Agricultural Water Management 182 (2017) 13–23

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Linking the transpirable soil water content of a vineyard to predawn leaf water potential measurements

Rémi Gaudin[a,*], Sébastien Roux[b], Bruno Tisseyre[c]

[a] Montpellier SupAgro, UMR SYSTEM (INRA-CIRAD-SupAgro), 2 place Viala, 34060 Montpellier Cedex 2, France
[b] INRA, UMR SYSTEM (INRA-CIRAD-SupAgro), 2 place Viala, 34060 Montpellier Cedex 2, France
[c] Montpellier SupAgro, UMR ITAP (IRSTEA-SupAgro), 2 place Viala, 34060 Montpellier Cedex 2, France

ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 5 December 2016
Accepted 8 December 2016
Available online 14 December 2016

Keywords:
Vitis vinifera L.
Soil water balance
Mediterranean vineyard
Water stress

ABSTRACT

A new expression of the time derivative of predawn leaf water potential was proposed by equalizing two expressions of the grapevine transpiration. This expression was established when transpiration is the only driver of the vineyard water balance. Under Mediterranean climate, this condition is met for long periods of drought i.e. most of the summer time under the hypothesis that there is no water movement (capillary rise) from the deep layers of the soil. The proposed approach showed that changes in predawn leaf water potential (Ψ_{pd}) values are in inverse relation with the Total Transpirable Soil Water (TTSW) which characterizes the maximal water stock of the soil and in direct relation with reference evapotranspiration (ET_o) and the basal crop coefficient (k_{cb}) of the vine. The relation between Ψ_{pd} changes and cumulated ET_o is linear with a slope related to the ratio of "k_{cb} to TTSW". This ratio can be therefore estimated from field measurements and climatic data.

This approach was tested on two year observations performed by Acevedo-Opazo et al. (2010) in vineyards cultivated with cv. Shiraz and Mourvedre, without any irrigation. Analysis of the data obtained in 49 sites per vineyard for several dates in the very dry summers of 2003 (Shiraz) and 2005 (Mourvedre) showed strong and significant adjustments of the model. These results proved the linear relationship between the sum of ET_o and Ψ_{pd}. For each site of the vineyard, the approach demonstrated the possibility to provide site-specific estimates of the ratio of k_{cb} to TTSW. This theoretical and practical development could have applications for water management and soil studies in Mediterranean vineyards.

1. Introduction

Many studies have shown that the dynamic of the grapevine water status determines the grape yield as well as grape quality at harvest (Van Leeuwen et al., 2004; Deloire et al., 2005; Pellegrino et al., 2006; Gaudin et al., 2014b). When soil water content measurements are possible, the grapevine water status can be defined by the fraction of transpirable soil water (*FTSW*) (Lebon et al., 2003; Van Leeuwen et al., 2009). The *FTSW* has to remain high during the vegetative growth in order to avoid significant water restrictions. After flowering, it should decrease and generate moderate water stress to give priority to generative over vegetative development (Pellegrino et al., 2004, 2005).

In Mediterranean conditions where significant water restrictions are regularly observed, the vine water status is commonly estimated through the pre-dawn leaf water potential (Ψ_{pd}) (Ojeda et al., 2001; Pellegrino et al., 2004; Ojeda, 2007). Environmental and varietal factors influence Ψ_{pd} in the field. Among environmental factors, the soil type (Koundouras et al., 2006) and the depth of the water-table at the landscape scale (Guix-Hebrard et al., 2007) are considered as the most important. Varietal effects on Ψ_{pd} values were clearly identified by Schultz (2003) and Ojeda et al. (2005). However, it seems that this only explains differences in Ψ_{pd} values for moderate water restrictions while the soil factor explains differences in Ψ_{pd} values for high level of water restrictions (Taylor et al., 2010).

The factors which influence the seasonal dynamic of Ψ_{pd} are also important drivers of the vineyard water balance. Irrigation and rain events rapidly affect the evolution of Ψ_{pd}. In Mediterranean vineyards where summer drought occurrence has high probability, it is possible to define an optimum time-course of Ψ_{pd} for the purpose

---

* Corresponding author.
E-mail address: remi.gaudin@supagro.fr (R. Gaudin).

http://dx.doi.org/10.1016/j.agwat.2016.12.006

of irrigation management (Ojeda, 2007). It is noteworthy that under dry conditions, the water balance equation is simplified: the evaporation term could be dropped and the soil water loss is assumed to be mainly due to vineyard transpiration in absence of capillary rise. In this condition, change in Ψ_{pd} can reasonably be linked to soil and grapevine variables.

This question is not solely theoretical since long summer drought episodes have already occurred in the twenty-first century, notably in 2003 where Ψ_{pd} values as low as −1 MPa have been observed by Acevedo-Opazo et al. (2010) putting the vines in extreme water stress conditions. Moreover, a comprehensive view of the Ψ_{pd} dynamic could help optimize the vineyard management during dry conditions. To understand this dynamic of Ψ_{pd} under dry conditions, *FTSW* has to be considered since it is associated to Ψ_{pd} in the water balance approach. A precise method for estimating *FTSW* is the use of a neutron probe which gives the water content of deep as well as shallow layers of the soil (Trambouze and Voltz, 2001; Pellegrino et al., 2004; Celette et al., 2008; Gaudin et al., 2010). However, presence of rocks constitutes an obstacle to its proper implementation in too many situations (Van Leeuwen et al., 2009).

This difficulty concerns most qualitative Mediterranean vineyards with moderate and controlled yield. Although the experimental estimation of *FTSW* can be problematic in these cases, its modelling using water balance models has proven to be robust and has given rise to many applications. Models have been applied in vineyards either in bare soil conditions (Lebon et al., 2003; Pellegrino et al., 2006) or with intercrop (Celette et al., 2010; Fandino et al., 2012). Hofmann et al. (2014) recently summarized the advantages and drawbacks of water balance models, recalling the historical context of their development. It leads these authors to recommend the intermediate approach of Lebon et al. (2003) which separates the evapotranspiration fluxes of grapevines and bare soil.

The same modelling concepts are used in this paper to focus on the transpiration flux under particular conditions. Our approach is based on a mathematical development equalizing two expressions of the vine water consumption when vine transpiration is its only driver (no evaporative term from the bare soil is considered). This formalization leads to a simple expression of the rate of change of the pre-dawn leaf water potential under dry conditions. This study considers periods of drought commonly experienced by Mediterranean vineyards of the Northern hemisphere in July-August. It applies to vineyards without a water-table. The mathematical derivation of this result and its validation using data from experimental vineyards of Pech Rouge (INRA-Gruissan, 43°08′47″N, 03°07′19″E) in particularly dry years are presented hereafter. Moreover, the dataset covers two different years and two cultivars (cv. Shiraz and Mourvedre) presenting differences in their hydric behavior, at least in moderate stress condition (Prieto et al., 2010; Taylor et al., 2010).

The modelling approach developed thereafter is an inverse approach applied when a long period of time under dry condition occurs. Such a condition is regularly met under rain-fed Mediterranean vineyard a few weeks every year.

Inversion is a classical approach in water balance studies. For instance, Campos et al. (2016) has recently used this method to estimate the Total Available Water of various rain-fed and irrigated vineyards by assimilating actual evapotranspiration data in a water balance model. The method we are proposing is based on reference measurements performed on Mediterranean vineyards: predawn leaf water potential, which are robust and quite commonly used by the wine industry to monitor vine water restriction. It opens the way to estimation of the Total Water reservoir of vineyards at local scale when/where other approaches (soil water measurements) are not possible.

2. Theory

In this section the expression of the time derivative of Ψ_{pd} is obtained using modelling concepts classically used in vineyard studies. These concepts applied in first instance for Shiraz (Lebon et al., 2003; Pellegrino et al., 2004) and Gewürztraminer (Lebon et al., 2003) have since been used for soil-vine water studies concerning other varieties: Aranel (Celette et al., 2010), Cabernet-Sauvignon (Gaudin et al., 2014a), Grenache (Pellegrino et al., 2006; Gaudin et al., 2014b), Mourvedre (Pellegrino et al., 2006), Riesling (Gruber and Schultz, 2005; Hofmann et al., 2014).

In the model of Lebon et al. (2003), the soil water content is represented by a reservoir characterized by its Total Transpirable Soil Water (*TTSW*, mm), the Available Soil Water (ASW, mm) and the Fraction of Transpirable Soil Water (*FTSW* = *ASW*/*TTSW*) remaining at any time during the season (Sinclair and Ludlow, 1986). The *TTSW* is measured as the water stock difference between the soil water content profile at field capacity and the driest soil water content profile. In dry conditions, the latter generally takes place around harvest and is usually obtained by multi-year experimentation to make sure the soil profile is in its minimal water condition at least once: examples of these profiles can be found in Pellegrino et al. (2004), Celette et al. (2008), and Gaudin et al. (2010).

In this study, it is assumed:

a) no capillary rise from any water-table and no influence from deep layers under the root zone of the vine,
b) the evaporative flux from the soil surface maintained in bare condition is zero,
c) the soil water content is low and has triggered an active stomatal regulation.

The second condition can be verified in summer approximately ten days after any rain event (Allen et al., 1998) for any vineyards with no intercrop. Less than ten days can be sufficient for this condition to be realized in Mediterranean summer.

When these conditions are met, following Lebon et al. (2003), daily vine transpiration (Tr in mm d^{-1}) can be summarized by two equations (Eqs. (1) and (2)):

$$Tr = (FTSW/0.4) \times k_{cb} \times \mathrm{ET_o} \tag{1}$$

$$Tr = -\mathrm{d}ASW/\mathrm{d}t \tag{2}$$

with:

k_{cb} basal crop coefficient of the vine (no unit), associated to vineyard radiation interception efficiency (Riou et al., 1989; Lebon et al., 2003)

ET_o reference evapotranspiration (mm d^{-1})

Eq. (1) states the regulation of vine transpiration by soil water availability occurring below a given threshold value of *FTSW*. Lebon et al. (2003) showed that, for Shiraz variety, the stomatal conductance decreases below *FTSW* = 0.4. When *FTSW* > 0.4, no limitation to the potential climatic demand of the vine is observed as established by Schultz (1996) with stomatal conductance measurements in a Mediterranean vineyard. The vine transpiration is then k_{cb} x ET_o. When *FTSW* < 0.4, there is a limiting influence of stomatal aperture on both the CO_2 assimilation (Pellegrino et al., 2006) and the H_2O transpiration (Lebon et al., 2003; Hofmann et al., 2014) leading to Eq. (1). This condition is experienced by vines grown without irrigation during most summers in Mediterranean conditions.

Eq. (2) corresponds to the simplified water balance under dry conditions: No rain, no irrigation, no evaporation and no capillary rise.

Equalizing Eqs. (1) and (2) leads to:

$$-\mathrm{d}ASW/\mathrm{d}t = (FTSW/0.4) \times k_{cb} \times \mathrm{ET_o}$$