Modelo para estimar el balance hídrico del suelo en el viñedo: Calibración y validación en condiciones semiáridas

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Resumen

En el marco de una viticultura sostenible, el correcto manejo del riego es esencial. Por tanto, el objetivo de este estudio es calibrar y validar un modelo de balance hídrico del suelo que predice el potencial hídrico de tallo a mediodía (Ψ_{tallo}), indicador empleado para gestionar el riego. Se requieren datos del suelo, de la plantación y meteorológicos. El modelo se ha calibrado con datos de un viñedo de la variedad Tempranillo localizado en Requena (Valencia). La validación se ha realizado bajo diferentes estrategias de riego durante cuatro campañas. La bondad de ajuste del modelo se ha cuantificado mediante tres estadísticos: error absoluto, error cuadrático medio relativo (ECMR) e índice de concordancia. Se han establecido correlaciones lineales entre Ψ_{tallo} observado (mediante cámara de presión) y simulado. El modelo tiende a proporcionar valores de Ψ_{tallo} más negativos que los medidos, si bien ha sido capaz de reproducir la evolución temporal del Ψ_{tallo} durante la campaña. Los errores absolutos oscilaron entre -0,32 y 0,24 MPa, y el ECMR entre 0,12 y 0,41 MPa. En conclusión, el modelo simuló correctamente la evolución del $\square_{tallo}$ por lo que puede resultar una herramienta útil para la gestión del riego en el viñedo.

Palabras-clave: Evapotranspiración, modelización, balance hídrico del suelo, viñedo.

Abstract

In the context of a sustainable viticulture, an efficient management of irrigation is crucial. Therefore, the aim of this current study was to calibrate and validate a soil water balance model that predicts midday stem water potential (Ψ_{stem}), an indicator employed for irrigation management. Soil and vineyard characteristics, as well as weather data, are required as inputs. The model has been calibrated with data from a Tempranillo vineyard located in Requena (Valencia). The model has been validated under different irrigation strategies for four growing seasons. The goodness-of-fit of the model was quantified using three indicators: absolute error, root mean-squared error (RMSE) and index of agreemeent. Linear correlations between observed (using a pressure chamber) and simulated Ψ_{stem} were established. The model tended to provide Ψ_{stem} values more negative than those measured, although it was capable of reproducing the temporal dynamics of Ψ_{stem} over the growing season. Absolute errors varied between -0.32 and 0.24 MPa, whereas RMSE between 0.12 and 0.41 MPa. In conclusion, the model simulated correctly the evolution Ψ_{stem}, so it could be a useful tool for managing irrigation in vineyards.

Keywords: Evapotranspiration, modelling, soil water balance, vineyard.

Introduction

Water availability is relevant for grapevine production and, consequently, wine quality (Deloire et al., 2004). Climate change is modifying weather conditions and raising a great concern in viticultural regions because it is affecting water availability worldwide (Fraga et al., 2016). In this context, an efficient management of irrigation is of importance for a sustainable viticulture, which requires an accurate estimation of vineyard water needs.

Soil water availability determination is difficult due to soil heterogeneity and uncertainty about grapevine rooting depth. Other water stress indicators, such as canopy temperature, stomatal conductance, or the different modalities of leaf water potential (Choné et al., 2001) are difficult to handle and can be expensive. Therefore, tools that allow for evaluating vineyard water use and assesing grapevine water status are required (Lebon et al., 2003). This work aims to calibrate and validate a soil water balance model for vineyards, allowing to predict grapevine midday stem water potential, which is the main indicator that wineries use for irrigation management.

Materials and Methods

Experimental vineyard and data collection

Data were collected on several experiments conducted in 2003, 2004, 2010 and 2011 in a vineyard planted in 1991 with Tempranillo (*Vitis vinifera* L.) grafted on 161-49 rootstock at a spacing of 2.45 m x 2.45 m (1,666 vines ha^{-1}). The vineyard was located near Requena, Valencia, Spain (39º 29º N, 1º 13’ W, 750 m a.s.l.). Soil was a typic Calciorthid with a clay-loam to light clay texture, highly calcareous and of low fertility. The climate is continental and semiarid.

In 2003 and 2004, three treatments were tested: rain-fed, full irrigation and sustained deficit irrigation (SDI) as described by Intrigliolo & Castel (2006) and Mirás-Avalos et al. (2017). Data obtained from the rain-fed treatment in 2003 were used for calibrating the model, whereas the rest of the datasets were used for validation.

Stem water potential (Ψ_{stem}) was determined every two weeks using a pressure chamber (Soil Moisture Corp., Santa Barbara, USA) on 4 representative vines per treatment. Leaves were located on the west side of the row and were enclosed in hermetic plastic bags covered with aluminum foil for at least 1 h prior to measurement (Choné et al., 2001). Determinations were carried out at midday (11:30 to 12:30 h).

Input data

Daily weather data (solar radiation, maximum and minimum temperatures, maximum and minimum relative humidity, wind speed, vapour pressure deficit, reference evapotranspiration) were collected from an automated station located nearby the vineyard (http://riegos.ivia.es/listado-de-estaciones/requena).

Vineyard characteristics needed include geographical location, elevation, orientation, spacings and canopy dimensions (height, width, proportion of gaps). These data were collected directly in the vineyard.

Data on soil properties were derived from samples collected in previous studies (Intrigliolo & Castel, 2006) and included textural fractions, bulk density, organic matter content and soil depth. Input parameters, including the climate and soil components for the equations describing evaporation of water from the soil and thermal times for reaching the maximum canopy growth were obtained from the literature (Brisson & Perrier, 1991; Lebon et al., 2003; Intrigliolo & Castel, 2006).

Model description

The soil water balance employed was taken from Lebon et al. (2003). In this approach, transpiration by the vines and evaporation from the soil are treated separately and all the water fluxes are expressed in mm. The starting point of the model is when the soil is at field capacity. Then, the model keeps a daily update of soil water content in which the remaining soil transpirable water on any day (TSW_d) is computed as:

$$TSW_d = (TSW_{d-1} + P_d - ES_d - TV_d) \quad (1)$$

where TSW_{d-1} is the transpirable soil water remaining from the previous day, P_d, ES_d and TV_d are, respectively, rainfall, evaporation from the soil and transpiration from the vine canopy, on that day.

Vine daily transpiration is closely related to the global radiation absorbed by the canopy, which is computed from canopy dimensions and vineyard attributes according to Riou et al. (1989). The feedback of water stress on plant transpiration is simulated with a bilinear function (Lebon et al., 2003). Evaporation of water from the soil is estimated using the model proposed by Brisson & Perrier (1991).

Data from this water balance allow for the calculation of several physiological variables, including predawn leaf water potential (Ψ_{pd}), employing previously published equations (Pellegrino et al., 2004). From Ψ_{pd} data, values of Ψ_{stem} are computed employing a relation obtained for Tempranillo (Intrigliolo & Castel, 2006):

$$\Psi_{stem} = 2.58 \times \Psi_{pd} - 0.11 \quad (2)$$

Statistical analysis

The relationships between observed and simulated values of Ψ_{stem} were assessed by means of the coefficient of determination (R^2). Model performance was assessed using three statistical indicators: mean bias error; root mean-squared error (RMSE) and index of agreement (d). These indices were computed according to Yang et al. (2014).

Results and Discussion

When comparing observed and simulated Ψ_{stem} values for the calibration data set (rain-fed treatment in 2003), a significant correlation existed (n = 8, r = 0.73; fig. 1), although a great dispersion was observed for the most negative values. Mean error was low, while the index of agreement was relatively high (table 1), as well as the RMSE. This suggests that the model needs improvements for enhancing its accuracy. Nevertheless, the representation of the temporal dynamics of Ψ_{stem} over the growing season (fig. 2a) is adequate, despite a trend to provide more negative values by the end of the season.

Statistical indicators showed that the estimations of Ψ_{stem} provided by the model resulted in high agreements with observed data, especially for the irrigated treatments in 2004 (table 1). However, the values of these indicators showed a great variability, with mean errors ranging from -0.32 to 0.24 MPa, RMSE from 0.12 to 0.41 MPa, and d from 0.77 to 0.97. The discrepancies between observed and simulated data reflected by these indicators might be due to several factors and a more detailed parameterization of the model is required, especially for those parameters involved in the routine for calculating the radiation intercepted by the canopy (Riou et al., 1989) and the evaporation of water from the soil (Brisson & Perrier, 1991). Another source of discrepancies is the fact that some of the routines included in the model are empirical, as the calculations of Ψ_{pd} from soil water content (Pellegrino et al., 2004).

Nevertheless, in its current state, the model was able to provide reliable estimates of Ψ_{stem} for irrigated data sets, such as that from 2004 (fig. 2b).

Conclusions

A previously developed model was calibrated and validated for estimating soil water content and midday stem water potential (Ψ_{stem}) for irrigation scheduling in vineyards. Data from four years and several irrigation strategies demonstrated that the model was able to estimate satisfactorily the evolution of Ψ_{stem} over the growing season. However, the model tended to provide more negative Ψ_{stem} values than those measured in the field. Therefore, further improvements are required for increasing the accuracy of the model and reduce its uncertainties. Nevertheless, it could be a useful tool for managing irrigation in vineyards.

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Tablas y figuras

Table 1 – Statistical indicators of model performance for the different scenarios considered in the current study. Abbreviations: R^2 = coefficient of determination; RMSE = root mean-squared error; d = index of agreement; SDI = sustained deficit irrigation. All indicators take MPa as units, except for the index of agreement, which is dimensionless.

Year	Treatment	Goodness of fit parameters			
		R^2	Mean error	RMSE	d
2003	Rain-fed	0.535	0.030	0.275	0.850
	SDI	0.627	0.015	0.181	0.910
	Full irrigation	0.612	0.047	0.164	0.900
2004	Rain-fed	0.852	0.057	0.163	0.950
	SDI	0.883	0.141	0.180	0.940
	Full irrigation	0.952	0.096	0.121	0.970
2010	Rain-fed	0.732	0.123	0.194	0.880
	Full irrigation	0.748	0.181	0.211	0.820
	SDI	0.839	0.234	0.245	0.770
2011	Rain-fed	0.767	-0.317	0.407	0.770
	Full irrigation	0.729	-0.183	0.229	0.810
	SDI	0.409	-0.163	0.223	0.780

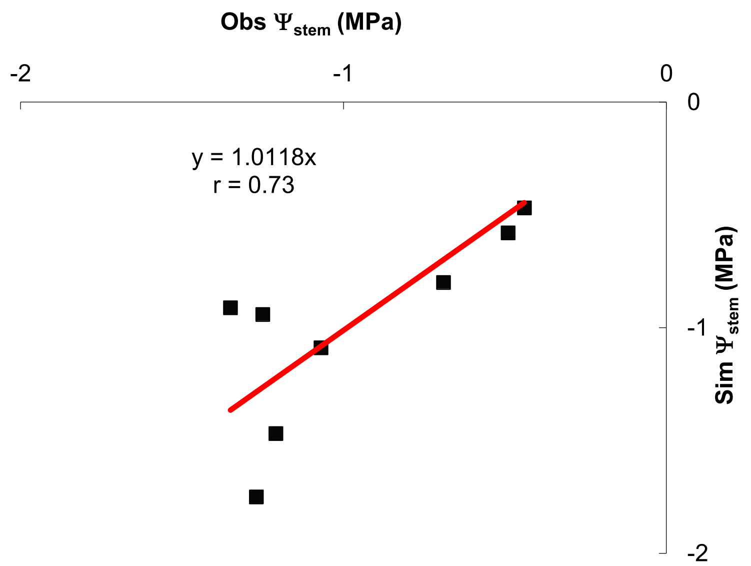

Figure 1 – Linear correlation between observed and simulated values of midday stem water potential (Ψ_{stem}) for the rain-fed treatment in 2003. The equation for the relationship and the correlation coefficient (r) are shown.

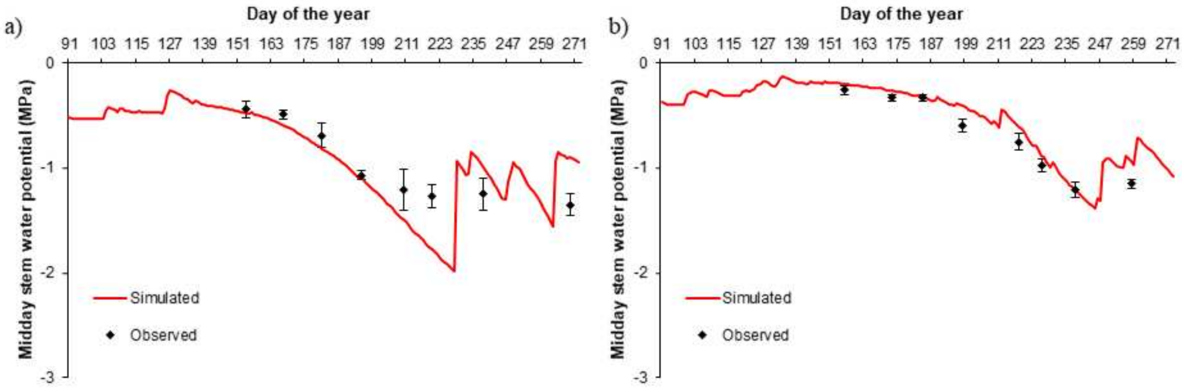

Figure 2 – Temporal evolution of midday stem water potential (Ψ_{stem}) values for a) the rain-fed treatment in 2003, and b) the fully irrigated treatment in 2004. Error bars indicate standard deviations.

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