Evaluation of seasonal water use and crop coefficients for ‘Cabernet Sauvignon’ grapevines as the base for skilled regulated deficit irrigation

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Abstract

Water consumption of wine grapevines (*Vitis vinifera* ‘Cabernet Sauvignon’) was measured during three consecutive growing seasons (2012-2014) using 6 drainage lysimeters. The lysimeters (1.5 m³ each) were installed within a two-hectare commercial vineyard in a Mediterranean region in the central mountain region of Israel. Water consumption of the lysimeter-grown vines (ET_c) was measured daily and reference evapotranspiration (ET_o) was calculated from regional meteorological data according to the Penman Monteith equation. Seasonal curves of crop coefficient (K_c) were calculated as $K_c = ET_c/ET_o$. Maximum ET_c values (weekly average) in different seasons ranged from 7.5 to 6.64 mm day^{-1} and seasonal ET_c (from DOY 99 through DOY 288) ranged from 746 to 780 mm over the growing seasons. Leaf area index (LAI) was measured weekly using the SunScan Canopy Analysis System. Maximum LAI ranged from 1.36 to 1.16 m² m^{-2} for the 2012-2013 seasons, the seasonal LAI pattern was quite similar to control vines grown in the surrounding vineyard. A linear curve relating K_c to LAI (R^2 values ranged from 0.76 to 0.85) is proposed as the basis for efficient irrigation management. Some of the differences in ET_c and K_c values that were observed are different from those obtained in table grapes (Williams et al., 2003; Netzer et al., 2009) and wine grapes (Picón-Toro et al., 2012) is explained by the different canopy size and architecture.

Keywords: *Vitis vinifera*, ‘Cabernet Sauvignon’, wine grapes, water consumption, water use, evapotranspiration, crop coefficient, drainage lysimeters, leaf area index

INTRODUCTION

Optimizing irrigation in vineyards is an essential need given the increase in water costs and its low availability. Traditionally in table grapes the growers use large amounts of water (compared to wine grapes); this is due to a larger canopy size and wider trellis systems. In table grapes, skilled irrigation is important in order to achieve high yields and big berry size. In wine grapes, exuberant irrigation may lead to high yields with pronounced negative effects on red wine quality. On the other hand, restricted irrigation aimed to improve red wine production may lead to over stressed vines with a limited hydraulic system, poor vegetation, extremely low yields and eventually can cause vine death.

Most of the water absorbed by plant roots returns to the atmosphere by evaporation from the soil and via transpiration from the canopy. The amount of water that actually transpires via the stomata is determined by atmospheric conditions, stomatal conductance, canopy area and canopy architecture. Skilled irrigation aimed to maximize the production potential of the yield and quality. In perennial crops the constant changes in canopy size and atmospheric conditions must be an integral part in water use evaluation. In the current study, vine water use (ET_c) was measured using 6 drainage lysimeters.

The relationship between crop evapotranspiration (ET_c) and reference evapotranspiration (ET_o) is termed the crop coefficient (K_c) (Allen et al., 1998). ET_c and K_c changes during the growing season due to phenological development and agro technical practices. These factors include: canopy management treatments, trellis type, row and inter

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row spacing and more factors.

The objective of the present study is to determine seasonal crop water use of *Vitis vinifera* 'Cabernet Sauvignon' (used for red wine production) grown under unlimited water supply in the central mountain region of Israel. A derivative of the objective is to correlate K_c to leaf area index (LAI).

MATERIALS AND METHODS

Experiment site

The vineyard and the lysimeters are located in the central mountain region of Israel (lat 32.2°N, long. 35°E), 759 m above sea level. *Vitis vinfera* 'Cabernet Sauvignon' vines were planted in 2007. The area is considered to be one of the premium quality wine regions in Israel. The climate is characterized as Mediterranean with relatively cool nights. Vine spacing was 1.5 m within rows and 3 m between rows i.e. 2222 vines per hectare. Rows were oriented east-west and the vines were trained to a 2-m-high vertical shoot positioning (VSP) system with 2 foliage wires. Each vine was trained to a bi-lateral cordon pruned to 16 spurs consisting of two buds each.

Lysimeters – structure and maintenance

ET_c of 'Cabernet Sauvignon' wine grapes was determined by the use of 6 drainage lysimeters. Each lysimeter tank was 1.2 m in diameter and 1.3m deep, for a total volume of 1.50 m^3. The lysimeters were filled with local soil (deep, stone free terra rossa composed of 36.4% sand, 30.6% silt and 33% clay) packed to the original bulk density. The lysimeters were installed in the ground with their top surfaces aligned with the soil surface (Figure 1). The lysimeters were located on the second row of the vineyard to avoid border row effect. To ensure drainage of water from the lysimeter into the receiver tank, the bottom of the tank was packed with 30 cm of rock wool. Two drainage pipe lines (50.8 mm in diameter) were connected to the bottom of each lysimeter. Each pipe was ~10 m long leading to an underground tunnel located 7.5 m outside the vineyard (Figure 1).

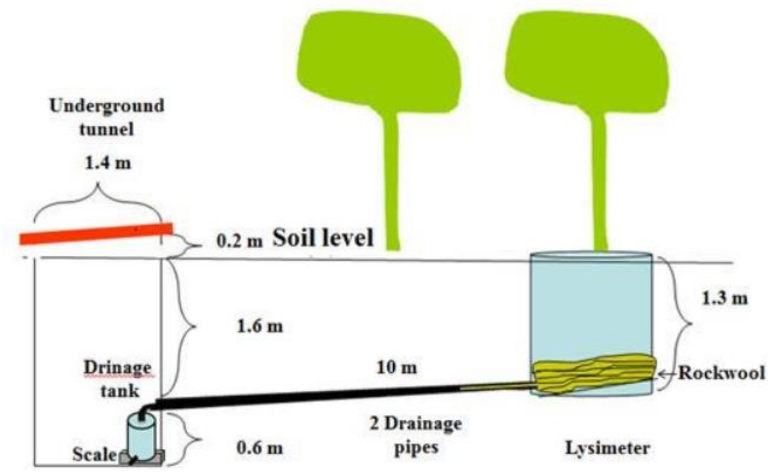

Figure 1. General scheme of one lysimeter (out of six) and the underground tunnel set up.

Each lysimeter was irrigated separately with a tailor-made computer controlled system (Crystal vision, Kibbutz Samr, Israel). The drip line that was connected to a fine water meter was equipped with four 1-L h^1 drip emitters spaced 30 cm apart. Drainage water was collected in receiver tanks located in a 2.5-m deep underground tunnel that was dug parallel to the row containing the lysimeters. The drainage was collected in a tailor-made 30 L round container placed on a scale. The data were recorded on the system data logger and were downloaded on a daily basis via cellular communication. The volume of water that drained through each lysimeter was recorded every 15 min. The drainage tank was automatically emptied between 23:46 and 23:59. The “drainage scales” and the fine water irrigation meters were calibrated manually twice a week. In order to ensure that the vines were not limited by water availability, the volume of water supplied by irrigation exceeded the vines estimated daily water consumption by 20-30%. During 2012, daily irrigation began at 6:00 am and continued for 4-8 hours depending on the amount of water that was applied. During 2013-2014, irrigation was set on an hourly basis, i.e. 24 irrigation pulses per day.

ET_c, ET_o and K_c calculation

The daily water consumption, ET_c (kg or L), was calculated by subtracting the volume of water collected as drainage (over a 24-h period) from the amount that was supplied by irrigation during the same period. ET_c (mm) was calculated by multiplying the average daily water consumption per vine as measured using the lysimeters, by 0.222 (2222 vines ha^{-1}, inter row spacing 1.5 m, row spacing 3 m). Reference evapotranspiration (ET_o) was calculated according to the Penman-Monteith equation (ASCE method). The meteorological data used for calculating ET_o were obtained from a weather station located 50 m east to the vineyard. The daily crop coefficient (K_c) was calculated by dividing daily ET_c (mm day^{-1}) by daily ET_o (mm day^{-1}) as detailed in Allen et al. (1998).

Leaf area index measurements

Leaf Area Index (LAI) of the lysimeter-grown vines and of 6 reference field-grown vines was measured weekly during the growing seasons, using a canopy analysis system (SunScan model SS1-R3-BF3; Delta-T Devices, Cambridge, UK). The canopy analysis system uses a line quantum sensor array sensitive to photosynthetic active radiation (PAR). The analyzer was operated using the standard protocol recommended by the manufacturer. Each sample consisted of equally spaced observations (10 cm apart), starting from the center of the row to half the distance between adjacent rows with the linear probe positioned parallel to the rows. The LAI values obtained by this method were correlated with destructive harvesting of leaves. After leaf defoliation, leaf area was then measured using an area meter (model 3100; Li-Cor, Lincoln, Nebraska). The leaf area of 27 vines (3 cultivars from 5 sites) was measured at different phenological stages during the growing seasons. Strong linear correlation (R^2=0.921. P<0.001, n=27) was observed between Sunscan’s measured LAI and destructively obtained LAI (Figure 2).

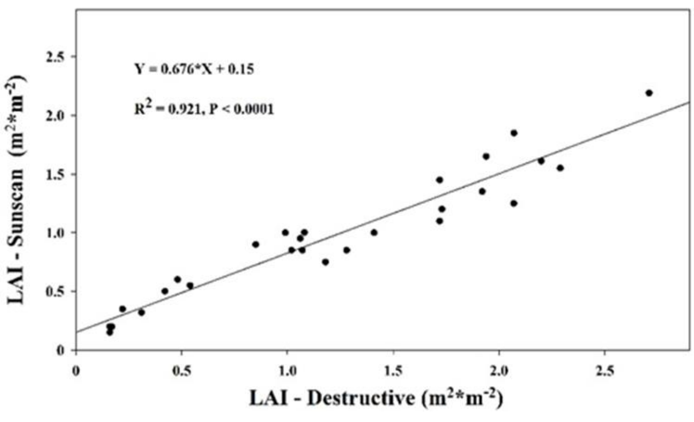

Figure 2. Correlation between Leaf Area Index (LAI) measured destructively (Li-Cor 3100) and Sunscan's estimated non-destructive measurements (n=27).

RESULTS AND DISCUSSION

In the current experiment we monitored the changes in vine water consumption, weather conditions and canopy area. In order to illustrate the changes of one full growing season, only the data of one season will be presented in detail (2013). However, important canopy to crop coefficient correlations of the three seasons (2012-2014) are also presented. Budbreak in all three seasons occurred in the beginning of April (Table 1), phenological stages were defined according to Kennedy (2002), and the end of stage I was defined as bunch closure. At this point ET_c values were ~1 mm day^{-1} while ET_o values were ~4 mm day^{-1} in the season of 2013 (Figure 3). Since LAI reading was minimal, most of the water use was actually water evaporation from fully exposed soil. Accelerated vegetative growth was recorded from DOY 110-150 (Figure 5) and accompanied by an increase in vine water use (ET_c) from ~1 mm day^{-1} to ~5 mm day^{-1}. Extreme weather conditions occurred between DOY 115-125 (ET_o above 7 mm day^{-1}), having a pronounced effect on the rapid and sharp ET_c increase.

Table 1. Phenological stages, and day of year (DOY) of *Vitis vinifera* 'Cabernet Sauvignon' vines, grown in lysimeters 2012-2014.

Year	Bud break (DOY)	Veraison	Harvest
2012	05 April (95)	25 July (206)	7 September (250)
2013	01 April (91)	06 August (218)	29 August (241)
2014[1]	08 April (98)	10 August (222)	5 September (248)

[1]2014 data from April 8 until September 15.

Stage II of berry development begins with bunch closure (mid-June) and ends in full veraison (end of July-beginning of August). At this stage we recorded slight changes in ET_c with close contact to ET_o changes. A sharp increase in ET_c and K_c occurred from DOY 204 until 224 (Figures 3 and 4). This can partially be explained by the exuberant canopy size in the lysimeter-grown vines, compared to the "regular" reference vines grown in the vineyard, as observed from DOY 190 to DOY 220 (Figure 5). The delay between the increase in ET_c and LAI growth can be explained by the fact that it takes about 25 days for young vine leaves to reach full maturity and to attain their maximum values of net assimilation rate and stomatal conductance (Poni et al., 1994). The hedging practice took place in DOY 226 reducing LAI by ~0.2 m^2 m^{-2} followed by an immediate and sharp decrease in ET_c and K_c.

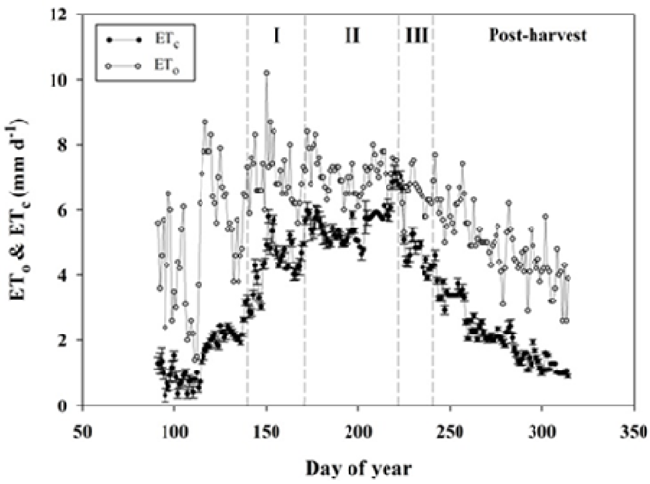

Figure 3. Seasonal curve of vine water use (ET_c) of *Vitis vinifera* 'Cabernet Sauvignon' vines as measured using 6 drainage lysimeters, and reference evapotranspiration (ET_o) calculated using the ASCE Penman-Montith equation. Each data point represents a daily average of six vines during 2013 season, Error bars represent ± standard error. Roman letters indicates the three phenological stages of berry development.

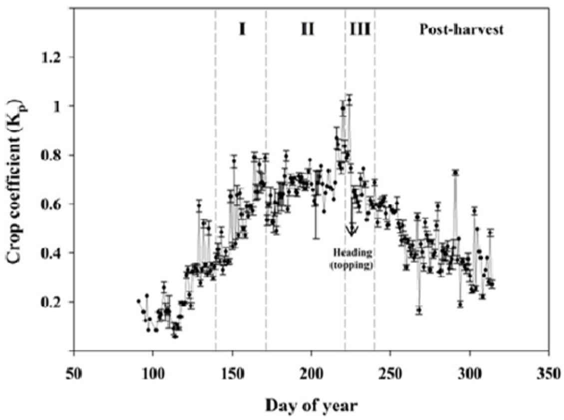

Figure 4. Seasonal curve of crop coefficient (K_c) of *Vitis vinifera* 'Cabernet Sauvignon' vines as calculated during 2013 season. Each data point represents daily average of six vines during 2013 season. Error bars represent ± standard error. Roman letters indicate the three phenological stages of berry development.

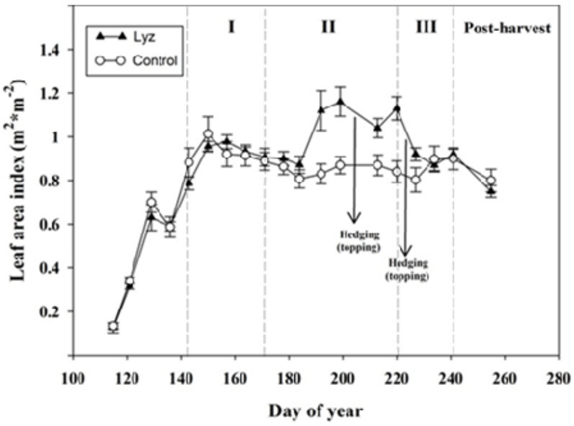

Figure 5. Seasonal course of Leaf Area Index (LAI) of *Vitis vinifera* 'Cabernet Sauvignon' vines as measured during 2013 season. Each data point represents daily average of six lysimeter-grown vines (marked as black triangles) and 6 reference vines (marked as open circles) grown in the vineyard under local agricultural standards. Error bars represent ± standard error. Roman letters indicate the three phenological stages of berry development.

During stage III (from full veraison to harvest) and post-harvest, ET_o decreased almost linearly due to shortening of the day and temperature reduction, this in turn led to reduced ET_c and K_c results. During stage III LAI was rather stable (Figure 5), while a slight decrease was recorded in DOY 255. No further measurements were made towards the end of the season since zenith angle during mid-day was larger than 30° causing the shade beneath the vines to be too wide. Seasonal K_c curve showed a normal (Gaussian) distribution pattern which increased up until mid-season, and then decreased throughout the rest of the season. This normal distribution pattern is similar to K_c curves recorded in 'Thompson Seedless' table grapes (Williams et al., 2003) and differs from polynomial patterns observed in 'Superior Seedless' table grapes (Netzer et al., 2009). It was explained that in table grapes, post-harvest heavy infection of downy mildew may cause an increase in transpiration and a high K_c (Netzer et al., 2009). In the current research, strictly observed pest management control was maintained during all seasons.

Total seasonal ET_c for 2012-2013 was 763 mm, which is 60.4% of ET_o. Similar relations were calculated for the 2014 season (Table 2).

Table 2. Seasonal vine water consumption (ET_c) and seasonal evapotranspiration of *Vitis vinifera* 'Cabernet Sauvignon' vines, grown in lysimeters 2012-2014.

Year	ET_c (L vine^{-1} season^{-1})	ET_c (mm season^{-1})	ET_o (mm season^{-1})
2012	3510	780	1205
2013	3357	746	1321
2014[1]	2660	583	992

[1]2014 data from April 8 until September 15.

A linear correlation was observed between LAI and K_c (Figure 6). In the first year of the experiment (2012) the R^2 value was 0.761. During this season we increased measurement accuracy by replacing the water meters with more accurate ones, and adopting a calibration protocol for water meters and drainage scales (applied twice a week). The LAI - K_c correlation improved during the 2013-2014 seasons (Figure 6) to R^2 values >0.8. The LAI - K_c correlation observed in the current study are in good agreement with similar correlations made in table grapes (Williams et al., 2003; Netzer et al., 2009). However, some differences in K_c values between table grapes and wine grapes were observed when LAI values ranged between 1-1.4 mm^2 mm^{-2}, i.e., higher K_c values in wine grapes compared to table grapes. These differences can be explained by the architecture of the canopies. While table grapes are trained to Geneva double curtain-GDC trellis system (Williams et al., 2003) or Y-shape open gable trellis system (Netzer et al., 2009), in wine grapes the VSP trellis system allows for a more effective canopy being exposed to the atmosphere, thus leading to relatively higher K_c and ET_c values. In Vegas Bajas del Guadiana, Spain, a 5-year study was conducted in order to measure ET_c and K_c of 'Tempranillo' vines while using weighing lysimeters (Picón-Toro et al., 2012). In comparison to our data the ET_c and K_c values were 20-30% higher. This can partly be explained by the planting density that was relatively high (1.2×2.5 m) in the Spanish research. This, along with vigorous vegetative growth and consequently high LAI values was similar to values previously measured in table grapes.

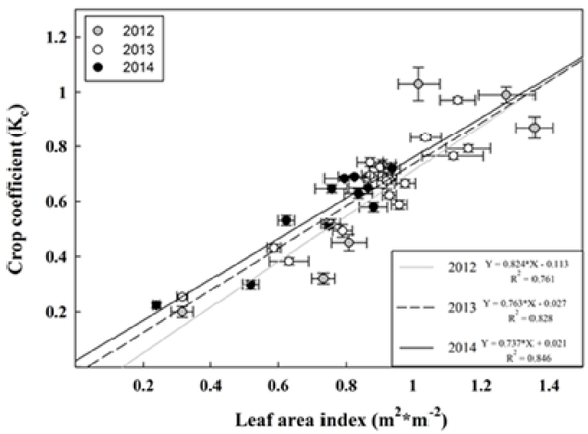

Figure 6. Correlation between Leaf Area Index (LAI) and crop coefficient (K_c) of *Vitis vinifera* 'Cabernet Sauvignon' vines grown in the lysimeters as measured during 2012-2014 seasons. Each K_c data point represents an average value of 7 days, 3-4 days before the LAI measurement and 3-4 days after the measurement. Each data point represents the average LAI value of 6 vines. Vertical and horizontal error bars represent ± standard errors. The curves were fitted to linear equations. Roman letters indicate the three phenological stages of berry development.

CONCLUSIONS

In the current work a pronounced effect of canopy size and climatic conditions on vine water consumption was observed. The strong and repeatable relations between LAI and K_c that was found by us, is similar to other LAI-K_c relations reported in the literature. Hence, it seems that LAI-K_c relation is reliable and adequate for the use as the base of skilled regulated irrigation regime.

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