Potential Vineyard Evapotranspiration (ET) Due to Global Warming: Comparison of Vineyard ET at Three Locations in California Differing in Mean Seasonal Temperatures

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Abstract

An increase in global temperature has been predicted to increase evaporative demand as it is controlled by temperature, net radiation, wind and relative humidity. This would suggest that vineyard evapotranspiration (ET) and/or irrigation requirements will increase under future climate scenarios. Crop evapotranspiration (ET_c) can be calculated using the following equation: $ET_c = ET_o * K_c$, where ET_o is reference ET and K_c is the crop coefficient. Vineyard ET was estimated during the 2009-growing season at three locations in California: Carneros (southern Napa Valley), Lodi (northern San Joaquin Valley) and Parlier (southern San Joaquin Valley). It was assumed that the vineyard sites used the same cultivar, training system and row spacing. The seasonal K_c values used were a function of degree-days. Mean seasonal (April 1 to October 31) temperatures for 2009 at Carneros, Lodi and Parlier were 15.2, 18.2 and 20.6°C and accumulated degree days (base of 10°C) were 1575, 2147 and 2670, respectively. Seasonal ET_o in 2009 was 1136 mm at the Parlier site while ET_o was 95 and 84% of that value at Lodi and Carneros, respectively. The increase in the K_c to the seasonal maximum value (0.82) was delayed at the Carneros site, compared to the Lodi and Parlier sites. Estimated ET_c was 778, 732 and 599 mm at the Parlier, Lodi and Carneros locations, respectively. A mean seasonal temperature increase of 5.4°C (Carneros/Parlier comparison) resulted in a 70% increase in accumulated degree-days. Using the same two locations comparison, ET_o increased ~19% while that for estimated ET_c increased ~30%. The increase in ET_c from Carneros to Lodi to Parlier was due to both increases in evaporative demand and temperature, the latter accelerating canopy development (affecting the K_c).

INTRODUCTION

The global temperature is increasing (IPPC, 2007). This warming is predicted to increase the frequency and duration of drought (Breshears et al., 2005). This may have profound effects on viticulture as many grape growing regions depend upon rainfall to produce a harvestable crop of high quality. An example of such occurred in 2003 where both increased temperatures during the summer months (in some instances > than 6oC above long-term averages) and annual precipitation deficits of up to 300 mm per year occurred in Europe decreasing primary productivity (Ciais et al., 2005). It has been demonstrated that regional warming (albeit only 1.13°C) has occurred over the coastal California wine grape production area during the period from 1951 to 1997 (Nemani et al., 2001). Such warming may shift premium wine production in the Unites States (White et al., 2006).

Most vineyard production areas in California receive no rainfall during the majority of the growing season (April to September) (Williams and Matthews, 1990). Therefore, irrigation is required at some time during this period across California.

Predictions concerning the effect of global warming on crop evapotranspiration (ET_c) are still uncertain but it is assumed that ET_c will increase (Morison et al., 2008). Goyal (2004) suggested that a 20% increase in temperature will increase ET_c by ~15%. However, such may not occur if there is a decrease in net solar radiation or an increase in vapor pressure. A continued increase in atmospheric CO_2 concentration though may actually decrease ET_c (Kruijt et al., 2008).

This paper will present estimated, seasonal vineyard ET_c at three locations in California using data from the 2009 growing season. The three locations differ in seasonal mean temperatures. The ET_c values at each location were calculated as the product of reference ET values and seasonal crop coefficients (Allen et al., 1998) developed specifically for a California sprawl type canopy in vineyards with a row spacing of 3.35 m row.

MATERIALS AND METHODS

The three locations chosen to calculate potential vineyard water use in this study differed in seasonal mean temperature. The first site chosen was in the Carneros district located in the southern portion of Napa Valley in California. It is within view of the San Francisco Bay. The weather station used to collect the data at this site was located 38°13' N;122°21'W at an elevation of 2 m. The second site, Lodi (located in the northern San Joaquin Valley of California), was located 38°8'N;121°23'W at an elevation of 8 m. The third site, Parlier (located in the southern San Joaquin Valley of California, southeast of the city of Fresno), was located 36°36'N;119°21'W at an elevation of 103 m. Vineyard ET was calculated using the following assumptions: the same cultivar/rootstock was used at each location, the trellis system (canopy type) was the California sprawl and row spacing was 3.35 m.

The weather data set used was that measured during 2009. The weather stations were operated by the California Information Management Information System (CIMIS) (www.cimis.water.ca.gov). Temperature data were obtained from the CIMIS weather stations at the University of California's Integrated Pest Management Website (www.ipm.ucdavis.edu). Degree-days were calculated at the IPM website using the single sine method with a base temperature of 10°C. Reference ET (ET_o) was obtained from the CIMIS website with ETo calculated according to the procedures of Synder and Pruitt (1992). Reference ET was calculated using the modified Penman equation with a wind function developed at the University of California. In addition, CIMIS also provided ET_o values using the Penman-Monteith equation.

Vineyard evapotranspiration (ET_c) was calculated using to the following equation:

$$ET_c = ET_o \times K_c \qquad (1)$$

where ET_o is reference ET and Kc is the crop coefficient (Allen et al., 1998). The seasonal crop coefficients were those specifically for a California sprawl canopy at a row spacing of 3.35 m. The seasonal K_c was developed from the relationship between percent shaded area measured beneath the canopy at solar noon and the K_c determined with the use of a weighing lysimeter that directly measured ET_c (Williams and Ayars, 2005b). The technique was subsequently validated in different vineyards (unpublished data). The seasonal K_c was a function of degree-days (Fig. 1). The equation to describe this relationship is as follows:

$$K_c = 0.82/(1+e(-(x-275)/150)) \qquad (2)$$

where x equals degree days from March 15 with a base temperature of 10°C and e equals 2.71828. The maximum K_c value was 0.82. The Kc did not decrease later in the growing season as it has been shown it does not decrease as long as the vines are being irrigated with water amounts at full ET_c (Williams and Ayars, 2005a).

RESULTS

The monthly mean high, low and average temperatures were approximately 5 and 2.5°C greater at the Parlier site compared to the Carneros and Lodi sites, respectively, from March through October (Table 1). Cumulative degree-days at the Parlier site were 2670 from March 15 to October 31 while those at Carneros and Lodi were 59 and 80% of that value, respectively. Monthly mean solar radiation values were similar (~250 W m^{-2}) for the Parlier and Lodi sites while 6% less at the Carneros site (Table 1).

Cumulative ET_o (March 15 to October 31) at the Parlier site was 1136 mm while those for the Carneros and Lodi sites were 84 and 95% of that value, respectively (Table 1). Differences in daily ET^o among locations on 7 July 2009, were primarily due to differences in relative humidity (Table 2). The weekly calculation of vineyard ET was greater earlier in the season at the Lodi and Parlier sites compared to those at Carneros (Fig. 2). Subsequent to the middle of July (Day of Year 210) weekly ET_c among the three sites were somewhat similar. The cumulative, estimated seasonal ET_c at the Parlier site was 778 mm (Table 1). Those at Carneros and Lodi were 77 and 94% of that value, respectively.

DISCUSSION

The estimated value of seasonal ET_c (778 mm) at the Parlier site is similar to that measured with a weighing lysimeter at the same location (Williams and Ayars, 2005a,b; Williams et al., 2003) using vines with a comparable canopy type and vineyard row spacing. This would indicate that the estimates of ET_c at the other two locations were realistic. Therefore, the calculation of ET_c using Equation 1 could be a useful method to estimate the response of ET_c to future climate scenarios. However, one needs reliable seasonal crop coefficients for the method to be useful. Using the relationship between the amount of shade cast on the ground at solar noon (% shaded area, which equals the amount of shade per vine divided by the total surface area per vine within the vineyard) and the K_c determined with a weighing lysimeter (Williams and Ayars, 2005b) would be a viable means to provide an estimate of the K_c as the season progresses. In the aforementioned reference the K_c is the product of the percent shaded area and 0.017 (slope of the relationship). This method has been used successfully to schedule irrigations for 'Cabernet Sauvignon' vines grafted to different rootstocks using a vertical shoot positioning (VSP) trellis (Williams, 2010).

Reference ET is used as a measure of evaporative demand and it is a function of net radiation, vapor pressure deficit and wind speed (Allen et al., 1998). Using the data set presented in this paper, ET_0 was greatest at the Parlier site while those at Lodi and Carneros were 84 and 95% of that value, respectively. The large differences in mean temperature and degree-days from one location to another were apparently not related to the much smaller differences in ET_0 at those locations. It has been shown that measurements of Class A pan evaporation in Israel's central coastal plain from 1964 to 1998 indicate a small but statistically significant increase due to increases in vapor pressure deficit and wind speed (Cohen et al., 2002). Conversely, pan evaporation over the western United States has been show to decrease in the past few decades (Peterson et al., 1995). Additionally, data collected from 1951 to 1997 in California's northern coastal valleys (locations of premium wine production) indicated that water vapor has increased with an average reduction in VPD of 7% (Nemani et al., 2001). It was concluded that the lower VPD would reduce evaporative demand and water stress. In this study the values of ET_0 from one location to another were primarily a function of differences in the diurnal patterns of VPD and to a lesser extent small changes in daily solar radiation.

The reduction in estimated ET_c at the Lodi site compared to that at Parlier was similar to the reduction in ET_0 between the two locations. However, ET_c at the Carneros site was only 77% that at Parlier. This was 7% lower than the differences in ET_0 at the two locations. It is assumed that the greater reduction in ET_c at the Carneros site was due to cooler temperatures and the delay in canopy development compared to the other locations. Since the K_c is a function of degree-days, and canopy development is highly dependent upon temperature this would be expected. Warming over the coastal valleys of California has been shown to be asymmetric (Nemani et al., 2001). Nearly all the warming has been caused by increases in minimum temperature (perhaps due to increased cloud cover) with very little change in maximum temperature. In addition, the increase in spring warming was double that that occurred during the rest of the year.

The results from this study would indicate that an increase in temperature would enhance grapevine canopy development thereby increasing ET_c. Interestingly, a recent study has shown that 'Shiraz' grapevines will significantly increase stomatal conductance in response to increased ambient temperatures at a common vapor pressure deficit (Soar et al., 2009). This may also increase vineyard ET_c as temperatures rise. However, an increase in atmospheric vapor pressure and continued increase in atmospheric CO_2 concentration may offset the increase in canopy development and stomatal conductance under future climate scenarios. The above indicate the complexity of the effects of potential increases in temperature on grapevine growth and physiology and the ability to predict global warming's effect on vineyard ET_c here in California and elsewhere.

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Tables

Table 1. Mean temperature and solar radiation data collected for the months March through October in 2009 at the three locations used in the study. Cumulative degree-days, reference ET (ET_o) and calculated vineyard ET (ET_c) are for the period from March 15 to October 31 during 2009.

Measured or calculated parameter	Location		
	Carneros	Lodi	Parlier
Mean low temperature (°C)	7.4	10.2	12.2
Mean high temperature (°C)	24.0	26.8	29.2
Mean temperature (°C)	15.2	18.2	20.6
Mean hourly solar radiation (W m^{-2})	250	249	215
Cumulative degree-days (>10°C)	1575	2147	2670
Cumulative ET_o (mm)	955	1080	1136
Cumulative ET_c (mm)	599	732	778

Table 2. Maximum temperature (Max. Temp.), minimum relative humidity (Min. RH), mean daily solar radiation (SR) and reference ET (ET_o) on 7 July 2009 at the three locations used in the study.

Location	Max. Temp. (°C)	Min. RH (%)	SR (W m^{-2})	ET_o (mm)
Carneros	23.3	56	321	5.58
Lodi	28.3	40	352	5.84
Parlier	33.3	18	334	7.11

Figures

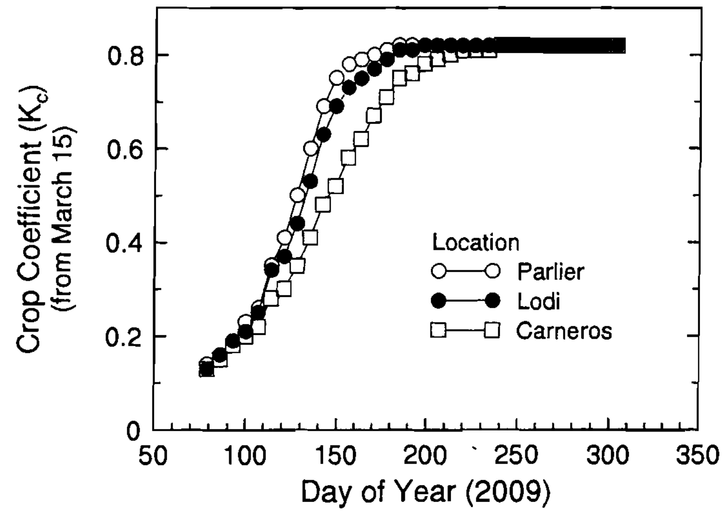

Fig. 1. The seasonal crop coefficients used in the study to calculate ET_c at each location. The crop coefficient is a function of degree days from March 15 but the data are plotted as function of day of the year to illustrate differences among locations. The equation describing the relationship between the crop coefficient and degree-days is given in the Materials and Methods section.

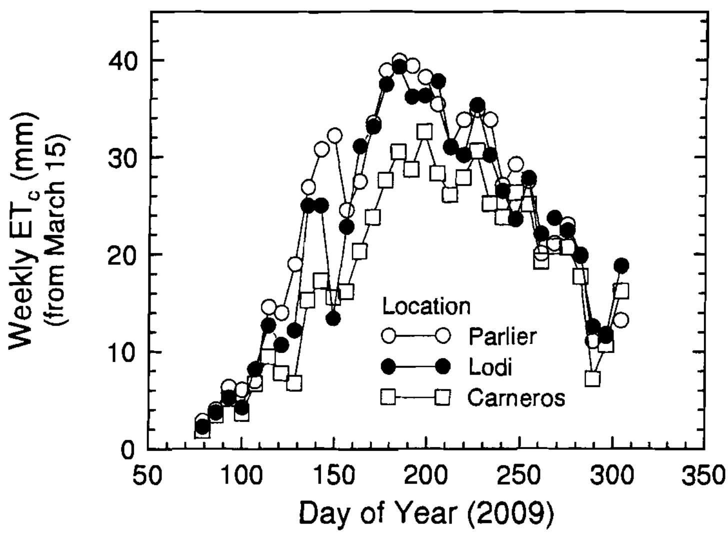

Fig. 2. Weekly calculated ET_c at the three locations throughout the 2009-growing season.

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