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Review

Sap flow measurements in young olive trees (*Olea europaea L.*) cv. Chétoui under Tunisian conditions

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ABSTRACT

Measurements of sap flux were carried out from May 2003 to March 2004 on 6 year-old irrigated olive trees of cultivar Chétoui cultivated at 6 m × 6 m spacing in Mornag (36.5°N, 10.2°E), Northern Tunisia. The aim of the research is to evaluate the sap flux technique for its applicability with young olive trees and to estimate their water consumption under field conditions. Three thermal sensors were implanted in the trunk of three olive trees following to North (N), South-East (SE) and South-West (SW) directions. Data were analyzed following to the procedure of Do and Rocheteau (2002b) that derives from Granier (1985). In this paper, data on probe calibration, wood conductive section estimation and sap flux spatial-variability are presented and discussed. Relationships between sap flux measurements, climate and soil water status have been investigated. Results show that sap flux values vary with sensor position, soil water content and climate demand. Good agreements between sap fluxes and global radiation and reference evapotranspiration measurements were observed. Some variations were recorded under water shortage conditions. Maximum and minimum daily fluxes of 4.5 l and 41.0 l per tree were found in February 2003 and in August 2003, respectively. Maximum transpiration represented only 53% of the crop evapotranspiration as determined by the F.A.O. method.

Contents

Abbreviations: ET_c, Crop evapotranspiration as determined by the FAO method (F.A.O. 1998); K_c, Crop coefficient; ET_o, Reference evapotranspiration determined following to Penman–Monteith equation; T, Transpiration flux; E, Soil evaporation flux; CHPV, compensation heat-pulse velocity system; F_d, Sap flow density (l/h/dm^2); (ΔT_a), Actual temperature difference between sensors; (ΔT_{max}), Maximum value of temperature difference between sensors; (K_a), Sap flow index; (a), Slope of the equation found between the sap flow density and the sap flow index. It is determined during the sensors' calibration experiment; F, Total sap flow of the tree (l/day); S_c, Conductive stem section (cm^2); S_t, Total section of the stem (cm^2); R_g, Global radiation (mm/day).

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1. Introduction

In Tunisia, irrigation has become a common practice in most olive orchards with more or less regular inputs depending on water availability. However, in most cases, these amounts don't match the crop water needs, making production largely dependent of these inputs. In Central and South Tunisia, where annual rainfall ranges between 300 mm and less than 100 mm, and where complementary irrigation is necessary to stabilize production and reduce alternate bearing, yields rarely exceed 1.0 T/ha. In Northern Tunisia, yields reach in the irrigated orchards 3.0 T/ha for an input of about 500 mm, including effective rainfall. This together, with the increment in irrigated olive area and the increasing national water deficit makes it crucial to improve the calculation of crop water needs.

The most useful method to estimate water requirements is that of the F.A.O. (Allen et al., 1998; Rana and Katerji, 2000). It has been used to determine crop evapotranspiration (ET_c) of adult orchards (Pastor et al., 1998; Fernandez and Moreno, 1999; Michelakis, 2000; Villalobos et al., 2000; Palomo et al., 2002; Bandino and Dettori, 2003; Habaieb and Masmoudi-Charfi, 2003) but also of young plantations (Le Bourdelles, 1977; Masmoudi-Charfi et al., 2004; Testi et al., 2004). However, despite being widespread, this method has two main disadvantages. First, we are always confronted to the problem of values to adopt. In many cases, the published values of the crop coefficient, K_c, are often used in orchards with conditions different from those under which they were obtained; second, the irrigation amount is always determined on the basis of long-term average reference evapotranspiration (ET_o) values calculated for a period of several days; in this case, the daily variations are not considered. In other cases, an average ET_o value is used for the next irrigation period, so there is a delay in the application of ET_o data.

Experimental methods based on field measurements are used in olive orchards to determine crop water use (Rana and Katerji, 2000). In Tunisia, Riou (1978) estimated for adult plants of cultivar Chétoui the actual evapotranspiration by using a lysimeter, while the soil water balance method was experimented on 25 years-old olive trees of cultivar Chemlali by Abid-Karray (2006). This author found through a study of root distribution and soil moisture monitoring made by a neutron probe, different distinguishable entities related each to a well defined tank ground and subjected each to a given climate request area. She built a mathematical model to characterize lateral water inflows in each of these tanks. For young plants, Masmoudi-Charfi (2008) found also distinguishable compartments where soil moisture varies considerably during the irrigation period. Even below the canopy, water status varies largely. In addition, Fernandez et al. (1991), Villagra et al. (1995) and Granier et al. (2000) proved that the water balance method is time-consuming and of low temporal resolution. Consequently and with regard to these constraints, sites of measurements should be chosen carefully to minimize errors when this method is used.

During the two last decades, other experimental methods based on sap flow measurements were developed in order to determine more precisely the amount of water consumed by trees. Descriptions of these techniques and their applicability in agriculture were detailed in Granier (1985, 1987a,b), Swanson (1994), Do and Rocheteau (2002a,b, 2003) and Pereira et al. (2007). Studies made on this item proved that such techniques can provide useful data which allow calculation of the crop evapotranspiration (ET_c) from independent measurements of its transpiration (T) and the soil evaporation (E) fluxes (Moreno et al., 1996; Smith and Allen, 1996; Cabibel and Isbérie, 1997; Fernandez et al., 2001, 2003). Ultimately, tree transpiration flux can be determined as sap (water) flow estimated by the heat-pulse (Green and Clothier, 1988), the heat-balance (Nasr, 1987) or the thermal dissipation (Granier, 1985, 1987a,b; Cohen, 1991) techniques. However, although sap flow methods have become increasingly widespread and have many applications in agriculture, they are suitable only for use on woody stems. Compared with forestry (Granier, 1987a,b), measurements of sap flow on tree crops have been less frequent and restricted to few species. Green and Clothier (1988) measured sap flow in apple and Kiwifruit after developing a compensation heat-pulse velocity (CHPV) system. For olives, this system has been used in Spain on either root to study hydraulic behavior or/and short-term water-use dynamics (Moreno et al., 1996) or trunks to estimate whole-tree water consumption and its relationship with physiological and environmental variables (Fernandez et al., 1991; Fernandez and Moreno, 1999; Giorio and D'Andria, 2002; Giorgio and Giorgio, 2003). In Tunisia, these methods were used for the first time in 1987 (Nasr, 1987) and experimented on olives many years later (Mahjoub, 2004; Masmoudi et al., 2004; Abid-Karray, 2006; Masmoudi-Charfi, 2008). The global aim of the present work is to carry out preliminary results for calculating water consumption of young olive trees. We intend to evaluate the sap flux technique for its applicability with young trees and to estimate the whole tree transpiration through individual sap flow measurements performed in field. Data on spatial sap flow variability, probe calibration and wood conductive section estimation are presented and discussed in this paper.

2. Materials and Methods

2.1. Experimental orchard

The study was performed on young olive orchard of about 1.6 ha located at the experimental farm of the *Institut National Agronomique de Tunisie*, about 15 Km South of Tunis, Northern Tunisia (36.5°N, 10.2°E). In this region, climate is Mediterranean with average annual rainfall of 450 mm and reference evapotranspiration (ET_o) of 1200 mm. Soil is clay loam (29%C, 49%L, and 23%S), of about 2 m depth and has volumetric water contents of $0.50\,m^3/m^3$ (θ_{cc}) and $0.26\,m^3/m^3$ (θ_{pFP}) measured at soil matrix potentials of −0.5 MPa and −1.5 MPa, respectively.

Weather variables were measured with an automatic weather station located 100 m from the olive orchard. Temperature, air relative humidity, wind spread, rainfall and global solar radiation were recorded continuously and used to calculate ET_o following to Penman–Monteith equation (Allen et al., 1998). Average daily values were used to estimate daily crop water evapotranspiration (ET_c) as

$$ET_c = ET_o \times K_c \times K_r \quad (1)$$

with K_c of 0.5 and K_r of 0.75 (COI, 1997) accounting for an average ground cover of 33%. The study was carried out from 1998 to 2003. However, we have considered for investigation only data recorded from May 2003 to March 2004 because many technical problems appeared and sap flux measurements dropped consistently in comparison with those obtained from May 2003 to March 2004. During the irrigation season (May 2003 to September 2003), ET_o value, rainfall and effective rainfall (USDA method – FAO, 1976) amounts were 982 mm, 346 mm and 239 mm respectively, while annual minimum and maximum average temperatures reached 14.9 °C and 24.9 °C, thus exceeding the averages of this region by +3% and +7%, respectively. Rising temperature has been felt particularly from 1999 to 2002. Three olive trees (*Olea europaea* L.) of 6-years-old, cv., 'Chétoui' planted in 1998 at 6 m × 6 m spacing have been chosen to be representative of the plot. They have similar shape and average leaf area of about 14 m^2. This last was determined in May 2003 by computing the number of leaves on representative branches and the individual foliar area by planimetry as reported by Fernandez and Moreno (1999). Mean tree height