COMPARISON BETWEEN SAP FLOW MEASUREMENTS AND TWO PREDICTION CLIMATE FORMULAS TO ESTIMATE TRANSPIRATION IN OLIVE ORCHARDS (OLEA EUROPAEA L. CV. CHEMLALI)

Bchir Amani, PhD
Institut Supérieur Agronomique de Chott- Mariem, Tunisie,
Laboratoire d'Ecophysiologie; Institut de l'Olivier de Sousse, Tunisie,
Laboratori de Fisiologia Vegetal, Departament de Biologia, Universitat de les Iles Balears, España
Boussadia Olfa
Laboratoire d'Ecophysiologie; Institut de l'Olivier de Sousse, Tunisie.
Lemeur Raoul
Laboratoire d'Ecologie des Plantes; Université de Gent, Belgique.
Braham Mohamed
Laboratoire d'Ecophysiologie; Institut de l'Olivier de Sousse, Tunisie.

Abstract

An experimental study was carried out on irrigated olive trees (cv. Chemlali) growing in the arid climate of Gafsa (Tunisia), aiming to estimate the irrigation water requirements of olive trees for a possible optimization of irrigation.

To achieve this objective, sap flow was estimated for whole trees using the heat dissipation method. Transpiration (T) was estimated by the Penman-Monteith and Priestley-Taylor formulas.

Results shows that sap flow depends essentially on solar radiation (with R2=0.857). This study showed a good correlation between the xylem sap flow and climatic parameters (air temperature, solar radiation, vapor pressure deficit). We also found a good regression between sap flow measured by the heat dissipation method and transpiration calculated by Penman-Monteith equation (PM) (R2=0.886) and by Priestley-Taylor equation (R2=0.883).

Keywords: Olive trees, sap flow, transpiration, water need, optimizing irrigation

Introduction

Olive (*Olea europaea* L.) trees are the most adapted ones in the semiarid Mediterranean regions. In fact, the tolerance of the tree to drought, and its capacity to grow in shallow, poor quality soils, make the species among the most interesting for cultivation in arid and semiarid areas. However, according Fernandez and Moreno (1999), the olive tree's outstanding adaptation to drought enables it to grow and to produce commercial yields under rain fed conditions in areas where the average rainfall is not much more than 500 mm, and where the dry season can last for five or six months. That's why the water supplied by irrigation minimizes the negative effects of water stress on crop performance. At the farm level, and more specifically in olive growing, it is necessary to optimize irrigation by the estimation of trees water needs.

To achieve this object, it is necessary to study climatic and ecophysiological parameters related to olive trees. These settings allow us to improve the economic management of water and increase the irrigation water use efficiency. According Fernandez and Moreno (1999), the short-term water-use dynamics of the olive tree can be evaluated from sap flow measurements in the trunk, branches, or roots. This method give us representative information about tree water status and allows us to have a better control of the high frequency irrigation systems. Both olive water consumption and the dynamics of transpiration and water uptake by main roots can be estimated from sap flow measurements (Fernandez, 2006). Nicolas et al. (2005) used grass reference evapotranspiration (ET_0), as computed by the PM-FAO-56 scheme (Allen et al., 1998), to estimate the daily sap flow (S) of well-irrigated olives and apricot trees. Due to many problems seach as water shortage, climate change, growing population and potential food shortages, it's increasingly important to find an appropriate management of water resources and to improve irrigation scheduling.

The aims of the present work were to: (1) establish the relationship between orchard olive transpiration from sap flow measurements and climatic parameters such as air temperature, solar radiation and vapor pressure deficit. (2) Compare transpiration (sap flow) measured and transpiration calculated with PM and PT equations.

Materials and methods

Site description

The study plot is planted with olive oil variety Chemlali (trees are aged 8 years) conduct intensive. Experiments were conducted in an irrigated olive orchards in the South of Tunisia (Gafsa) (34°28'N, 5°50'E, 350m), between 2009 and 2010. This region is characterized by an arid climate with dry, hot summers and humid, mild winters, resulting in an average annual rainfall of 50 mm and temperature of 20 °C. The orchard was planted in

2001 with Olea europaea L. cv. Chemlali trees at 4 x 3m spacing. These trees were irrigated by a localized irrigation system with, for each tree, four drip nozzles located at a distance of 1.0 m to the north, east, south and west of the trunk, respectively. An automatic weather station was located in the field at 2 m above the canopy surface, which measured every 5 min and logged 30 min averages with a data-logger type DL2 (Delta-T Devices, Cambridge, England) the following parameters: air temperature (T, °C), relative humidity (RH, %), global radiation (Rg, W m^{-2}), soil heat flux (G, W m^{-2}) and wind speed (u, m s^{-1}).

Sap flow measurements in the trunk

Sap flux thermal dissipation probes (TDP30, Dynamax Inc., Houston, TX, USA) were continuously monitored at 30 cm above soil level. On each tree two probes were installed in two directions (South and North) at depth of 30 mm.

As natural temperature gradients were considered a risk, a cyclical heating scheme as suggested by Do and Rocheteau (2002) was applied. The heater element was discontinuously heated (10 min heating, 20 min cooling) in order to use less energy. The temperature difference is inversely proportional to the flux density. Under laboratory conditions, Granier (1985) obtained a relationship between sap flux density (U) and the ratio of temperature differences, called the flow index (K):

$$U = 119 \times 10^{-6} K^{1.231} \ (m^3 m^{-2} s^{-1})$$

Where $$K = (\Delta T_0 - \Delta T_u) / \Delta T_u$$

Where ΔT_0 is the maximum temperature difference obtained under zero flow conditions and ΔT_u is measured temperature difference at a given flux density U.

The noncontinuous, cyclic TDP system is based on the same radial flowmeter but with a cyclic schedule of heating and cooling. As defined by Do and Rocheteau (2002), the alternate signal (ΔT_a) was calculated as:

$$\Delta T_a = \Delta T_{on} - \Delta T_{off} \qquad (3)$$

Where ΔT_{on} is the temperature difference at the end of the heating period and ΔT_{off} is the temperature difference at the end of the cooling period. By analogy with the continuous TDP system, an alternate flow index (K_a) was then calculated as:

$$K_a = (\Delta T_{0a} - \Delta T_{au}) / \Delta T_{au} \qquad (4)$$

Where ΔT_{0a} is the maximum alternate signal obtained under zero flow conditions and ΔT_{au} is the measured alternate signal at a given U.

The Penman-Monteith equation

Climate data allow us to calculate the evapotranspiration using the following formulas:

$$T = \frac{\Delta * A + \rho cp \frac{(es - ea)}{ra}}{\lambda * [\Delta + \gamma \left(1 + \frac{rc}{ra}\right)]}$$ (Allen et al., 1998)

Where: T: transpiration (mm/day); λ (2.45 MJ L^{-1}) is the latent heat vaporization; A = 0.303*Rn*L (Pereira et al., 2007.a) with L : leaf area; (es - ea) represents the vapor pressure deficit of the air; ρ is the mean air density at constant pressure; c_p is the specific heat of the air; Δ represents the slope of the saturation vapor pressure temperature relationship; γ is the psychrometric constant; and r_c and r_a are resistance and aerodynamic resistances.

The Priestley-Taylor equation

The Priestley-Taylor model to estimate transpiration from a large wet surface under conditions of minimal advection (Priestley and Taylor, 1972):

$$T = \alpha \frac{\Delta \ (Rn - G)}{(\Delta + \gamma) \ \lambda}$$

With α an empirical correction for our case α = 1,41-(0,0064*L) (Pereira et al., 2007.b) was used, Rn: net radiation (W m^{-2}), G: soil heat flux (W m^{-2}), Δ: slope of the curve of saturated vapor pressure at air temperature, γ: psychrometric constant, λ: the latent heat of vaporization (=2.45MJL^{-1}).

Results and discussion

Relations between sap flow and climatic factors (Air temperature, solar radiation and vapor pressure deficit)

The sap flow is associated with climatic parameters as reference evapotranspiration, air temperature, solar radiation and vapor pressure deficit (VPD) (Rousseaux and al., 2009). That's why in this paper we try to study the sap flow dependence on climatic parameters (Fig.1).

Figure 1.a shows the correlation between sap flow and air temperature. We can see a highly significant regression (R^2 = 0.780) between sap flow and air temperature. This type of relationship was also shown in the olive with very high correlation coefficients in the studies done by Rousseaux and al. (2009) and Orgaz and al. (2007). The relationship between sap flow and solar radiation, assessed by the correlation between them (R^2 = 0.857), shows a highly significant positive effect of solar radiation on the sap flow (Fig. 1.b). A strong linear relationship was found between solar radiation and daily sap flow by Rousseaux and al. (2009). In fact, solar radiation and vapor pressure deficit have an effect on the instantaneous sap flow and on total tree transpiration (Pereira and al. 2007.b; Oguntunde and al., 2007). Comparing relationship of sap flow and vapor pressure deficit (Fig.1.c), regression is less important than the two first ones (R^2= 0.614).

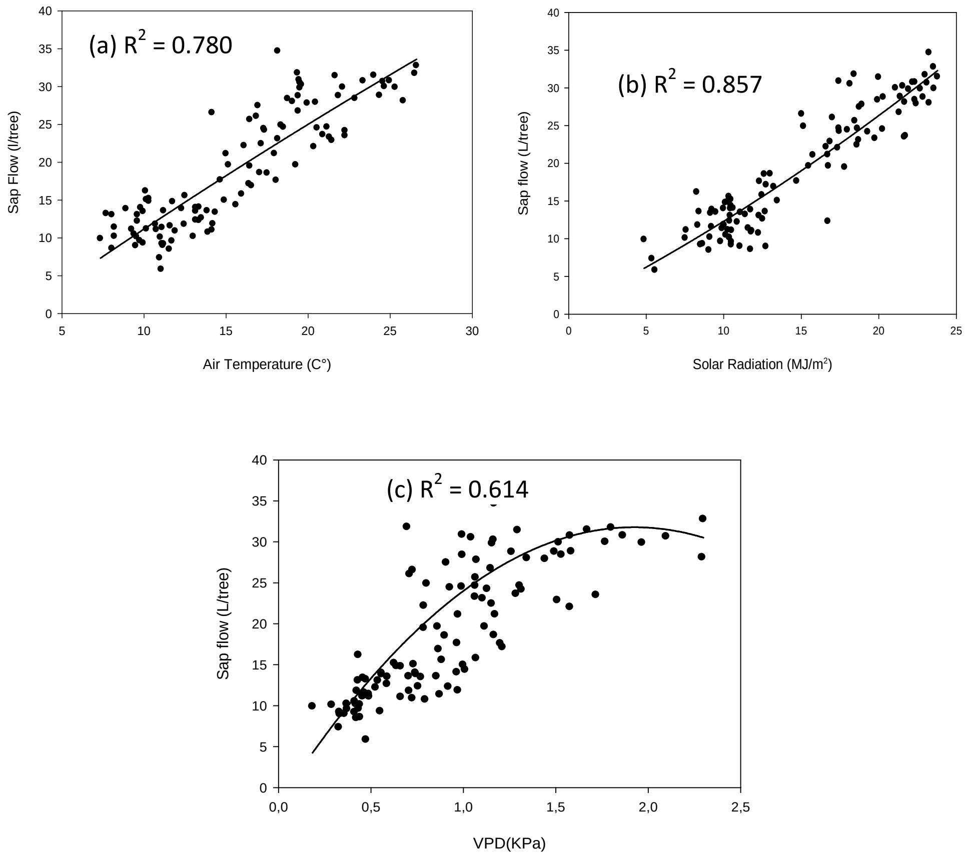

Fig.1. Relation between the daily measured sap flow rate and air temperature (a); solar radiation (b) and vapour pressure deficit (c)

Relationship between measured sap flow and calculated transpiration

Figure 2.a shows the relationship between transpiration was estimated from sap flow records and that calculated by the Penman-Monteith (T-PM) formula. Here we have a linear and highly significant relationship between the values of transpiration calculated and measured sap flow (R^2 = 0.886). This correlation shows that many of the climatic factors involved in the Penman-Monteith formula allows a good estimation of transpiration for olive tree. Pereira et al. (2006) found that transpiration calculated by the Penman-Monteith equation and that measured by sap flow, are linearly correlated. Zhang et al. (1997) showed that a good relationship can be found between calculated and measured transpiration. According to these authors, this relationship allows us to consider the whole tree in a large sheet with the use of conductance (or resistance) to estimate the average of stomatal transpiration.

This Fig (2.b) shows that there is a linear relationship (R^2 =0.883) between measured sap flow and Priestley-Taylor calculated transpiration (T-PT). A similar result was found in olive trees by Pereira et al. (2007) with a high regression coefficient R^2 = 0.91.

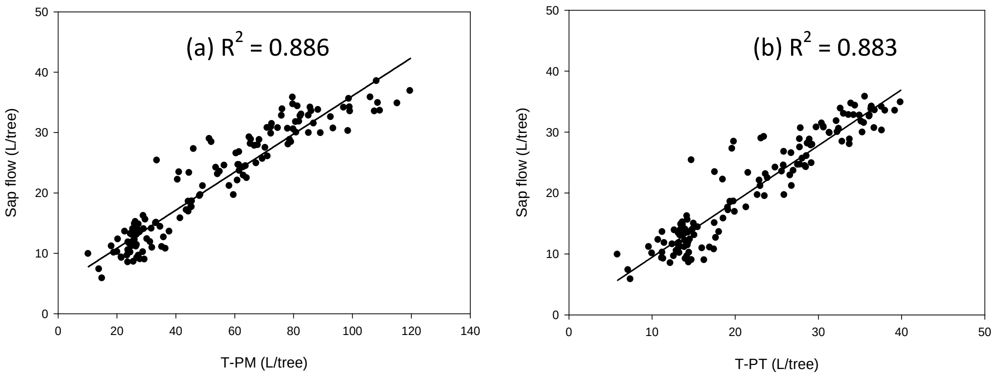

Fig 2. Relation between the measured sap flow rate and transpiration predicted by the PM equation (a) and by the PT equation (b).

Conclusion

The study of the interaction between the sap flow and climatic parameters showed that sap flow is strongly controlled by solar radiation and air temperature. Comparing the sap flow measured by dissipating heat method and the transpiration calculated by the Penman-Monteith equation and that calculated by the equation of Priestley-Taylor, the results showed a good correlation. So that allows us to estimate water consumption of olive orchards in Tunisia by means of transpiration modeling.

To achieve the aim of disseminating the physiological method in different bioclimatic regions, the use of transpiration modeling is the best way to meet to the needs of the profession in water economic management.

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