associated with yield loss (Fig. 1). Indeed, while water savings accounted for \$341 ha^{-1} and cost operation savings due to a diminution of harvested fruits totalised 5539 ha^{-1}, yield losses reached \$11,077 ha^{-1} for a net loss of \$5198 ha^{-1}. This can be explained by the fact that the cost of water used in this study was not high enough for this crop to justify a decrease water use.

Figure 1. Cost-benefit analysis associated with increasing WUE using a dry irrigation strategy (saving 0.14 m of water at the expense of yields). The cost-benefit analysis applies to both conventional and ψ-based managements.

Fig.1 shows that both triggering irrigations at -40 kPa instead of -22.4 kPa with conventional management and triggering irrigations at -27.4 kPa instead of -10 kPa with the ψ-based management lead to water savings of 45% (0.14 m or 0.47 acft ac^{-1} of water) and increased WUE by 64%. However, yield losses of 10% (5035 $kgha^{-1}$) were associated with such a practices. In terms of money, yield losses are more important than gains associated with water savings, resulting in a net loss for the grower.

Hence, results show that there are no economic benefits associated with increasing water use efficiency based on a deficit irrigation strategy with such crop, for both conventional and ψ-based managements.

CONCLUSIONS

The following conclusions can be drawn from the study:

- Irrigation management based on soil matric potential substantially improved WUE compared to conventional management, regardless of the production region and soil type.
- The economic analysis revealed that, for conventional and matric potential based irrigation strategy, the benefit-cost ratio is mainly driven by the marketable yield since the cost of water is low.
- There are no economic benefits associated with increasing water use efficiency based on a deficit irrigation strategy in strawberry production in California, for both conventional and ψ-based managements, because the benefits associated with water savings are negligible compared to yield losses.

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