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Relating plant and soil water content to encourage smart watering in chestnut trees

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A R T I C L E I N F O

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A B S T R A C T

Chestnut orchards are facing new limitations due to scarce of soil water during summer times, mainly attributed to the low precipitation amount typically occurred on such period. The present study aims to define a methodology to improve in a smart way the utilization of water on chestnut irrigation. Based on leaf gas exchanges parameters, there is done a transposition for the soil water content and matric potential, to allow an optimization of the irrigation scheduling in chestnut trees. Trial was installed in a loamy soil at the northeast of Portugal between 2013 and 2016 with micro-sprinkler and drip irrigation system. Stem water potential, photosynthetic rate, soil water content and soil water potential were monitored during the vegetative cycle (June–October). The stem water potential was dependent on air's temperature and soil moisture. The higher photosynthetic rate (9–11 $\mu molCO_2 \cdot m^{-2} s^{-1}$) was reached when midday stem water potential ranged between −1.2 to −0.5 MPa and the regression between stem water potential and soil water content on the top 10–40 cm of soil was of $r^2 = 0.38$. According to these, it was admissible to trigger irrigation when the probe registers 16% and watering must keep soil's moisture near 23%. The regression between stem and soil water potential was of $r^2 = 0.43$ and irrigation scheduling may be triggered when 'Watermark' sensor at 30–60 cm soil depth is above −100 cbar to promote good tree water status although this last is air temperature dependent.

1. Introduction

Portugal had 35.595 ha of chestnut trees with a total production of 27.628 tons in 2015 (INE, 2015). The chestnut tree is mainly found in rainfed conditions but the irrigated area is growing: from the new 835 ha planted within 2007–2013 about 23% are in irrigation conditions (Proder, 2014). Irrigation increases chestnut productivity and fruit size (Breisch, 1995) but so far only Martins et al. (2010, 2011) studied the effect of irrigation in chestnut trees under different soil's management and soil-plant relationship was approached. Additionally, only a field study made in France and developed by Jayne (2005) can be consulted, although it did not approach the soil-plant relationship. The soil-water-plant relationship is deeply dependent on plant's physiology and morphology as well as on soil's features (Clothier and Green, 1994; Meinzer et al., 2004). It is difficult to establish a clear and straight relationship between soil and plant water status since climatic conditions also intervenes (Kenneth et al., 1997; Naor, 2006; Sanjit et al., 2012) but preferably all the factors must be consider for a correct water management. In the absence of models that integrate all the factors, in practice, irrigation can be programmed based in one factor alone or in two. The midday stem water potential (Ψw_{md}) has been indicated as the most sensitive and reasonable in the detection of water status of perennial crops such as the prune tree (McCutchan and Shackel, 1992; Shackel et al., 2000a; Shackel et al., 2000b; Lampinen et al., 2004), pecan tree (Sanjit et al., 2012) and walnut tree (Fulton et al., 2002). Similar conclusions were found in vineyards (Williams and Araújo, 2002), olive trees (Gómez-del-Campo, 2013) or peach trees (Mirás-Avaloz et al., 2016). However, Ψw_{md} is relatively new in terms of on-farm adoption and has the disadvantage of not being an automatic method leading that fruit growers are more accustomed to guide their irrigation decisions by adopting a water budget method using climate based estimates of crop evapotranspiration or methods of soil moisture monitoring (Girona et al., 2002). The understanding of a correlation between Ψw_{md} and soil water content overcomes this disadvantage

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because soil moisture can be monitored by probes in an automatic and continuous way (Munoz-Carpena, 2015). Additionally, the Ψw_{md} indicates when irrigation should start, but it does not indicate how long the irrigation should last; something that can be overcome by placing soil water sensors to record when the effective root depth is wet (Gómez-del-Campo, 2013). In which concern the soil moisture-based optimized irrigation it consists of keeping the soil within a target moisture range by replenishing the plant water uptake with irrigation. This practice reduces the potential for soil water excess and leaching of agrochemicals present in the soil, however it requires selection of a suitable method for soil moisture estimation (Munoz-Carpena, 2015). The soil moisture can be approached by indirect methods such as volumetric or by tensiometric methods and the decision for one or another depends on the cost, accuracy, response time, installation, management and durability (Munoz-Carpena, 2015). The first method measures the amount of water in the soil either by weight or volume, and the second measures the potential energy status of a small parcel of water in the soil. We define smart irrigation as the one that is based on controllers that reduce outdoor water use by monitoring and using information about site conditions (soil and climatic features). Ideally this controller should also access plant's physiological parameters to better meet the plant water needs but so far technology is not there yet. However, and in a tentative to get close to this smart irrigation in a crop that usually is rainfed, this study aims to define reference soil water values, both by using volumetric or tensiometric methods, departing from plants' water status and photosynthetic productivity, for proper irrigation on chestnut trees.

2. Material and methods

Several steps were followed to achieve the purpose of the study. First the photosynthetic rate was used to infer which plant's water potential reflects the most adequate water status. Later a regression between Ψw_{md} and soil water content/soil water potential was established to define the soil values from where it can be decide the irrigation. The data used in this regression was gathered during three years (2013, 2015 and 2016) from watered and non watered trees located in two different experimental plot described forwards. More details can be consulted in Mota et al. (2014) and Mota et al. (2018).

2.1. Orchard characterization

The experiment was conducted during 2013, 2014, 2015 and 2016 in the northeast of Portugal, 862 m altitude, on a commercial orchard planted in 1993, with compass 5 by 10 m. The rootstocks were seedlings from *Castanea sativa* M. grafted with 'Judia' variety. The soil is kept with seeded pasture since plantation. The soils are Cambisols, with 100 cm of thickness and C horizon shows many coarse gravel and cobbles. Soils are loam and, on the toppest 10–60 cm, the organic matter is about 3% and has 26 and 115 mg kg^{-1} of extractable P_2O_5 and K_2O (Egnér-Rihem method) respectively, and pH (H_2O) of 4.7. The moisture contents at field capacity (FC) and wilting point (WP) were determined with a pressure plate apparatus at 10 KPa (pF value 2) and 1500 kPa (pF value 4.2), respectively (Table 1). In this method, undisturbed soil sample is placed on a porous ceramic plate in a chamber and saturated with water. A pressure of 10 or 1500 kPa is applied until equilibrium in water content between the plate and the soil sample is reached at which time soil water content is determined (Klute, 1986).

2.2. Experimental plots

In the following plots, border trees were kept around the study area and between each tree sample. In 2013/14, a micro sprinkler irrigation system was installed in twenty four trees and irrigation started at August 28th in 2013 when stem water potential measured at 09:00 h GMT fell below −0.6 MPa (full irrigated treatment, FI) or −0.8 MPa (deficit irrigated treatment, DI). In each irrigation event the water furnished was about 30 mm. As far as our knowledge, there are no studies about the stem water potential of the chestnut trees so the definition of this threshold took into consideration Martins et al. (2010) and Brown et al. (2014) that refer an hydric comfort level when the predawn water potential is within −0.4 and −0.6 MPa, and thus we admitted a slight decreased of these values at 9AM. Twelve non irrigated trees (NI) were kept for control. Five sample trees per treatment were selected (Fig. 1, left). Each sprinkler had a debit of 40 L/h, placed 1.5 m away from the trunk, and wetting an area of 13 m^2. The mean total amount of water (*W*) furnished during the vegetative cycle in 2013 was of 1040 m^3/ha (1490 m^3/ha and 590 m^3/ha for FI and DI, respectively). 2014 was a very humid year and no irrigation was done since the tree water potential did not always reach the values to initiate the irrigation and, when it did, irrigation was not initiated since the weather forecast indicated rain for the following days, as it happened. In 2015/16 two types of irrigation systems were installed under the purpose of other study which aimed an economical comparison (Mota et al., 2018), each one in forty trees, as follow: TI − drip irrigation − two pipes per tree row, emitters spaced 1 m with debit of 3.6 L/h; SI − sprinkler irrigation − one suspended pipe with emitters every 5 m with debit of 50 L/h. Forty non irrigated trees (NI) were kept for control. Ten sample trees per treatment were selected (Fig. 1, right). In 2015 the mean *W* was 470 m^3/ha (461 and 479 m^3/ha for TI and SI, respectively) and in 2016, the *W* = 925 m^3/ha (871 and 979 m3/ha for TI and SI, respectively). In both years, the first irrigation started on the third week of July and it was triggered every time $\Psi w_{md} < -1.2$ MPa and the mean water amount given in each irrigation event was about 5 mm. The decision to change the tree water potential threshold for −1.2 MPa was based on the preliminary data of 2013 which indicated that the highest photosynthetic rate was achieved when the midday stem water potential (Ψw_{md}) was around −1 MPa. Plus we decided to define a value below it in a tentative to create a deficit irrigation condition that for one hand saves water and for another hand did not prejudice to much the photosynthetic rate.

Table 1
Bulk density and volumetric water content at field capacity (FC) measured with a pF value of 2.0 (10 KPa) and permanent wilting point (WP) measured with a pF value of 4.2 (1500 KPa) on different soil depths from an adult chestnut orchard in the northeast of Portugal, obtained in laboratory by the method of the pressure plate.

Soil depth (cm)	Bulk density (g/cm^3)	Soil water content (%) at different pF's			
		2	2.5	3	4.2
10	1.47	29.85	25.51	21.27	11.43
30	1.45	33.42	28.78	23.15	14.63
60	1.49	35.20	32.15	26.19	17.22
80	1.49	30,81	27.01	22.40	14.90

2.3. Measurements

2.3.1. Tree water status

Plant water potential was assessed by measuring midday stem water potential (Ψw_{md}) with a Schoelander-type pressure chamber (model "pump-up", PMS Instrument® Corvallis, Oregon, USA) between 12:00 h and 13:30 h GMT. In 2013, measurements were registered weekly from August to September in ten irrigated trees on two leaves per tree (n = 20) and in five non-irrigated trees on two leaves per tree (n = 10). In 2015/16, measurements were registered weekly from June to September in twenty irrigated trees on one leaf per tree (n = 20) and in ten non-irrigated trees on one leaf per tree (n = 10). Sample leaves were from the fruiting branches on the outer north side of the canopy, located as close as possible to the main branch. Leaves were covered with aluminium foil and put into a plastic bag for at least one hour before excision as recommended by Fulton et al. (2014). The readings