Water use of Thompson Seedless grapevines as affected by the application of gibberellic acid (GA$_3$) and trunk girdling – practices to increase berry size

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Abstract

Seasonal water use of *Vitis vinifera* L. (cv. Thompson Seedless, clone 2A) was determined with a large weighing lysimeter in the San Joaquin Valley of California from 1994 to 1996. The first year of the study, the vines growing within the lysimeter were treated as would be done to produce fruit for use as table grapes; the application of gibberellic acid (GA$_3$) and trunk girdling at berry set (approximately 2 weeks after anthesis). Both practices will increase berry size of this seedless cultivar. In 1995, the vines in the lysimeter were only girdled at berry set, no application of GA$_3$ at that time. Reference crop evapotranspiration (E$_{To}$) between March 15th and the end of October averaged 1124 mm across the 3 years. Water use shortly after the vines were girdled in 1994 increased as would be expected for non-girdled grapevines while in 1995 water use after girdling decreased for a period of approximately 4 weeks. Once the girdles healed (callused over) in 1995 water use increased to values similar to those of the previous year. The crop coefficient ($K_c$) subsequent to girdling in 1994 remained constant for a period of 4 weeks while the $K_c$ decreased after girdling in 1995. The $K_c$ increased after the girdles healed both years and remained at a value of approximately 0.9 until the end of October. In 1996, the vines in the lysimeter received none of the treatments used the previous 2 years. The seasonal water use and maximum daily water use in 1996 of the vines in the lysimeter were greater than in 1994 and 1995. Water use of the vines was equivalent to 838, 708 and 936 mm from March 15 until the end of October while that of E$_{To}$ was 1136, 1060, and 1176 during the same period in 1994, 1995 and 1996, respectively. At full canopy in 1996 the $K_c$ leveled off at a value of 1.1 and remained such until the end of October. The results indicate that girdling the trunks of grapevines can affect water use when compared to non-girdled grapevines. Additionally, the $K_c$ of this perennial horticultural crop does not decrease after harvest or later in the season if the vines are fully irrigated and insect pests are controlled.

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Keywords: Crop evapotranspiration (E$_{To}$); Crop coefficient ($K_c$); *Vitis vinifera* L.; Table grape production; Trunk girdling
1. Introduction

Thompson Seedless grapevines are planted throughout the world and are used to produce dried fruit (raisins), grapes for the fresh market (table grapes) and juice for concentrate or blending in wine (Mullins et al., 1992). Natural berry size (~1.5 g) of this cultivar is not large enough for commercial use as table grapes so cultural practices are used to increase its size several fold (up to 10 g berries have been found in some vineyards, L.E. Williams personal observation). Berry size is increased with the use of several gibberellic acid (GA3) applications; prior to anthesis, at anthesis and at berry set approximately 2 weeks after anthesis (Harrell and Williams, 1987b). Girdling, which consists of removing a small section of phloem (~4 mm in width) from around the trunk, has long been used to increase berry size commercially (Jacob, 1931). This procedure is performed at berry set (Harrell and Williams, 1987b). Callus formation (a wound response by the vine) will usually bridge the girdle in approximately 4 weeks and reestablish vascular connections (Williams et al., 2000). Girdling and the application of GA3 are also used on other seedless table grape cultivars in vineyards around the world (Mullins et al., 1992).

Girdling will increase berry size despite the fact that it reduces net CO2 assimilation rate (A) and stomatal conductance (gs) of individual leaves of grapevines (Harrell and Williams, 1987a; Hofacker, 1978; Kriedemann and Lenz, 1972; Roper and Williams, 1989). The increase in berry size due to girdling may result from better carbohydrate nutrition above the girdle as the transport of sugars from leaves to the root system is effectively blocked (Roper and Williams, 1989). Alternatively, changes in the hormone balance of the vine after girdling may have a role on increasing berry size (Kriedemann and Lenz, 1972). The reduction in A and gs will last until the girdle wound heals, approximately 4 weeks later (Williams et al., 2000). The application of GA3 to the vine’s canopy though has been shown to mitigate the depressing effect of girdling on leaf gas exchange (Harrell and Williams, 1987a; Roper and Williams, 1989).

The reduction in stomatal conductance for a significant period time after girdling should affect water use of grapevines. Bucks et al. (1985) reported a 25% decrease in water use of Perlette grapevines after girdling when compared to the vine’s water use prior to girdling the trunk. Once the girdle healed, vine water use increased up to harvest and then leveled off.

Water use of Thompson Seedless grapevines has been measured in a weighing lysimeter since it was installed at the Kearney Agricultural Center in 1986 and the vineyard was planted in 1987 (Williams et al., 2003a, 2003b). Prior to 1994 the vines were managed for use as raisins and ETc (vineyard evapotranspiration) ranged from 811 to 865 mm per growing season (March 15 to October 31). The production of natural raisins does not involve the use of cultural practices to increase berry size. The vines in the lysimeter and surrounding vineyard were sprayed with GA3 and trunk girdled in order to increase berry size in 1994. In 1995 the vines within the lysimeter were only trunk girdled at berry set (no GA3 applications) while for the next growing season none of the previously mentioned cultural practices were performed on the vines in the lysimeter. This study will report on the effects of trunk girdling and GA3 applications on whole vine water use.

It is often assumed that the $K_c$ will decrease linearly for agricultural and horticultural crops after the mid-season plateau has been reached (Allen et al., 1998; Synder et al., 1989). In a previous study on water use of mature grapevines Williams et al. (2003b) found that the $K_c$ did in fact decrease towards the end of the season. However, for the last 3 years of that study variegated leafhoppers (Erythroneura variabilis Beamer) were not controlled as an entomological study was conducted in the vineyard at that time (Daane and Williams, 2003). Due to high population numbers of the leafhopper, vines were nearly defoliated by the third brood, coinciding with fruit harvest or shortly thereafter. Throughout the 1994 to 1996 growing seasons insecticides were used to control the variegated leafhopper. Therefore, the present study was also conducted to determine the response of the $K_c$ after harvest if there was no leafhopper pressure and irrigation continued.

2. Materials and methods

The study was conducted at the University of California Kearney Agricultural Center (36°48' N,
119°30' W) where a weighing lysimeter had been installed in 1986 (Williams et al., 2003a). The lysimeter contained two Vitis vinifera L. (cv. Thompson Seedless, clone 2A) grapevines. The two vines were 2.15 m apart and 0.925 m from either end of the 4 m long lysimeter and 1 m from the sides. The trellis consisted of a 2.13 m long wooden stake driven 0.45 m into the soil at each vine. A 0.6 m cross-arm was placed atop the stake and wires attached at either end of the cross-arm to support the vine’s fruiting canes. The 1.4 ha vineyard surrounding the lysimeter was planted to east–west rows with vine and row spacings of 2.15 and 3.51 m, respectively. The length allocated to the two vine’s canopies within the lysimeter was similar to that of the vines in the vineyard surrounding the lysimeter.

The vines in the lysimeter were irrigated with 4 L h⁻¹ in-line drip emitters, spaced every 0.3 m. The drip tubing was attached to a wire suspended 0.4 m above the soil surface. The lysimeter’s mass was recorded hourly to determine ETc of the two vines and the lysimeter soil surface, and the change in mass was compared with a 16-L threshold value of water loss, equivalent to 2 mm ETc over the 8 m² lysimeter surface. When the threshold was exceeded, the lysimeter was irrigated. The number of irrigations per day ranged from 0 to 7 once irrigations commenced (Table 1) until the end of October each year.

The summation of hourly ETc values was used with the summed hourly values of measured vine evapotranspiration (ETv) to calculate the daily crop coefficient (Kc). The Kc was the ratio of ETc/ETv. Once irrigation commenced, the ETc measured by the lysimeter was adjusted to an area equivalent loss of an individual vine in the lysimeter (4 m² of surface area), to that of vines in the surrounding vineyard (7.55 m² of surface area), by multiplying by 0.53. It was determined that soil water evaporation in the area outside the lysimeter was minimal (Williams et al., 2003b). Soil evaporation between rows in that study was shown to range from 0.26 mm day⁻¹ at the end of May to 0.09 mm day⁻¹ in September. Further technical aspects of measuring vine water use (ETc) and estimation of leaf area of the vines within the lysimeter were similar to those previously given (Williams et al., 2003a, 2003b).

Reference crop evapotranspiration (ETr) data were obtained from a California irrigation management information system (CIMIS) weather station (number 39) located 2 km from the vineyard site. Variables measured and calculation used to determine hourly and daily ETr from CIMIS can be found in Synder and Pruitt (1992). Degree-day data were obtained from the University of California Statewide Integrated Pest Management Project’s website. Temperature data used in calculating degree-days were obtained from the CIMIS weather station at the Kearney Agricultural Center. Degree-days were calculated using the sine method with a lower threshold of 10 °C.

Soil water content (SWC) within the lysimeter was monitored using the neutron back-scattering technique with a neutron moisture probe (Model 503 DR Hydroprobe moisture gauge: Boart Longyear, Martinez, California). Two access tubes were placed approximately 0.5 m from each vine within the row (approximately 1.0 m between the two tubes) and inserted to a depth of 1.8 m. Readings were taken at depths of 0.23, 0.45, 0.75, 1.05, 1.35 and 1.65 m from the soil surface. Field capacity of this soil type was approximately 22.0% by volume (uv) while SWC at a soil moisture tension of −1.5 MPa was approximately 8.0 uv (Araujo et al., 1995).

Vines were sprayed with gibberellic acid (GA3 – ProGib, Abbot Laboratories) at a rate of 12 g ai ha⁻¹ when approximately 50% of the flowers had opened in 1994 and 1995. Vines were sprayed with GA3 (104 g ai ha⁻¹) and trunk girdled at berry set (berry

<table>
<thead>
<tr>
<th>Year</th>
<th>Date of budbreak</th>
<th>Date of first irrigation</th>
<th>Date of anthesis</th>
<th>Date of harvest</th>
<th>Degree-day accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>17 March (76)</td>
<td>28 April (118)</td>
<td>12 May (132)</td>
<td>12 August (224)</td>
<td>2478</td>
</tr>
<tr>
<td>1995</td>
<td>4 March (63)</td>
<td>8 May (128)</td>
<td>18 May (128)</td>
<td>18 August (230)</td>
<td>2420</td>
</tr>
<tr>
<td>1996</td>
<td>15 March (74)</td>
<td>7 May (127)</td>
<td>10 May (130)</td>
<td>21 August (233)</td>
<td>2606</td>
</tr>
</tbody>
</table>

Day of year is given after each calendar date in parentheses.
diameter ~5 mm) in 1994 but they were only girdled (no GA3) at berry set in 1995. Girdling took place on May 25 and June 6 in 1994 and 1995, respectively. Vines were trunk girdled with a double-bladed 4.8 mm knife and rechecked for completeness (to insure that no phloem remained) each year. Approximately 3 weeks after girdling small clusters were removed from the vines and leaves up to the fourth or fifth basal node on all shoots were removed as were any non-fruitful shoots and lateral shoots growing in the fruiting zone. Numerous times during the 1994 and 1995 growing seasons shoots were hedged (the apical portion of the shoot/cane was removed) keeping the foliage curtains on each side of the vines ~0.4 m from the soil surface. This is a normal practice in commercial table grape vineyards allowing easier access to the fruiting zone for vineyard workers. Leaf and lateral shoot removal were not performed during the 1996 growing season and shoot hedging only occurred once that season, on August 5. Leaf blades were removed from the portion of the shoots that had been hedged and total area was measured with an area meter. Leaf areas of the vines in the lysimeter were estimated by removing 50% of the leaves from three individual vines elsewhere in the vineyard of similar size. This technique was shown to provide a good estimate of the leaf areas of the vines in the lysimeter (Williams et al., 2003a, 2003b).

Transient measurements of net CO2 assimilation (A) and stomatal conductance (gs) taken on individual, fully expanded leaves from the top of the canopy were conducted as previously described (Roper and Williams, 1989). Midday leaf water potential (ΨL) was measured on leaves similar to those used for A and gs measurements using the procedure described by Williams and Araujo (2002). Briefly, leaves were enclosed in a plastic bag prior to cutting the petiole. The bagged leaf was placed into a pressure chamber and pressurization at a rate of 0.03 MPa/s commenced within 15 s of the petiole being cut.

3. Results

The initiation of seasonal irrigation commenced the last week of April in 1994 and at the end of the first week of May the remaining 2 years (Table 1). The monthly rainfall distribution resulted in the least amount of rain the last 2 weeks of March (beginning the 15th of the month) in 1994 compared to 1995 and 1996 while total rainfall during the months of April and May were somewhat similar across years (Table 2). Dates of anthesis varied by 8 days during the 3-year study. The vineyard harvest date occurred early to mid-August as fruit used for table grape production is harvested at a lower soluble solids (sugar concentration) than would normally had occurred if the fruit had been used for raisins. The accumulation of degree-days was a little greater in 1996 compared to the earlier 2 years. Seasonal ET0 totals were similar in 1994 and 1996 but ~8% less in 1995 (Table 2). Daily maximum ET0 was approximately 7 mm in 1994 and 1996 while a little less during the 1995 growing season (Fig. 1). The large variations in daily ET0 early in each growing season were associated with rainfall events.

The seasonal pattern of total soil water content within the lysimeter was reflective of the date irrigations were initiated and the fact that vines were irrigated with water amounts equal to the amounts used by the vines (Fig. 2). There was a decrease in soil water content prior to the initiation of irrigation each year followed by an increase that subsequently leveled off and remained such until the end of October.

Once the vine’s canopies were fully developed each growing season, the width of the canopy above the cross-arm was 1 m and the width of the canopy’s curtains on either side of the vine was ~1.6 m when the shoot tips touched the soil surface. Shoots were not allowed to touch the soil surface in 1994 and 1995 while in 1996 shoots were allowed to grow along the soil surface prior to hedging. Based upon visual

### Table 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Monthly rainfall (mm)</th>
<th>ET0 (mm)</th>
<th>ETc (L vine⁻¹)</th>
<th>ETc (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>Mar. 10; Apr. 30; May 21; Sep. 23</td>
<td>1136</td>
<td>6328</td>
<td>838</td>
</tr>
<tr>
<td>1995</td>
<td>Mar. 60; Apr. 22; May 7</td>
<td>1060</td>
<td>5347</td>
<td>708</td>
</tr>
<tr>
<td>1996</td>
<td>Mar. 75; Apr. 20; May 7; Oct. 39</td>
<td>1176</td>
<td>7070</td>
<td>936</td>
</tr>
</tbody>
</table>

Rainfall amounts (mm listed behind monthly abbreviations) are given when precipitation exceeded 5 mm for the month.
observations and the relationship between the $K_c$ and leaf area established in a previous study (Williams et al., 2003b) it was estimated that the maximum leaf area in 1994 and 1995 was approximately 25 m$^2$ per vine.

Daily water use increased similarly in 1994 and 1995 from March 15th until the vines were girdled (Fig. 3). Water use continued to increase after girdling in 1994 but decreased during the next 4 weeks in 1995. Water use in 1995 was reduced approximately 15% the fourth week after girdling compared to prior to girdling (31 L day$^{-1}$ versus 26.7 L day$^{-1}$) and then increased to 33 L day$^{-1}$ the following week. During this period of time, $A$ and $g_s$ were reduced when compared to measurements taken prior to girdling and once the girdle had healed (Table 3). Midday $\psi_l$ was higher during the period when the girdle was open compared to before girdling and after the girdle had healed. Maximum daily water use was 48 and
38 L day$^{-1}$ in 1994 and 1995, respectively. The diurnal patterns of grapevine water use in 1995 when the girdle was open and when it had healed were similar (Fig. 4). The greatest differences in hourly water use between the two occurred from 1000 to 1600 h.

The seasonal crop coefficients for 1994 and 1995 were similar early and late in the season but differed in response to girdling (Fig. 5). The $K_c$ remained constant for a 4-week period in 1994 while it decreased for the same length of time in 1995. Once the girdles had healed, the $K_c$ increased up to a value of 1.0 at the end of July (DOY 210 or $\sim$1500 DDs) in 1994 and leveled off thereafter while that in 1995 slowly increased season long finally reaching a value of almost 1.0 at the end of October.

A comparison in vine water use and $K_c$ was made among years for the 6-week period beginning the week vines were girdled in 1994 and 1995 and a comparable time frame during the 1996 growing season (Table 4). Reference ET was greater in 1994 during this time period compared to the 1995 and 1996 growing seasons. Grapevine water use in 1994 and 1995 was 93 and 78% of that in 1996. The mean crop coefficients were similar for 1994 and 1995 while that in 1996 was 25% greater than those of the previous 2 years.

Maximum daily water use in 1996 was greater than 50 L day$^{-1}$ (Fig. 3). The spike in water use at 700 DDs was due to a large increase in ET$\alpha$ (up to 7 mm day$^{-1}$) followed by a slow decrease to only 5 mm day$^{-1}$. The increase in the seasonal $K_c$ during 1996 was similar to the previous 2 years but the maximum $K_c$ was greater than 1.2. Leaf area of vines in the surrounding vineyard and similar in appearance to the vines within the lysimeter averaged 34 m$^2$ vine$^{-1}$ the first week in August. The vines in the lysimeter were hedged on August 5 (DOY 217, $\sim$1600 DDs) and 6 m$^2$ of leaf area per vine were removed. This reduced the $K_c$ to a value of less than 1.1 and it remained lower than 1.1 (with one exception) for the next 7 weeks.

### 4. Discussion

Girdling grapevines will reduce $g_s$ of individual leaves as was shown here and elsewhere (Harrell and Williams, 1987a; Hofacker, 1978; Kriedemann and
until the girdle healed. The reduction in the $K_c$ for 1995 is similar to that reported by Bucks et al. (1985) on the cultivar Perlette grown in Arizona when the $K_c$ also decreased in response to girdling for a 4-week period and then increased after the girdle healed. It has been demonstrated that GA$_3$ will mitigate some of the depressing effects of girdling on A and $g_s$ of individual leaves of grapevines (Roper and Williams, 1989). However, the effect of GA$_3$ alone on A and $g_s$ in that study was no different from the control. The reduction in $g_s$ and concomitant reduction in vine water use in response to girdling is probably due to the accumulation of abscisic acid (ABA) in the leaves (During, 1978; Loveys and Kriedemann, 1974; Williams et al., 2000). It would appear that the reduction in $g_s$ due to girdling is a non-hydraulic response of the grapevine and as such, vine water status (leaf water potential) is more favorable (less negative) for girdled vines compared to non-girdled vines due to reduced transpiration (Williams et al., 2000). The daily pattern of a girdled vine’s water use was similar to that of the vines prior to girdling, the exception being a reduction in magnitude. This is similar to that reported by Roper and Williams (1989) for single leaves of girdled and non-girdled vines.

Seasonal vine water use was the lowest in 1995 compared to 1994 and 1996. This was probably due to ET$_o$ being lower in 1995 (~8% less compared to 1994 and 1996) and the small reduction in vine water use due to girdling. Vine water use in 1994 was similar to that reported from 1991 to 1993 (mean of 844 mm) for these same vines (Williams et al., 2003b) but less than that in 1996. The study by Williams et al. (2003b) demonstrated that leaf area was an important determinant of seasonal vine water use. In the present study leaves, non-fruitful shoots and lateral shoots in the fruiting zone of vines treated for table grape production were removed subsequent to berry set which may have affected whole vine water use. In fact, leaf and shoot removal in commercial table grape vineyards using different cultivars (not Thompson Seedless) is much more extensive than that done in this study. In addition, shoots were hedged (removal of the apical portion close to the ground) quite often, as would have been the normal practice in a commercial table grape vineyard. Conversely, total vine leaf area in 1996 was allowed to reach 34 m$^2$ per vine resulting in greater daily vine water use mid and later in the growing season.
season when compared to the 1994 and 1994 growing seasons. It is estimated that maximum leaf area for the vines in the lysimeter during the 1994 and 1995 growing seasons was approximately 25 m² per vine once canopies reached full coverage.

The early season $K_c$ was similar among the 3 years in this study and to those previously reported for the same vines (Williams et al., 2003b). In 1994 the $K_c$ leveled off for a period of 4 weeks after girdling (the period in which the girdle remained open). The $K_c$ actually decreased subsequent to girdling in 1995, going from 0.7 to 0.58. Both years the $K_c$ increased rapidly after the girdle healed up until final canopy size was obtained. It is often assumed by commercial table grape growers that girdling is stressful for the vines and that vines should be irrigated with more water than normal during this time period. The data reported in this study indicates that this is not the case in this study. This differs from data presented by Williams et al. (2003b) and Peacock et al. (2000). The decrease in the seasonal $K_c$ reported by Williams et al. (2003b) was due to leafhopper damage (Daane and Williams, 2003) as insecticides were not used to control the insect and foliage damage and defoliation reduced vine water use and the $K_c$ at the insect’s third brood. It should also be pointed out that the production of natural raisins, where the fruit is laid on the ground to dry on paper trays, requires that the soil be dry (Christensen and Peacock, 2000). Therefore, the reduction in the $K_c$ as reported by Peacock et al. (2000) could be due to the lack of irrigation and plant stress and as such the $K_c$ should be replaced by $ET_c/ET_o$. This may change as many raisin growers in California are converting to ‘dried on the vine’ raisin production (Christensen and Peacock, 2000) where vines may continue to be irrigated while the fruit is drying.

The lack of a decrease in the $K_c$ after harvest or later reported in this study is similar to that recently published for peach trees (Ayars et al., 2003). Unlike most annual crops, harvesting the crop (fruit) of grapevines (and other woody, fruit tree species) does not necessarily signal the end of the growing season. The previous assumptions that the $K_c$ will start to decrease at harvest or later for tree and vine crops

Vines were girdled on day of year (DOY) 145 (490 DDs after 15 March) and 157 (539 DDs after 15 March) in 1994 and 1995, respectively. The amount of DDs accumulated from March 15th to DOY 141 in 1994, DOY 159 in 1995 and DOY 145 in 1996 were 560, 584 and 553, respectively. Each value is the daily average for the 7-day period ending on the DOY which is given in the table. The 6-week mean and total $ET_c$ and $ET_o$ for the 42-day period for each year are also given in the table.

### Table 4

Comparison of daily grapevine water use ($ET_c$), reference ET ($ET_o$) and crop coefficient ($K_c$) for a 6-week period beginning the week vines were girdled in 1994 and 1995 and for the vines from 1996

<table>
<thead>
<tr>
<th>Year</th>
<th>DOY</th>
<th>$ET_o$ (mm)</th>
<th>$ET_c$ (mm)</th>
<th>$K_c$</th>
<th>DOY</th>
<th>$ET_o$ (mm)</th>
<th>$ET_c$ (mm)</th>
<th>$K_c$</th>
<th>DOY</th>
<th>$ET_o$ (mm)</th>
<th>$ET_c$ (mm)</th>
<th>$K_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>151</td>
<td>6.10</td>
<td>4.20</td>
<td>0.69</td>
<td>159</td>
<td>5.95</td>
<td>4.10</td>
<td>0.69</td>
<td>145</td>
<td>5.91</td>
<td>3.84</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>158</td>
<td>6.81</td>
<td>4.60</td>
<td>0.68</td>
<td>166</td>
<td>5.75</td>
<td>4.03</td>
<td>0.70</td>
<td>152</td>
<td>6.19</td>
<td>4.46</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>165</td>
<td>7.27</td>
<td>5.21</td>
<td>0.72</td>
<td>173</td>
<td>6.47</td>
<td>3.81</td>
<td>0.59</td>
<td>159</td>
<td>7.03</td>
<td>6.75</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>172</td>
<td>7.07</td>
<td>4.90</td>
<td>0.69</td>
<td>180</td>
<td>6.10</td>
<td>3.54</td>
<td>0.58</td>
<td>166</td>
<td>6.52</td>
<td>6.46</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>179</td>
<td>7.20</td>
<td>5.01</td>
<td>0.70</td>
<td>187</td>
<td>6.26</td>
<td>4.38</td>
<td>0.70</td>
<td>173</td>
<td>6.06</td>
<td>5.58</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>187</td>
<td>7.12</td>
<td>5.50</td>
<td>0.78</td>
<td>196</td>
<td>6.31</td>
<td>5.05</td>
<td>0.80</td>
<td>180</td>
<td>5.06</td>
<td>4.61</td>
<td>0.91</td>
</tr>
<tr>
<td>Mean (42 days)</td>
<td>6.93</td>
<td>4.90</td>
<td>0.71</td>
<td>6.14</td>
<td>4.15</td>
<td>0.68</td>
<td>6.13</td>
<td>5.28</td>
<td>0.86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (42 days)</td>
<td>291</td>
<td>206</td>
<td>258</td>
<td>174</td>
<td>257</td>
<td>222</td>
<td></td>
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</tbody>
</table>
fruit is dried on the ground. The season long production of natural raisins in California where the fruit is dried on the ground. The season long \( K_c \) data presented in this paper is reflective of the standard definition of a crop coefficient. The \( K_c \) “relates to ET of a disease-free crop under optimum soil water and fertility conditions and achieving full production potential under the given growing environment” (Doorenbos and Pruitt, 1977) or when the \( K_c \) is used to predict \( \text{ET}_c \) (Eq. (56) in Allen et al., 1998) “it represents the upper envelope of crop evapotranspiration” under “conditions where no limitations are placed on crop growth or evapotranspiration due to water shortage, crop density, or disease, weed, insect or salinity pressures”.

5. Conclusions

The results indicate that water use of vineyards used for table grape production, where only girdling is employed, can be reduced for the period of time the girdle remains open. This will also affect the \( K_c \). However, seasonal water use for these vineyards may only be minimally affected compared to those in which this practice is not used. The lack of an actual decrease in either water use or a constant \( K_c \) when the vines were girdled in combination with an application of GA3 indicates that GA3 may possibly mitigate the depressing effect of girdling on \( g_s \) and subsequently whole vine water use. Additional studies are required to determine if this is the case.

In this study the \( K_c \) did not decrease after harvest or later as long as the vines were continually irrigated and that the foliage remained functional due to the season long control of insect pests. This was independent of whether the grapevines were farmed for use as table grapes or for the production of natural Thompson Seedless grapes used for raisins or crushed for juice or concentrate. Therefore, the decrease in the crop coefficient after the mid-season plateau for grapevines given in several publications may not be appropriate where irrigation continues through harvest and later in the season and the canopy remains fully functional, such as is the case for commercial table grape vineyards in the Coachella and San Joaquin Valleys of California.

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