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Water use of Thompson Seedless grapevines as affected by the application of gibberellic acid (GA_3) and trunk girdling – practices to increase berry size

L.E. Williams [a,*], J.E. Ayars [b]

[a] *Department of Viticulture and Enology, University of California – Davis and Kearney Agricultural Center, 9240 S. Riverbend Avenue, Parlier, CA 93648, USA*

[b] *Water Management Research Laboratory, USDA-ARS, Parlier, CA 93648, USA*

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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 (ET_o) 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 ET_o 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.

Keywords: Crop evapotranspiration (ET_c); Crop coefficient (K_c); *Vitis vinifera* L.; Table grape production; Trunk girdling

* Corresponding author. Tel.: +1 559 646 6558; fax: +1 559 646 6593.
E-mail address: williams@uckac.edu (L.E. Williams).

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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 (GA_3) 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 GA_3 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 CO_2 assimilation rate (A) and stomatal conductance (g_s) 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 g_s will last until the girdle wound heals, approximately 4 weeks later (Williams et al., 2000). The application of GA_3 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 ET_c (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 GA_3 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 GA_3 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 GA_3 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 ET_c 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 ET_c over the 8 m^2 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 ET_o values was used with the summed hourly values of measured vine evapotranspiration (ET_c) to calculate the daily crop coefficient (K_c). The K_c was the ratio of ET_c/ET_o. Once irrigation commenced, the ET_c measured by the lysimeter was adjusted to an area equivalent loss of an individual vine in the lysimeter (4 m^2 of surface area), to that of vines in the surrounding vineyard (7.55 m^2 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 (ET_c) 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 (ET_o) 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 ET_o 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 (θ_v) while SWC at a soil moisture tension of −1.5 MPa was approximately 8.0 θ_v (Araujo et al., 1995).

Vines were sprayed with gibberellic acid (GA_3 – 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 GA_3 (104 g ai ha^{-1}) and trunk girdled at berry set (berry

Table 1
Dates of budbreak, initiation of irrigation within the lysimeter, anthesis, harvest and the accumulation of degree-days (base temperature is 10 °C) from March 15 until October 31 observed for each year of the study

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

Day of year is given after each calendar date in parentheses.

diameter ~5 mm) in 1994 but they were only girdled (no GA_3) 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 CO_2 assimilation (A) and stomatal conductance (g_s) 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 (Ψ_l) was measured on leaves similar to those used for A and g_s 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 ET_o totals were similar in 1994 and 1996 but ~8% less in 1995 (Table 2). Daily maximum ET_o was approximately 7 mm in 1994 and 1996 while a little less during the 1995 growing season (Fig. 1). The large variations in daily ET_o 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
Rainfall amounts, reference ET (ET_o) and vine water use (ET_c) for the grapevines growing in the weighing lysimeter measured from March 15 until October 31 for the 3 years of the study

Year	Monthly rainfall (mm)	ET_o (mm)	ET_c (L vine^{-1})	ET_c (mm)
1994	Mar. 10; Apr. 30; May 21; Sep. 23	1136	6328	838
1995	Mar. 60; Apr. 22; May 7	1060	5347	708
1996	Mar. 75; Apr. 20; May 7; Oct. 39	1176	7070	936

Rainfall amounts (mm listed behind monthly abbreviations) are given when precipitation exceeded 5 mm for the month.

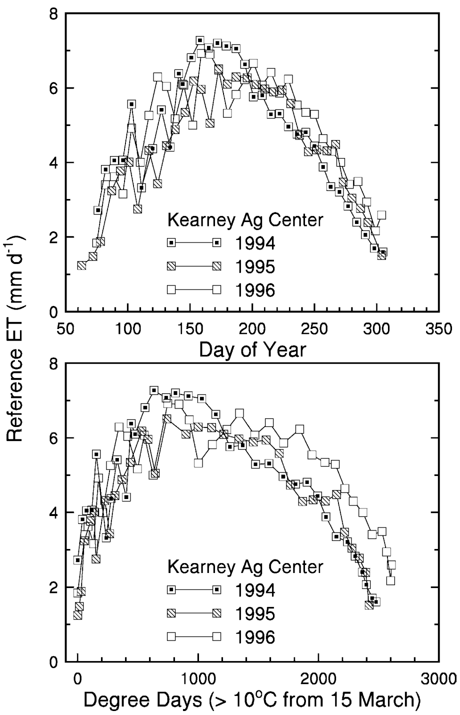

Fig. 1. Seasonal (from March 15 to October 31) reference ET (ET_o) for 1994, 1995 and 1996 measured at the Kearney Agricultural Center near Fresno, California as a function of day of the year and degree-days. Data were obtained from a California Irrigation Management Information System (CIMIS) weather station (number 39) located approximately 2 km from the grape lysimeter. Daily ET_o is averaged across 7 days.

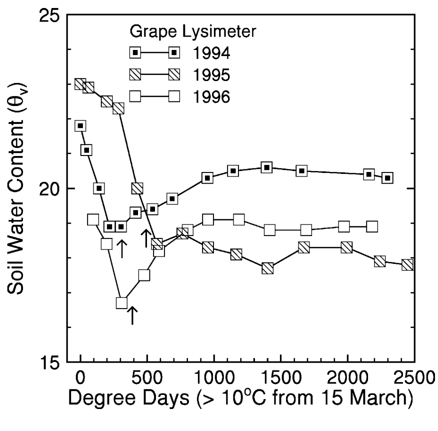

Fig. 2. Soil water content (expressed as percent by volume: θ_v) measured in the lysimeter during each growing season of the study. An individual data point is the mean of two access tubes measured at six depths (from 0.23 to 1.65 m below the soil surface). Arrows indicate approximate dates of the first irrigation each season (see Table 1 for calendar date of first irrigation each season).

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 Ψ_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

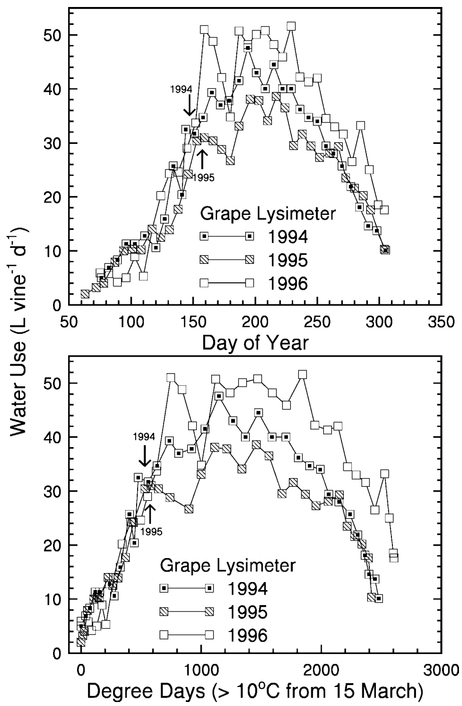

Fig. 3. Water use measured on Thompson Seedless grapevines grown in a weighing lysimeter for the 1994, 1995 and 1996 growing seasons as a function of day of year and degree-days from March 15. Each data point is the average daily value for a 7-day period. The arrows represent the approximate day the vines were girdled in 1994 and 1995.

Table 3
Net CO_2 assimilation (A), stomatal conductance (g_s) and midday leaf water potential (Ψ_l) measured between 1230 and 1330 h on various dates during the 1995 growing season

Calendar date	Day of year	A (μmol m^{-2} s^{-1})	g_s (mmol m^{-2} s^{-1})	Ψ_l (MPa)
26 May	146	13.2 ± 0.5	578 ± 24	−0.60 ± 0.03
20 June	171	9.1 ± 0.8	425 ± 44	−0.55 ± 0.02
30 June	181	–[a]	–	−0.52 ± 0.02
6 July	187	15.3 ± 0.3	583 ± 36	−0.70 ± 0.04
28 July	209	13.2 ± 0.5	548 ± 49	−0.69 ± 0.01
8 August	220	15.7 ± 0.4	610 ± 64	−0.72 ± 0.01

Vines were trunk girdled on June 6 (day of year 157). Each value is the mean of 12 individual leaf measurements for A and g_s and 6 measurements for Ψ_l ± S.E. Two of the measurements were taken on the vines in the lysimeter and the remainder was taken on vines within the same row and receiving identical amounts of water as the lysimeter vines.
[a] No measurements of A and g_s were taken on this date.

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 ∼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.

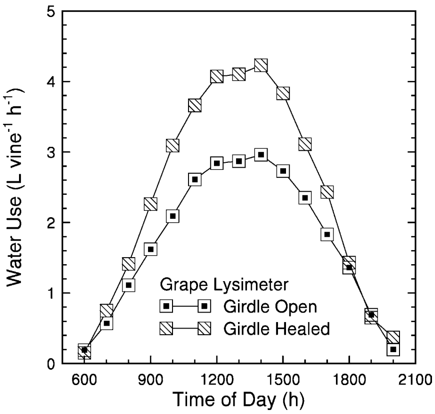

Fig. 4. The daily time course of Thompson Seedless water use measured 3 weeks after the vines were trunk girdled in 1995 (June 27 to July 1 [DOY 178–182]) and once the girdle had healed (callused over) the same year (July 13–17 [DOY 194–198]). Each data point is the mean of hourly values averaged across a 5-day period. Reference ET averaged 6.1 and 5.95 mm day^{-1} for the two periods; June 27 to July 1 and July 13–17, respectively.

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_o (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, ∼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

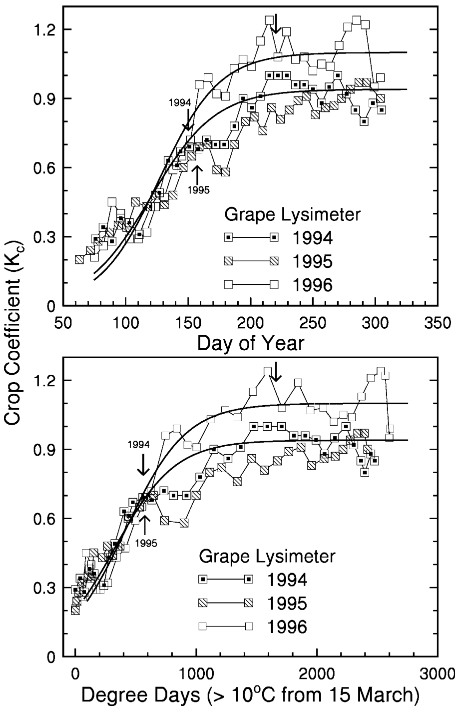

Fig. 5. The seasonal progression of the crop coefficient for Thompson Seedless grapevines calculated for the 1994, 1995 and 1996 growing seasons as a function of day of year and degree-days from 15 March. Each data point is the average daily value for a 7-day period. The first two arrows (from left to right) represent the approximate day the vines were girdled in 1994 and 1995 and the third arrow indicates when the vines were hedged for the first time in 1996. The lines within the figure represent equations fitted to the 1994 and 1995 data, excluding the period in which the girdles were open, and the 1996 data separately. The equations for the 1994 and 1995 data as a function of DOY and degree-days were $y = 0.94/(1 + e^{-(x - 120)/26})$ and $y = 0.94/(1 + e^{-(x - 325)/250})$, respectively. The equations for the 1996 data as a function of DOY and degree-days were $y = 1.1/(1 + e^{-(x - 127)/24})$, $r^2 = 0.85$ and $y = 1.1/(1.0 + e^{-(x - 415)/250})$, $r^2 = 0.93$, respectively.

Lenz, 1972; Roper and Williams, 1989) and g_s will remain lower until the girdle heals (Williams et al., 2000). Vine water use in response to girdling in this study reflected that measured on single leaves but the response from one year to the next appeared to be dependent upon the use of GA_3 and/or values of ET_o. Water use continued to increase in 1994 when vines were girdled and sprayed with GA_3 at berry set but the K_c leveled off for a period of 4 weeks. Subsequent to girdling in 1995, without an application of GA_3 at berry set, water use decreased approximately 15% 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

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

1994				1995				1996			
DOY	ET_o (mm)	ET_c (mm)	K_c	DOY	ET_o (mm)	ET_c (mm)	K_c	DOY	ET_o (mm)	ET_c (mm)	K_c
151	6.10	4.20	0.69	159	5.95	4.10	0.69	145	5.91	3.84	0.65
158	6.81	4.60	0.68	166	5.75	4.03	0.70	152	6.19	4.46	0.72
165	7.27	5.21	0.72	173	6.47	3.81	0.59	159	7.03	6.75	0.96
172	7.07	4.90	0.69	180	6.10	3.54	0.58	166	6.52	6.46	0.99
179	7.20	5.01	0.70	187	6.26	4.38	0.70	173	6.06	5.58	0.92
187	7.12	5.50	0.78	196	6.31	5.05	0.80	180	5.06	4.61	0.91
Mean (42 days)	6.93	4.90	0.71		6.14	4.15	0.68		6.13	5.28	0.86
Total (42 days)	291	206			258	174			257	222	

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.

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 m^2 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 and that the actual water requirement during this period is less when compared to non-girdled vines. It should be pointed out that callus formation across the girdle (healing) could be delayed by a week or two if the vines are deficit irrigated during this time period (L.E. Williams, unpublished data).

The seasonal K_c reached a maximum value between 750 and 1000 DDs after March 15th. The K_c was unaffected by harvest date each year of the 3-year study and it remained high to the end of the irrigation season, normally mid-October in San Joaquin Valley vineyards. Published values of crop coefficients, including those for grapevines, assume a linear decrease after the mid-season plateau (Allen et al., 1998; Synder et al., 1989). However, this was 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

(Allen et al., 1998; Synder et al., 1989) probably reflects the fact that those crop coefficients had been developed in vineyards or orchards where irrigations were terminated or water withheld prior to harvest. Deficit irrigation practices and/or a suspension of irrigation takes place in many wine grape vineyards throughout the world's grape production areas prior to harvest in order to affect fruit quality (Williams and Matthews, 1990; Williams et al., 1994) or for the 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 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 GA_3 indicates that GA_3 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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