Irrigation scheduling protocols using continuously recorded trunk diameter measurements

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Abstract Theoretical and experimental aspects of developing irrigation scheduling strategies using continuous measurements of trunk diameter are presented. The behavior of parameters derived from trunk diameter measurements (TDM), including maximum daily trunk shrinkage (MDS), maximum daily trunk diameter (MXTD), and minimum daily trunk diameter (MNTD) is evaluated for both rapidly growing peach [Prunus persica (L.) Batsch, cv. September Snow] and mature almond [Prunus dulcis (Mill.) Webb cv. Price] trees subjected to mild deficit irrigation. Stem water potential (SWP) and MDS were highly correlated in the mature almond trees but a poor relationship was found in the rapidly growing peach trees. Conversely, daily changes in MXTD and MNTD correlated well with SWP in the fast growing trees. While there was relatively high variability (“noise”) in the MDS measurements (CV 15.8%), the greater changes in the magnitude of the MDS (“signal”) resulted in a significantly higher signal/noise ratio than found with the SWP measurements. In addition to soil water and trunk growth rate, MDS patterns were influenced by irrigation frequency and evaporative demand. Based on the experimental results, protocols for utilizing the trunk diameter-derived indicators for scheduling irrigations are presented for three cases: (1) mature trees under low frequency irrigation, (2) mature trees under high frequency irrigation, and (3) young trees under high frequency irrigation. The scheduling protocols provide guidelines that address both under- and over-irrigation and are predicated on the sensitivity of TDM to very mild plant water deficits. The necessity for and approaches to developing reference (baseline) and threshold values derived from TDM are emphasized. We conclude that protocols using TDM for precise irrigation scheduling hold promise as an additional tool for progressive growers who want to link irrigation management to an automated, electronic, plant-based stress indicator.

Introduction

Evidence of diurnal oscillations in the diameter of tree trunks was identified long ago (Kozlowski 1967). Short-term changes in stem diameter have been related to concomitant changes in plant water status as transpiration loss draws water from the stem, primarily from xylem tissues (Klepper et al. 1971; Molz and Klepper 1972). Huck and Klepper (1976) found that stem diameter measurements could provide continuous records of plant water potential in cotton plants and suggested that plant water status measurements could be automated.

Interest in using trunk diameter measurements (TDM) for irrigation scheduling in fruit trees was sparked more recently by the work of Garnier and Berger (1986) who did a comprehensive study in peach trees and concluded that it was feasible to automate irrigation based on TDM. Since then, TDM have been taken on a number of fruit tree species, such as apple (Huguet et al. 1992), cherry (Cabib et al. 1997), citrus (Ginestar and Castel 1996) and walnut (Cohen et al. 1997). In all cases, good correlations were found between the degree of trunk shrinkage and swelling and the changes in tree water status. One advantage of TDM is that they provide trunk growth rate records and can characterize growth responses to the environment.

The use of TDM for irrigation scheduling requires that some parameter be derived from the TDM that is indicative of irrigation requirements. It would be desirable for TDM to provide an early warning of water deficits, well before the monitored stress can negatively affect important physiological processes. Goldhamer et al. (1999) evaluated the relative sensitivity of trunk

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diameter-derived parameters and conventional indicators of plant water status in peach trees, including various measurements of tree water potential, stomatal conductance, fruit growth and photosynthesis. They concluded that parameters derived from TDM were more sensitive than the other indicators in that they detected water stress earlier in a drying cycle.

Plant water status is very dynamic because it reflects the balance between soil water supply and atmospheric demand. A single observation of plant water status may not be very informative, as a water deficit may be caused by either the soil water level or by changes in evaporative demand. Therefore, it is not surprising that irrigation scheduling is normally based on soil or atmospheric parameters (Martin et al. 1990); not only because they are easier to measure than plant parameters but because they are more robust and can be readily interpreted. Nevertheless, plant water potential and canopy temperature measurements have been used successfully for irrigation scheduling in a few crops, such as cotton, once the measurements have been calibrated for a given environment (Grimes and Yamada 1982). In fruit trees, research has shown that leaf water potential (LWP) can be a reliable indicator of tree water status (Fereres and Goldhamer 1990). More recently, the superiority of stem water potential (SWP) over other water potential measurements, including predawn LWP, has been established for a number of fruit tree species (Shackel et al. 1997). In any case, monitoring SWP or other water potential indicators with a pressure chamber requires substantial manpower and cannot be automated.

Recent enhancement of the robustness of the sensors used to measure trunk diameter and continued improvements in the quality and affordability of electronic data collection and transfer devices suggest that irrigation scheduling can be automated using a plant-based indicator. This paper discusses the indicators that can be derived from TDM and, based on theoretical considerations and new experimental evidence, presents protocols for using these indicators in scheduling localized irrigations (drip or microsprinkler).

**Theory**

Derivation of parameters based on TDM

Trunk diameters oscillate over a 24-h cycle, reaching a maximum value (MXTD) just before sunrise and a minimum (MNTD) sometime in the afternoon (Fig. 1). The difference between MXTD and MNTD is termed maximum daily shrinkage (MDS); a parameter that has been shown to increase as tree water deficits increase in peach (Garnier and Berger 1986), cherry (Cabibel and Isberie 1997), walnut (Cohen et al. 1997) and other species (Huguet et al. 1992). Goldhamer et al. (1999) found that the MDS of field-grown peach trees increased from 0.27 to 0.63 mm when the SWP decreased from –0.99 to –2.1 MPa, respectively. In a few cases, MDS has been shown to decrease as severe water stress increases, such as in apple (Huguet et al. 1992) and lysimeter-grown peach (Goldhamer et al. 1999).

The evolution of MXTD and MNTD also provides useful information (Fig. 1). The difference between two consecutive MXTD values gives one measure of the trunk growth rate while the trend of MXTD establishes the cumulative growth. Analysis of MNTD trends also gives a measure of the trunk growth rate, as represented in Fig. 1, and this can be one of the earliest signs of water stress (Goldhamer et al. 1999). The high sensitivity of MNTD probably reflects the combined effects of soil water supply and evaporative demand on maximum shrinkage while MXTD is mostly affected by the rehydration process, which depends primarily on soil water supply and may be

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**Fig. 1** Parameters that can be derived from trunk diameter measurements (TDM), including maximum daily trunk shrinkage (MDS), and trunk growth expressed as daily differences in maximum and minimum daily trunk diameters (MXTD and MNTD, respectively)