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Soil water content criteria for peach trees water stress detection during the postharvest period

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ABSTRACT

Irrigation scheduling based on soil water moisture sensors requires that the soil water status be maintained within a range that is optimal for plant growth. The objective of this work was to evaluate whether soil water content dynamics, measured by multi-sensor capacitance probes, could be used to determine indices of a drying soil to detect the commencement of water stress in a peach tree orchard. For this, an experiment was carried out in a drip irrigated mature peach tree orchard in Murcia (Spain). During the postharvest period well irrigated trees (control treatment) were compared with two water stress treatments consisting of a drying cycle applied for one month in two ways: withholding irrigation (Rapid Stress) and progressively reducing irrigation (Gradual Stress). The soil water content (SWC) was measured continuously using multi-sensor capacitance probes. The beginning of plant water stress was identified by the first significant difference in midday stem water potential (Ψ_{stem}) between stressed and control trees. The 'breaking point' (the transition between a relatively rapid reduction of SWC in the drying soil to a slower rate) as well as the stabilization of the SWC-derived indices coincided with appearance of a water stress level as severe as to reduce plant water uptake, as judged from the Ψ_{stem} reduction. The results suggested that a lower SWC limit could be established for irrigation management in early maturing peach trees using capacitance probes at 90% of the field capacity value during the postharvest period.

1. Introduction

Agriculture faces severe water shortage in many areas of the world. Increased competition from other sectors and growing environmental awareness has resulted in increasing pressures to improve water use efficiency. Improvements in irrigation scheduling will reduce water losses. Together with the recognition of crop sensitivity to water stress at different stages of development, these improvements will help ensure that the right amount of water is added at the proper time (Jury and Vaux, 2007).

Irrigation scheduling in peach trees under semi arid conditions has been studied with the aim of increasing water use efficiency by means of deficit irrigation strategies (Abrisqueta et al., 2010; Boland et al., 1993; Girona et al., 2003, 2005; Naor et al., 2005) or by using suitable plant based indicators (Conejero et al., 2007; Goldhamer et al., 1999). Monitoring the soil water content is also essential for estimating plant water needs and for scheduling efficient irrigation (Girona et al., 2002).

The soil water status has long been used for scheduling irrigation (Campbell and Campbell, 1982). Measuring the soil water content (SWC) is a less tedious task than it was previously because of new methods, which include automatic data acquisition (Evett et al., 2002a,b). Different approaches and instruments for the direct and indirect measurement of soil moisture content have been extensively reviewed elsewhere (Gardner et al., 2001; Jones, 2007). Direct methods involve soil sampling, whereas indirect methods are non-intrusive, less labor intensive and can provide immediate feedback, for which reason such method are known as soil moisture sensing. Several commercially available sensors based upon capacitance, impedance and time domain transmission are able to make measurements continuously and in real-time, which makes decision-making easier for precise irrigation scheduling (Paltineanu and Starr, 1997; Starr and Paltineanu, 2002). Experiments concerning soil water dynamics using the continuous monitoring of soil water content by means of capacitance probes may offer helpful information for irrigation management (Evett et al., 2002a,b; Fares and Alva, 2000; Fares and Polyakov, 2006; Girona et al., 2002; Roberson et al., 1996; Thompson et al., 2007).

Automatic soil water sensor-based irrigation requires that the soil water status be maintained within upper and lower limits. Commonly, the upper limit approximates field capacity (FC) and

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the lower limit, often referred to as threshold, is slightly above the level where a crop begins to experience water stress. Maintaining soil water within this range ensures that the crop enjoys adequate water status, while avoiding excess drainage (Campbell and Campbell, 1982). To define the upper limit of SWC using FC, laboratory-determined (Fares and Alva, 2000) and *in situ* field-determined values (Starr and Paltineanu, 1998a) have been used, while to define the lower limit of SWC, the combined concepts of allowable depletion and available water content have been used (Fares and Polyakov, 2006).

Starr and Paltineanu (1998a,b) indicated that the decline in SWC in a drying soil occurred in two phases: a relatively rapid phase and a subsequent slower phase, when the soil water content strongly limits crop water uptake. These authors termed the transition between the two phases as the 'breaking point' and suggested that it could be used to identify the beginning of crop water stress. Very few studies have related the progressive decline in the day-time reduction of SWC in the root zone with the assessment of plant water status (Thompson et al., 2007).

Automatic irrigation modeling should consider the soil as a "steady and slow" component, the climatic water demand as a "variable and quick" component and the plant as a "reactive and resilient" component; therefore, irrigation scheduling should deal with those issues (Vera et al., 2010).

The objective of this work was to evaluate whether soil water content dynamics, measured by multi-sensor capacitance probes, could be used to determine indices of a drying soil to detect the appearance of water stress in a peach tree orchard.

2. Materials and methods

2.1. Plant material, treatments and experimental conditions

The work was conducted in a 0.8 ha orchard of seven-year-old peach trees (*Prunus persica* L. Batsch, cv. Flordastar, on GF-677 rootstock) at the CEBAS-CSIC experimental field station, in Santomera, Murcia, Spain (38°06′31.2″N; 1°02′13.7″W, 110 altitude). Trees were planted in a 5 m × 5 m grid and trained to an open-centre canopy; other details concerning the phenological stages have been described elsewhere (Mounzer et al., 2008). Standard agronomic practices were applied to the orchard including fertilization and pest control, no weeds were allowed in the soil. The soil is highly calcareous (56% calcium carbonate), stony and 0.9 m deep, with a clay–loam texture classified as Lithic xeric haploxeroll. The analysis pointed to a low organic matter content (0.34%), low cationic exchange capacity and low available potassium and phosphorus concentrations. The average bulk density of the soil was 1560 kg m^{-3} and the saturated hydraulic conductivity was 5.4 mm h^{-1}. The mean values of soil water content at field capacity (θ_{FC}) and at permanent wilting point (θ_{PWP}), as determined in undisturbed soil samples by the Richards pressure plate technique (Richards, 1965), were 0.29 and 0.15 m^3 m^{-3}, respectively, which implied an available soil water content of 140 mm m^{-1}. The climate in the region is semiarid Mediterranean with hot and dry summers and an average crop reference evapotranspiration (ET_0) and rainfall of 1340 and 350 mm year^{-1}, respectively.

All trees were irrigated daily during the night above the estimated crop evapotranspiration (130% of ET_c) from the beginning of the growing season (control treatment). Irrigation system consisted of a single lateral line per tree row with eight self-compensating emitters per tree, spaced 0.5 m apart from the tree trunk, and providing 2 L h^{-1} each. Estimated crop water requirements were determined as the product of ET_0 of the preceding week, calculated with the Penman–Monteith equation (Allen et al., 1998), and a crop coefficient corrected by the percent of ground shaded area (Fereres and Goldhamer, 1990).

On June 4, coinciding with the post-harvest stage, peach trees were submitted to two stress treatments for 34 days, consisting of a drying cycle applied in two ways: Rapid Stress treatment, in which irrigation was withheld from June 4 to July 8, and Gradual Stress treatment, in which irrigation was progressively reduced, providing 80, 60, 40, 20 and 0% of ET_c for one week period each. On 9 July, all trees were irrigated at 100% of ET_c. The trees in control treatment were maintained fully irrigated as described above, and the average run time per day was about 6 h.

The three treatments were distributed in a completely randomized design with four plots, each consisting of one row of 13 trees. Measurements were taken in one of the inner representative tree of each plot.

2.2. Measurements

Irrigation was controlled by a head unit programmer operating on electro-hydraulic valves and the irrigation water volumes for each treatment were measured with in-line flow meters. Meteorological parameters including air temperature, solar radiation, relative humidity, wind velocity and rainfall were continuously monitored by an automated weather station located near the peach tree orchard.

The volumetric soil water content was monitored continuously by multi-depth capacitance probe (C-probe; Agrilink Inc. Ltd., Adelaide, Australia). Four PVC access tubes were installed near four representative trees of each treatment (one per plot), 0.1 m from the second emitter (which was located 1 m from the tree trunk). These measurements are based on frequency domain reflectrometry (FDR). Each capacitance probe had sensors which had been previously fitted at 0.05, 0.15, 0.25, 0.45 and 0.75 m along the probe which was then inserted into the installed PVC tubes and connected to a radio telemetry unit, which read the value of each sensor every 5 min and stored an average value every 15 min. The stored raw data were sent by radio through a relay station and then to a gateway connected to a computer for data analysis using the AddVANTAGE software (ADCON Telemetry Vienna, Austria). The accuracy of the data obtained by capacitance probes depends on the installation procedure because the radius of influence of the electric field of the sensors is relatively small (Mounzer et al., 2010). A tripod with vertical leveling capability was used to hold the PVC access tubes in a vertical position while a soil auger was inserted through the tube to remove the soil.

Each sensor inside its PVC access tube was previously normalized taking readings exposed to air and irrigation water (≈22 °C) before being installed in the field. The normalization equation is defined in dimensionless scaled voltage (SV), as:

$$SV = \frac{V_a - V_s}{V_a - V_w}$$

where V_a is the voltage reading of the sensor inside the PVC access tube exposed to air; V_s is the reading in the soil; and V_w is the reading in irrigation water (all in mV). Then, a field calibration was carried out taking readings from the sensors and simultaneously volumetric soil water content (θ) from non disturbed soil samples. The relationship between θ and SV was not linear (Dean et al., 1987; Starr and Paltineanu, 1998a), but a linear equation was found for the soil moisture range 0.12–0.40 m^3 m^{-3}:

$$\theta = 0.44\,SV + 12.0, \quad R^2 = 0.98$$

Soil water content (SWC) was expressed as the sum of water content in the 0–0.8 m soil profile, in mm.

From the continuously measured SWC data for 0–0.8 m soil depth during the stress period, and following Thompson et al.