Agricultural Water Management 97 (2010) 333–338

Contents lists available at ScienceDirect

Agricultural Water Management

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

Influence of crop load on maximum daily trunk shrinkage reference equations for irrigation scheduling of early maturing peach trees

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ARTICLE INFO

Article history:
Received 19 May 2009
Accepted 6 October 2009

Keywords:
Irrigation scheduling
Reference equations
Stem water potential
Water relations

ABSTRACT

The effects of high crop load (unthinned trees, 22–23 fruits cm^{-2} of trunk cross-sectional area (TCSA)), commercial crop load (3–4 fruits cm^{-2} of TCSA), and no crop load (all fruitlets removed) on maximum daily trunk shrinkage (MDS), trunk growth rate (TGR) and stem water potential (Ψ_{stem}) were studied during the fruit growth period and 20 days following harvest in fully irrigated early maturing peach trees, *Prunus persica* (L.) Batsch, cv. Flordastar. Even though crop load did not affect plant water status, the MDS and TGR values increased and decreased, respectively, as a result of the crop load effect. In this sense, for the same Ψ_{stem} value, there was a linear increase in MDS with crop load, with a slope of 6.6 μm MPa^{-1} per unit of crop load increment. The effects of environmental conditions on daily MDS values were also dependent on crop load, suggesting that MDS reference values should be obtained by representing the relations between MDS and the climatic variables (daily mean air temperature, daily mean vapour pressure deficit and daily crop reference evapotranspiration) for a given crop load. The constancy of the relation between MDS and Ψ_{stem} across crop load underlined the constancy of the elastic properties of the bark tissues.

1. Introduction

To determine what the exact crop water requirements are at any moment, measurements of the plant water status could provide a promising technique for irrigation management because of its dynamic nature, which is directly related with meteorological and soil conditions, as well as with crop productivity (Goldhamer et al., 2003; Remorini and Massai, 2003).

Continuous records of stem diameter have been widely proposed as a management tool for irrigation scheduling (Huguet et al., 1992; Cabibel and Isberie, 1997; Cohen et al., 2001; Goldhamer and Fereres, 2001). In this sense, recently, Ortuño et al. (2010) have reviewed the state of the art as regards the use of trunk diameter fluctuations derived parameters for irrigation scheduling in woody crops. To our knowledge, Goldhamer and Fereres (2004) were the first to demonstrate that it is feasible to develop a deficit irrigation schedule based only on maximum daily trunk shrinkage (MDS) measurements in almond trees. Subsequently, García-Orellana et al. (2007), Velez et al. (2007) and Ortuño et al. (2009c) confirmed that in citrus MDS measurements are indeed suitable for adjusting the deficit irrigation schedule.

Recent results have showed that maintaining MDS signal intensity (SI, actual MDS/well irrigated MDS) around the unity could be successfully employed for scheduling full irrigation, avoiding the absence of soil water deficit (Conejero et al., 2007b; Ortuño et al., 2009a). This irrigation management will be very useful to precisely match the irrigation applied with the actual amount of crop water used. In addition, in situations where drainage can be avoided, and in the absence of rainfall, this strategy could be considered as a tool for estimating crop evapotranspiration (Ortuño et al., 2010).

The concept of MDS SI arises taking into account that the plant water status is the result of the effects of the soil water available to the plant and the climatic conditions. Then, the use of absolute values for plant-based water status indicators is meaningless and it is more meaningful to use the concept of signal intensity, normalizing the absolute values with respect to values in non-limiting soil water conditions (Goldhamer and Fereres, 2001; Naor and Cohen, 2003; Ortuño et al., 2006).

Plant-based water status indicators reference values can be obtained by maintaining trees in conditions of non-limiting soil water supply (Conejero et al., 2007a; García-Orellana et al., 2007). Nevertheless, when trees are irrigated much above their water requirements in order to obtain non-limiting soil water conditions, oxygen status may be affected. Moreover, under flooding stress conditions, MDS values increase in the same manner as observed in response to drought stress (Ortuño et al., 2007), which complicates

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doi:10.1016/j.agwat.2009.10.003

the information needed for irrigation scheduling. It would therefore be useful to develop reference equations to interpret the values of a plant-based water status indicator. These reference values can be obtained by relating their values in trees under non-limiting soil water conditions with the evaporative demand of the atmosphere (Moreno et al., 2006; Conejero et al., 2007b; Ortuño et al., 2009b).

Some authors have indicated that crop load may increase transpiration rates (Chalmers et al., 1983), stomatal conductance (DeJong, 1986), leaf photosynthesis (Gucci et al., 1995), and tree water use (Mpelasoka et al., 2001). In contrast, Williamson and Coston (1989) pointed to a reduction in water uptake as a result of the crop load effect, while other authors showed that the effect of crop load on tree water status is not obvious (Naor et al., 1999) or is apparent only under deficit irrigation conditions (Naor, 2004).

It has been shown that MDS values can also be affected by other factors, such as tree age (Moriana and Fereres, 2004) or phenological period (Marsal et al., 2002; Intrigliolo and Castel, 2004; Moriana and Fereres, 2004; Conejero et al., 2007b). Moreover, Marsal et al. (2002) and Intrigliolo and Castel (2006) showed that the relationship between MDS and Ψ_{stem} is affected by the presence or absence of fruits, indicating that crop load might directly influence this relationship. However, Intrigliolo and Castel (2007a) showed that despite a trend for MDS to increase with a heavy crop load, the slope of the MDS vs Ψ_{stem} relationship was not significantly affected by crop load.

Taking into account these considerations, the specific objectives of this paper were: (1) to evaluate the crop load effect on plant water status and TDF-derived parameters during the fruit growth period, (2) to determine the influence of climatic factors on MDS as a function of crop load, and (3) to evaluate the influence of crop load on the MDS vs Ψ_{stem} relationship.

2. Materials and methods

2.1. Experimental conditions, plant material and treatments

The experiment was performed in 2008, in a seven-year-old early maturing peach orchard (*Prunus persica* (L.) Batsch, cv. Flordastar grafted on GF-677 peach rootstock) at the CEBAS-CSIC experimental station in Santomera (Murcia, Spain) (38°06′N, 1°02′W, elevation 110 m). The soil is stony (33%, w/w) and shallow, with a clay–loam texture. Analytical data showed a high lime content, very low organic matter content, low cationic exchange capacity, and low available potassium and phosphorus levels. Available soil water and bulk density were 200 mm m^{-1} and 1.58 g cm^{-3}, respectively. The volumetric soil water content at saturation and field capacity were 0.49 and 0.35 $m^3 m^{-3}$, respectively. The irrigation water had a mean EC of 1.1 dS m^{-1} and a mean Cl^- concentration of 26 mg l^{-1}. The trees were trained to an open-centre canopy. Tree spacing followed a 5 m × 5 m square pattern, with an average ground cover of about 78.5%. Pest control and fertilization practices were those commonly used by the growers, and no weeds were allowed to develop within the orchard.

From 11 March 2008 (day of year 71, DOY 71) to 19 May (DOY 140), peach trees were irrigated daily above the estimated crop evapotranspiration (156% ETc) in order to obtain non-limiting soil water conditions. Crop irrigation requirements were determined according to daily crop reference evapotranspiration (ETo), calculated using the Penman–Monteith equation (Allen et al., 1998), and a crop factor based on the time of the year (FAO 56, Allen et al., 1998) and the percentage of ground area shaded by the tree canopy (Fereres and Goldhamer, 1990). Irrigation was carried out during the night using a drip irrigation system with one lateral pipe per tree row and eight emitters (each delivering 2 l h^{-1}) per plant. Total water amounts applied were measured with in-line water meters.

On 10 March (DOY 70) peaches were thinned in order to obtain three different crop load treatments. In the control treatment (T0) fruits were not thinned; in T1 fruitlets were hand-thinned to leave 25 cm between the fruits (commercial crop load), and in T2 all the fruitlets were removed by hand.

2.2. Measurements

Every 30 min micrometeorological data, namely air temperature, solar radiation, air relative humidity, rainfall and wind speed 2 m above the soil surface, were collected by an automatic weather station located near the experimental site. Daily mean vapour pressure deficit (VPD_m) was calculated according to Allen et al. (1998).

The soil volumetric water content (θ_v) of the top 150 mm of the soil profile was measured by time-domain-reflectometry (TDR) (model 1502C, Tektronix Inc., OR), as described by Moreno et al. (1996). The θ_v content of the soil from 0.2 m down to a maximum depth of 0.80 m was measured every 0.1 m using a neutron probe (model 4300, Troxler Electronic Laboratories, Inc. NC) in access tubes installed 1.0 m away from the trees and besides the emitters. Measurements were taken in the morning during the experimental period.

At midday (12.00 h solar time), stem water potential (Ψ_{stem}) was measured in two mature leaves per plant (four trees per treatment), taken close from the trunk. Leaves were enclosed in a small black plastic bag covered with aluminium foil for at least 2 h before measurements were made in a pressure chamber.

The micrometric trunk diameter fluctuations (TDF) were measured throughout the experimental period in four trees per treatment, using a set of linear variable displacement transducers (LVDT) (model DF ±2.5 mm, accuracy ±10 μm, Solartron Metrology, Bognor Regis, UK) attached to the trunk, with a special bracket made of Invar, an alloy of Ni and Fe with a thermal expansion coefficient close to zero (Katerji et al., 1994), and aluminium. Sensors were placed on the north side and were covered with silver thermo-protected foil to prevent heating and wetting of the device. Measurements were taken every 2 s and the datalogger (model CR10X with AM25T multiplexer, Campbell Scientific, Logan, UT) was programmed to report 15 min means. Maximum daily trunk shrinkage (MDS) was calculated as the difference between maximum and minimum daily trunk diameter, and trunk growth rate (TGR) was determined as the increment in maximum daily trunk diameter.

The effect of T0 and T1 treatments on fruit size was assessed by evaluating the proportions of marketable and non-marketable fruit production (fruits with a diameter above or below 56 mm, respectively). According to EEC directive 3596/90 (Ministerio de Agricultura, Pesca y Alimentación, 1995), 56 mm is the minimum diameter for a fruit to be considered in the extra category, which can be subdivided into different categories: A, 73 mm > diame-diameter ≥ 67 mm; B, 67 mm > diameter ≥ 61 mm and C, 61 mm > diameter ≥ 56 mm.

2.3. Statistical design and analysis

The design of the experiment was completely randomized with four replications, each replication consisting of three adjacent tree rows of 13 trees. Measurements were taken in the central tree of the central row of each replicate, and the other trees served as border trees. All the trees presented a very similar appearance (leaf area, trunk cross-sectional area, height, ground shaded area, etc.), A two-way ANOVA was performed and means were separated by $LSD_{0.05}$ range test. Percentage values were arc-sin-transformed before statistical analysis.