Up Scaling Table Grape Water Requirements in the Low-Middle São Francisco River Basin, Brazil

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Abstract

Landsat satellite images and a net of 15 agro-meteorological stations were used together for determining actual evapotranspiration (ET) and crop coefficient (K_c) of table grapes on a large scale in the Low-Middle São Francisco river basin. Inside the area covered by the stations, a commercial table grape farm, with a mixture of varieties located in the Petrolina-PE municipality, Brazil, was used for modelling vineyard water variables. The application of a relation between K_c and the accumulated degree days (DD_{ac}), together with weather data for 2011, allowed the quantification of vineyard water requirements (VWR) along the crop stages and for a whole generalized growing season (GS) in the centre of development of Petrolina/Juazeiro, considering three pruning dates covering different weather conditions and an average four months GS. Comparing the results for the pruning periods studied, the highest water requirements were when the pruning is done from September to December, with an averaged VWR_{GS} value of 620 mm. On the other hand, the lowest rates are for pruning dates in May, when the VWR_{GS} values were around 460 mm. Due to a higher atmospheric demand in Petrolina, Pernambuco (PE) state compared to Juazeiro, Bahia (BA) state, the first presented a mean VWR_{GS} about 8% higher than that found for Juazeiro. The results of the current research are important to subsidize the table grapes water management and to ensure their water availability in the actual conditions of land and climate changes in the Brazilian semi-arid region.

INTRODUCTION

Vineyards under the hot Brazilian semiarid conditions present different agronomic behaviour when compared with those from temperate climates. While in these last climates, cold winters induce a dormancy stage, tropical growing regions allow irrigated commercial grape crop in any time of the year. However, the rainy period is avoided for table grapes, because of a high risk of direct damage to the berries and the incidence of diseases (Teixeira, 2009).

Considering the increase of commercial irrigated vineyard areas in the Low-Middle São Francisco river basin, mainly in the centre of development Petrolina/Juazeiro, the knowledge about table grape water variables on a large scale is important for the rational management of water resources. These variables include actual evapotranspiration (ET), which can be determined with lysimeters (Williams and Ayars, 2005), eddy covariance techniques (Ortega-Farias et al., 2007) and/or by the Bowen ratio method (Teixeira et al., 2007). However, field experiments for ET estimations on a large scale are missing. This problem can be solved by using tools like remote sensing and/or Geographic Information Systems (GIS), excluding the need of quantifying complex hydrological processes and being a useful way for determining and mapping vineyard water variables under different cultural managements and spatial scales (Teixeira, 2009).

Moller et al. (2007) demonstrated the efficiency of using visible and thermal images with good spectral resolution for vineyards irrigation scheduling in Israel. Naor (2006) concluded that measurements in the range of thermal infrared in fruit crops allow mapping water stress conditions and, thereby contributing to a better irrigation management. Teixeira et al. (2009b) confirm the suitability of combining remote sensing measurements and GIS for the assessment of vineyard water productivities in commercial wine and table grapes in the semiarid region of Brazil.

The objective of the current research was to combine remote sensing measurements and GIS for modelling the table grape water requirements located in the centre of development of Petrolina/Juazeiro in the Low-Middle São Francisco river basin, Brazil, aiming to subsidize the rational water management and new irrigation projects dimensioning, under the conditions of fast replacement of the natural vegetation by commercial vineyards.

MATERIAL AND METHODS

The remote sensing parameters involved the surface albedo (α_0), surface temperature (T_0) and NDVI (Teixeira, 2010), which were used to acquire the actual evapotranspiration (ET) and the surface resistance to the water fluxes (r_s). A curve for the crop coefficient (K_c) with additional data on reference evapotranspiration (ET_0) was elaborated and a model relating K_c as a function of the accumulated degree-days (DD_{ac}) was applied to obtain the vineyard water requirements (VWR) on a large scale.

For ET and K_c modelling, a net of 15 agrometeorological stations were used together with the remote sensing parameters and GIS in the Low-Middle São Francisco river basin. The "Vale das Uvas" farm in the Petrolina municipality, Pernambuco (PE) state, was used for modelling table grape water variables on a large scale. This commercial farm is one of the largest table grape producers in the Brazilian semi-arid region. The K_c model was then applied by using grids of ET_0 to retrieve VWR in the centre of development of Petrolina/Juazeiro (Fig. 1).

Four Landsat images free of clouds were chosen to model a generalized table grape K_c curve, for the days 06 Jul 2003, 12 October 2004, 16 November 2005 and 30 July 2006, covering different crop stages within a mean four months growing season (GS). Weather data from the agrometeorological stations for 2011 were: global solar radiation, air temperature, relative humidity and wind speed, which were used to calculate ET_0 by the Penman-Monteith method (Allen et al., 1998). Although the Landsat images did not cover the same year of the weather data, the table grapes cover conditions in the "Vale das Uvas" farm for the period from July to October do not vary too much along the years, as this period is the main commercial growing season for almost all the farm plots.

The table grape varieties in the "Vale das Uvas" farm (see location of the agrometeorological station inside the farm in Figure 1.) were composed of a mixture of varieties named 'Italia', 'Red Glob', 'Sugraone' and 'Benitaka', involving an area around 200 ha, with the majority being micro sprinkler irrigated, and only 10% of the cultivated area being the drip irrigated cv. 'Sugraone'. Even with the possibility of farmers to manage the crop having commercial table grapes in any time of the year, yield is concentrated during the driest natural conditions of the second semester, due to disease problems during the rainy period in the previous first half of the year. Then K_c was modelled from July to November, where there are a larger number of active grapevine canopies.

Table 1 summarizes the regression equations to acquire ET and K_c for the entire area depicted in the right side of Figure 1 (Teixeira, 2009, 2010; Teixeira et al., 2009a). Simple atmospheric corrections were applied to the planetary albedo (α_p) and brightness temperature (T_{sat}) based on energy balance field experiments (Teixeira, 2009a, 2010). The only satellite parameters needed to model ET and r_s are α_0, T_0 and NDVI. The satellite overpass ET/ET_0 ratio is applied to the grids of daily ET_0 for obtaining the regional ET for 24 hours, assuming that this ratio does not differ for these two time scales (Teixeira, 2010).

The K_c values were obtained with logical functions for r_s images with a threshold of 85 s m^{-1}. Values above this limit indicated some degree of water stress, so that it represents the potential moisture conditions (Teixeira et al., 2008). The K_c values for the mixture of table grape varieties in the "Vale das Uvas" farm were correlated with the accumulated degree days - DD_{ac} (Table 1) and the VWR values were then obtained by multiplying ET_0 by K_c.

RESULTS AND DISCUSSION

To have an idea on the magnitude of ET for a generalized GS at the farm level, firstly modelling the ET/ET_0 ratio from remote sensing parameters was applied (Table 1) by using the four representative images for different crop stages in the "Vale das Uvas" farm. The mean value of this ratio was applied to the grid of the accumulated ET_0 for the main GS from July to October, together with weather data for 2011 (Teixeira, 2010). The totals of ET pixel values as well as the histograms are presented in Figure 2.

The average total ET corresponds to a mean daily rate of 3.7 mm d^{-1}, while the maximum values are around 5.4 mm d^{-1}. Higher frequencies of the ET_{GS} are between 450 and 650 mm GS^{-1}, representing well irrigated vineyards with berry maturation occurring during the hottest conditions of October and harvest in November. In a field energy balance experiment with micro sprinkler irrigated table grapes plot inside the studied farm, Teixeira et al. (2007) reported similar daily and maximum ET rates for three year old cv. 'Sugraone', in Petrolina-PE. This is the basis for confidence to the up scaling processes for the mix of table grape cultivars in the current research.

Interpolating the ET/ET_0 images and using logical functions for the threshold r_s value of 85 sm^{-1} to separate potential conditions (Allen et al., 1998; Teixeira et al., 2008; Teixeira, 2010), during the generalized growing season from July to October, the elaboration of the relation between K_c and DD_{ac} was possible, taking ET_0 and air temperature data from the agrometeorological station "Vale das Uvas" farm for 2011 using a base temperature of 10°C (Fig. 3). The K_c values were in the range from 0.74 to 0.90. High direct soil evaporation from the plots under micro sprinkler irrigation contributes to the increase of this coefficient, mainly at the initial stages (Teixeira et al., 2007). This relationship is very useful, because it incorporates thermal effects. This is important for up scaling VWR to different scenarios, eliminating the difficulty and subjectivity of the crop stage characterization in situations of year to year air temperature variation, which will affect vine phenology.

To analyze the VWR_{GS} variation on a large scale, the main table grape growing municipalities in the Low-Middle São Francisco basin, Petrolina and Juazeiro in Pernambuco (PE) and Bahia (BA) states, respectively, were cut from the entire area showed on the right side of Figure 1. Three pruning periods in the year of 2011, which involved different weather conditions, were considered (Fig. 4). The pruning date with the highest VWR_{GS} values was in September, when the average total is 620 mm, while the lowest ones with around 460 mm were found when the pruning is done in May. October is the month when the Sun is at the zenith position in the study region and together with low cloud conditions, the ET rates are the highest of the year, while in June, time of the winter solstice in the Southern hemisphere, the larger atmospheric path for the solar radiation to reach the vineyard surfaces is the reason for the low rates for table grapes pruned around this month.

In general, the highest VWR_{GS} values occur in the eastern side of both municipalities, Petrolina-PE and Juazeiro-BA, while the lowest ones were in their southeastern sides (even lower than 400 mm for pruning periods in May). This last condition should be a good option, where irrigation is possible but water competition among different water users exist (Teixeira, 2009). According to the standard deviations (STD), the smallest and the largest spatial variations occur, respectively, for pruning dates in January (STD = 19 mm) and May (STD = 39 mm).

Figure 5 presents the variation of the monthly mean VWR values for an average GS period of four months and the growing municipalities of Petrolina-PE and Juazeiro-

BA, considering the three different pruning dates along the year. Highest values were observed for the period from September to October because of the largest atmospheric demand along the year. In this case, the highest average value is found in October (173 mm month^{-1}) for Petrolina (PE). The lowest ones were observed in May (99 mm month^{-1}) for the Juazeiro (BA) municipality, with pruning date in May. The extremes of VWR_{GS} values represent a daily range from 3.3 to 5.8 mm d^{-1}.

For both municipalities when the pruning is done in January, the monthly VWR values present a continuous decreasing trend until harvest time, while when happening towards the middle of the year there will be continuous increments of VWR values till the harvest time contributing to a progressive biomass production. On the other hand, pruning dates in September will promote a more stable trend in VWR throughout the table grape crop stages.

CONCLUSIONS

Regression models resulting from remote sensing and agrometeorological data and based on the relations between the actual to reference evapotranspiration and the accumulated degree days, allowed a large scale determination of the water requirements for table grape production in the centre of development of the Low-Middle São Francisco river basin Petrolina-PE/Juazeiro-BA, Brasil. Considered were three different pruning dates covering different weather conditions. The modeling has the advantage of incorporating air temperature effects during the crop stages, extrapolating vineyard water variables to different thermal conditions.

Differences in table grape water consumption could be detected between Petrolina-PE and Juazeiro-BA, with indications of possibilities for water productivity improvements. The delimitation of the vineyard water requirements, joined with other ecological characteristics, permits a rational planning for the expansion of commercial table grape production and water productivity improvements in the Brazilian semi-arid region considering different pruning dates. This information is essential in situations of rising water competition by irrigated agriculture and non-agricultural sectors.

ACKNOWLEDGEMENTS

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Tables

Table 1. Summary of regression equations used for modelling the vineyard water variables.

Parameter	Equation	a	b	c	R^2
α_0	$\alpha_0 = a\alpha_p + b$	0.70	$6\ 10^{-2}$	-	0.96
T_0	$T_0 = aT_{sat} + b$	1.11	-31.89	-	0.95
r_s	$r_s = \exp[a(T_0/\alpha_0)(1 - NDVI) + b]$	0.04	2.72		0.93
ET/ET_0	$ET/ET_0 = \exp\{a + b[T_0/(\alpha_0 NDVI)]\}$	1.90	$-8\ 10^{-3}$	-	0,91
K_c	$K_c = aDD_{ac}^2 + bDD_{ac} + c$	$-1\ 10^{-7}$	$2\ 10^{-4}$	0.79	0.82

Figures

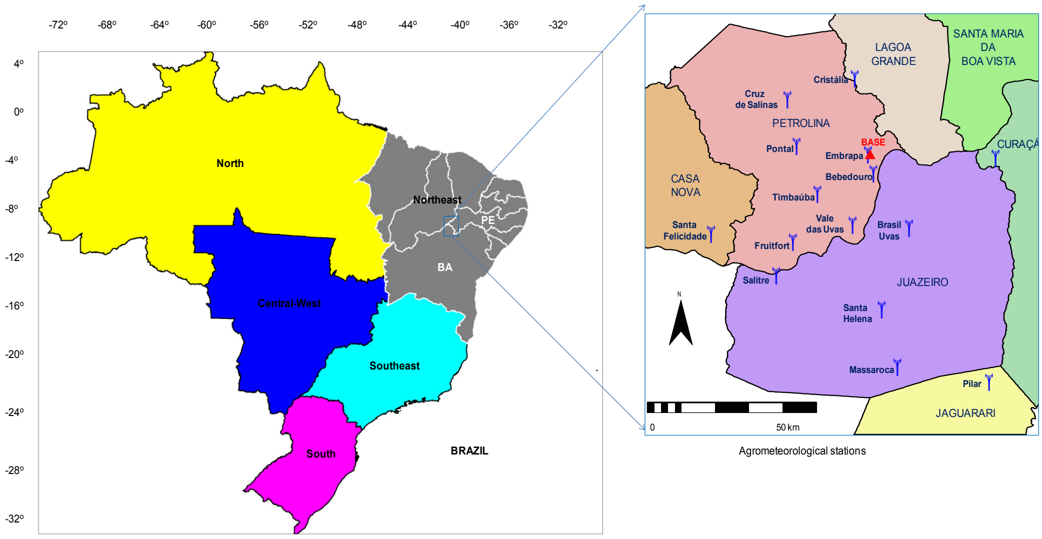

Fig. 1. Brazilian regions and the locations of the agrometeorological stations in the Low-Middle São Francisco River basin, involving the states of Pernambuco (PE) and Bahia (BA).

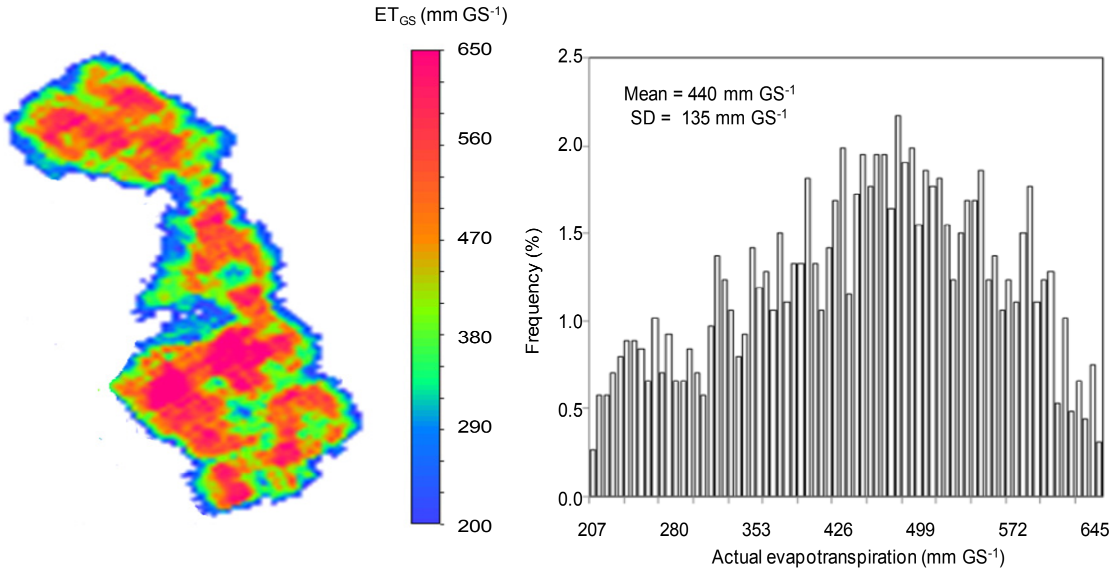

Fig. 2. Actual evapotranspiration (ET) and histograms for a generalized growing season (GS), from July to October of 2011, of irrigated table grapes at the commercial "Vale das Uvas" farm, Petrolina-PE, Brazil.

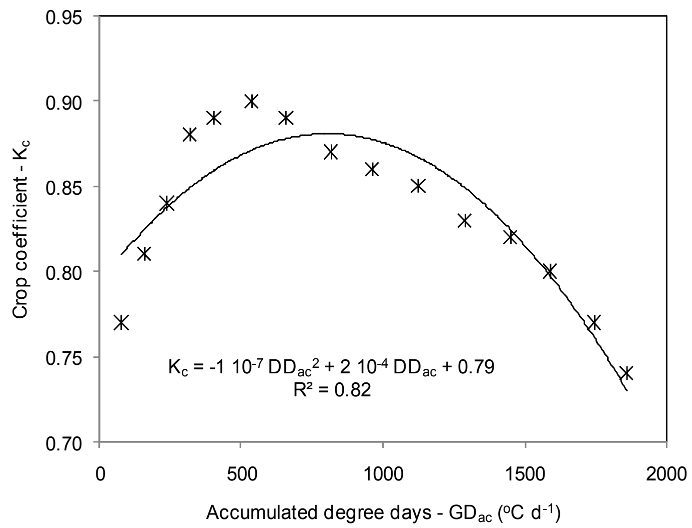

Fig. 3. Relationship between the crop coefficient (K_c) and the accumulated degree days (DD_{ac}), considering a base temperature of 10°C, during a generalized table grape growing season from July to October in 2011 at Petrolina-PE, Brazil.

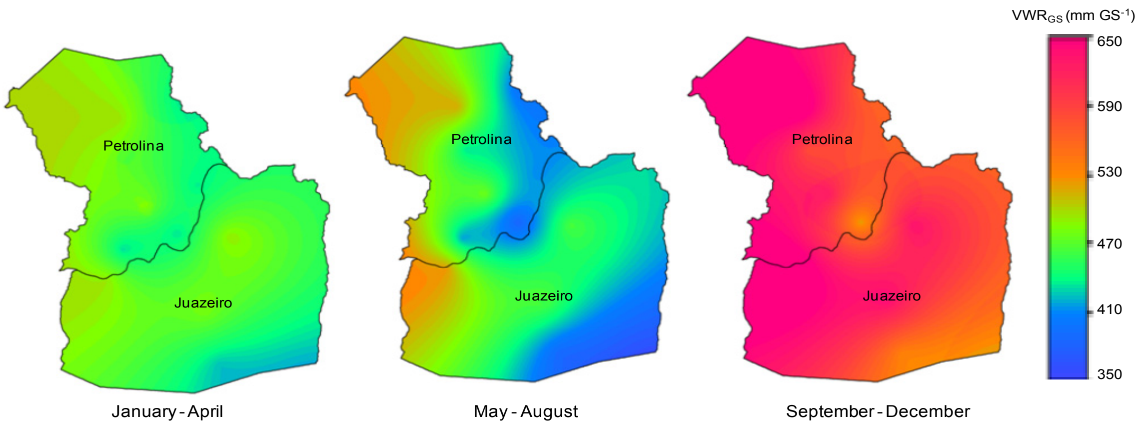

Fig. 4. Maps of the table grape water requirements, for different pruning dates along the year of 2011, for a generalized growing season of four months (VWR_{GS}), in the municipalities of Petrolina-PE and Juazeiro-BA, Brazil.

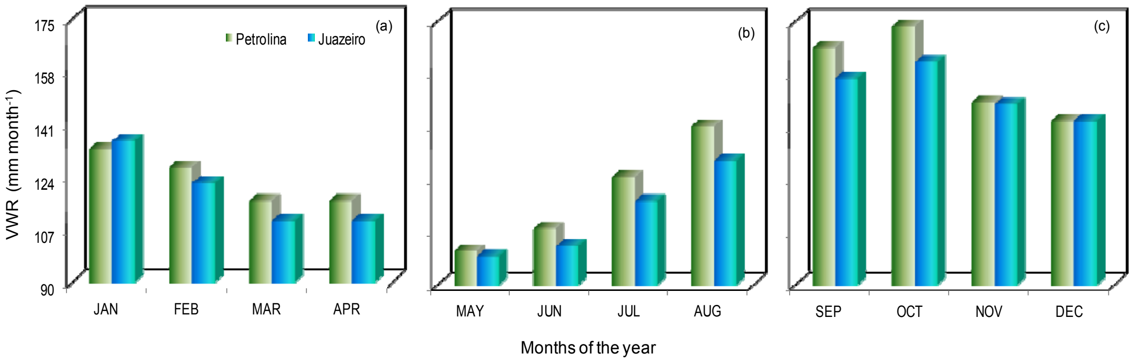

Fig. 5. Mean values of the vineyard grape water requirements, cv. 'Sugraone', for three different pruning dates along the year of 2011, considering an average growing season of four months (VWR_{GS}), in the table grape growing municipalities of Petrolina-PE, Juazeiro-BA, Brazil.