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Determining reference values for stem water potential and maximum daily trunk shrinkage in young apple trees based on plant responses to water deficit

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ABSTRACT

The use of plant water status indicators such as midday stem water potential (Ψ_{stem}) and maximum daily trunk shrinkage (MDS) in irrigation scheduling requires the definition of a reference or threshold value, beyond which irrigation is necessary. These reference values are generally obtained by comparing the seasonal variation of plant water status with the environmental conditions under non-limiting soil water availability. In the present study an alternative approach is presented based on the plant's response to water deficit. A drought experiment was carried out on two apple cultivars (*Malus domestica* Borkh. 'Mutsu' and 'Cox Orange') in which both indicators (Ψ_{stem} and MDS) were related to several plant physiological responses. Sap flow rates, maximum net photosynthesis rates and daily radial stem growth (DRSG) (derived from continuous stem diameter variation measurements) were considered in the assessment of the approach. Depending on the chosen plant response in relationship with Ψ_{stem} or MDS, the obtained reference values varied between −1.04 and −1.46 MPa for Ψ_{stem} and between 0.17 and 0.28 mm for MDS. In both cultivars, the approach based on maximum photosynthesis rates resulted in less negative Ψ_{stem} values and smaller MDS values, compared to the approaches with sap flow and daily radial stem growth. In the well-irrigated apple trees, day-to-day variations in midday Ψ_{stem} and MDS were related to the evaporative demand. These variations were more substantial for MDS than for midday Ψ_{stem}.

1. Introduction

For the last decade, several water-saving irrigation strategies have been developed to meet shrinking water supplies and to improve water use efficiency (Naor, 2006). Newly developed methods of irrigation tend to rely on approaches based on sensing the plant's response to water deficit. Information on the plant water status is indeed best provided by physiological indicators, because of their dynamic nature and their direct relation with climatic and soil conditions, as well as with crop productivity (Remorini and Massai, 2003; Jones, 2004; Ortuño et al., 2006b).

Maximum daily shrinkage (MDS) of the trunk diameter (Garnier and Berger, 1986; Intrigliolo and Castel, 2004) and stem water potential (Ψ_{stem}; McCutchan and Shackel, 1992; Choné et al., 2001) are the most useful drought stress indicators cited in literature for irrigation purposes. As with other irrigation scheduling protocols, these plant-based water status indicators require a reference or threshold value to which the actual measured value can be compared and beyond which irrigation

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Table 1 – Literature review of stem water potentials (Ψ_{stem}) for well-watered trees.

Species	Location	Ψ_{stem} (MPa)	Source
Deciduous trees	–	−0.5 to −0.8	Taylor and Ashcroft (1972)
Citrus limon L.	Murcia (Spain)	−1.32	Ortuño et al. (2006a)
Malus domestica Borkh.	Golan Heights (Israel)	−0.5 to −1.5	Naor et al. (1995)
Prunus spp.	California (USA)	−0.5 to −1.0	McCutchan and Shackel (1992)
Prunus domestica L. cv. 'French'	California (USA)	−0.5 to −0.9	Lampinen et al. (2004)
Prunus dulcis (Mill.)	California (USA)	−0.5 to −1.0	Shackel et al. (1997)
Prunus persica L.	California (USA)	−0.9 to −1.1	Goldhamer et al. (1999)
Prunus persica L.	Montpellier (France)	−1.1	Garnier and Berger (1985)
Prunus persica Batsch cv. 'Suncrest'	Pisa (Italy)	−1.3	Remorini and Massai (2003)
Prunus salicina Lindl.	Valencia (Spain)	−0.6 to −1.3	Intrigliolo and Castel (2006)
Vitis vinifera cv. 'Cabernet'	California (USA)	−0.96	Williams and Araujo (2002)
Vitis vinifera cv. 'Chardonnay'	California (USA)	−0.6 to −0.86	Williams and Araujo (2002)

is necessary (Fereres and Goldhamer, 2003; Jones, 2004; Steppe et al., 2008).

Some efforts have already been made to develop seasonal reference relationships or baselines for Ψ_{stem} and MDS in order to allow interpretation of the actual measured values (e.g. Fereres and Goldhamer, 2003; Moreno et al., 2006; Ortuño et al., 2006b; Velez et al., 2007). These reference values are generally obtained by measuring the indicators (Ψ_{stem} and MDS) in plants under non-limiting soil water conditions. Although these plants are well-watered throughout the season, the obtained reference values for both indicators might show some variation in response to changing vapour pressure deficit (VPD) (Shackel et al., 1997; Intrigliolo and Castel, 2004). Additionally, a variation across the growing season is observed for MDS due to changes in stem tissue elasticity within one season (Büntemeyer et al., 1998; Proseus et al., 1999; Léchaudel et al., 2007). Tentative reference values of Ψ_{stem} obtained in woody plants under non-limiting soil water conditions range from −0.5 down to −1.5 MPa and MDS values vary between 0.1 and 0.4 mm (Tables 1 and 2). Instead of focusing on non-limited soil water conditions only, an alternative approach is to define reference values for both water status indicators based on measured plant responses to water deficit. As a plant tissue loses water, a reduction in cell turgor is observed. Since many important plant processes, such as expansive growth, are turgor-driven, overall plant growth will reduce as plant water deficit becomes more pronounced (Shackel et al., 1997; Steppe et al., 2006; De Pauw et al., 2008).

The main objective of this study is therefore to present an alternative approach to define reference values for MDS and midday Ψ_{stem}. To this end, relationships between these water status indicators and three measured plant responses to water deficit were investigated. Responses in sap flow rate (F_{H_2O}), maximum photosynthesis rate ($P_{n,max}$) and daily radial stem growth (DRSG) were related to Ψ_{stem} and MDS during a drought stress experiment and these relationships were used to define reference values. This approach was tested on two apple tree cultivars (*Malus domestica* Borkh. 'Mutsu' and 'Cox Orange'), each grown in a different period of the growing season. The responsiveness and tree-to-tree variability of the plant responses to water deficit, as well as the day-to-day variability of MDS and midday Ψ_{stem} are discussed.

2. Materials and methods

2.1. Plant material and experimental setup

Measurements were carried out on 3-year-old potted apple trees (*Malus domestica* Borkh.). In 2005 the cultivar 'Mutsu' was used, while in 2006 experiments were conducted on 'Cox Orange'. The young trees were grown in 50-L containers (0.4 m diameter × 0.4 m height) in the greenhouse facilities of the Faculty of Bioscience Engineering of Ghent University, Belgium. The containers were filled with a mixture of fine (45%) and coarse (40%) white peat, complemented with black peat fibres (15%) and fertilized with a NPK plus magnesium mix (Basacote plus 6M, COMPO Benelux, Belgium). The trees were ~3 m high and had a stem diameter at soil surface between 17 and 27 mm.

In order to define reference values beyond which irrigation is necessary, two apple trees were selected and were continuously monitored from 2 till 19 August (Day of Year (DOY) 214–231) in 2005 (cultivar 'Mutsu') and from 1 till 14 September (DOY 244–257) in 2006 (cultivar 'Cox Orange'). A drought stress experiment was carried out by withholding irrigation on one of the selected trees (henceforth referred as stressed tree) from 5 till 15 August (DOY 217–227) in 2005 and from 4 till 12 September (DOY 247–255) in 2006. Meanwhile, the other tree (henceforth referred as control tree) remained well-watered. Soil water potential, measured in the containers with electronic tensiometers (Type SWP4, Delta-T Devices, Cambridge, UK), was kept above −20 kPa to ensure that control trees were well-watered.

Table 2 – Literature review of maximum daily trunk shrinkages (MDS) for well-watered trees.

Species	Location	MDS (mm)	Source
Citrus limon L.	Murcia (Spain)	0.32–0.4	Ortuño et al. (2006a)
Prunus dulcis Mill.	California (USA)	0.2	Goldhamer and Fereres (2001)
Prunus persica L.	California (USA)	0.2–0.3	Goldhamer et al. (1999)
Prunus salicina Lindl.	Valencia (Spain)	0.1–0.25	Intrigliolo and Castel (2006)