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Review

Plant-based sensing to monitor water stress: Applicability to commercial orchards

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ABSTRACT

Despite their potential for water stress monitoring, sap flow (SF), trunk diameter variation (TDV) and leaf turgor pressure (LTP) related measurements are rarely used in commercial orchards. The reasons for this lack of popularity are analysed here, as well as possible solutions for the identified limitations. I worked with data collected from different olive orchards as well as with findings from the literature reported for other fruit tree species. SF sensors are difficult to install but easy to maintain. TDV sensors are easier to install, but require greater maintenance. Both methods are highly demanding in terms of data processing, especially sap flow. The usefulness of SF records for monitoring water stress is curtailed on recovery periods, due to the delayed recovery of stomatal conductance. TDV records, on the other hand, depend on plant water status, but also on plant age, phenological stage and crop load, among other factors. For correct data interpretation, therefore, a deep understanding of the response of the monitored variable to plant and environmental conditions is required. For LTP related measurements we used ZIM probes. They showed to be easy to install and use, and robust enough to withstand field conditions for long irrigation seasons. Severe water stress, however, limited their performance. New approaches are being developed to increase the potential of the tested methods for being used in commercial orchards. These include combining the plant-based methods with remote imagery, deriving more user-friendly water stress indices from the collected records and hiring the services of specialized companies which provide the user with easy-to-interpret summaries of the collected information. With the help of new tools and applications, and the hiring of specialized companies if required, the assessed plant-based methods can be reliable and profitable tools for monitoring water stress and scheduling irrigation in commercial orchards.

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1. Introduction

The need for a sustainable water use in agriculture has impelled the scientific community to develop new methods for monitoring water stress. Special interest has been paid to plant-based methods, since plant measurements have the advantage of integrating the soil and atmospheric water status, as well as the response of the plant to the surrounding conditions (Jones, 2004). Conventional plant-based methods to monitor water stress, such as those based on the use of Scholander-type chambers, are destructive and time and labour consuming. In the last decades, however, new methods have been developed for non-destructive, automatic and continuous measurements, easily implemented with data transmission systems for the user to have nearly real time access to the collected data from a remote computer, smart phone or similar. Most of these methods and related systems are highly sensitive and capable of working under field conditions for long periods of time. These characteristics confer them a great potential both for monitoring water stress and scheduling irrigation in commercial orchards (Fernández and Cuevas, 2010).

The new plant-based methods are based on a wide range of variables. Measurements of stem electrical conductivity with TDR probes inserted in the trunk (Nadler and Tyree, 2008; Nadler et al., 2008) and of electric potential differences between plant tissues (Gurovich and Hermosilla, 2009; Oyarce and Gurovich, 2011) can be used to monitor plant water status. The temperature of a fraction (Akkuzu et al., 2010; Çamoğlu, 2013) or the whole canopy (Ben-Gal et al., 2010, Agam et al., 2013) has also proven to be a useful indicator of water stress for a variety of fruit trees, and airborne thermal images are being used to assess the heterogeneity in water status in commercial orchards (Zarco-Tejada et al., 2009; Gonzalez-Dugo et al., 2013). The most widely studied plant-based methods, however, are those based on measurements or estimations of sap flow (SF), trunk diameter variation (TDV) and leaf turgor pressure (LTP). Sap flow methods have a potential for in situ determinations of plant water consumption and transpiration dynamics (www.wgsapflow.com. Website of the Working Group on Sap Flow of the International Society for Horticultural Science). Comparisons between several stress-related indices derived from SF records and other water stress indicators have been made (Escalona et al., 2002; Ortuño et al., 2006; Intrigliolo and Castel, 2006), and the potential of SF-related measurements to schedule irrigation has been explored (Fernández et al., 2001, 2008a,b). The usefulness of TDV records both for monitoring water stress and scheduling irrigation has been evaluated for a great number of species (Fernández and Cuevas, 2010; Ortuño et al., 2010), and comparative studies between TDV and other water stress indicators have also been made (Ehrenberger et al., 2012a; Cuevas et al., 2013). More recently, the leaf patch clamp pressure probe or ZIM-probe (Zimmerman et al., 2008) is being used to monitor water stress from estimations of relative changes in LTP (Fernández et al., 2011a; Bramley et al., 2013).

Several irrigation protocols based on the three methods mentioned above have been suggested and some of them have been successfully tested (Fernández et al., 2008a; Ortuño et al., 2010; Zimmermann et al., 2013). However, and although the methods are being widely used in research, their use with commercial purposes, i.e. to improve irrigation in commercial orchards, is much lower. Some believe that the new plant-based methods based on automatic and continuous recording are superior to conventional water stress indicators, and that they will become popular when prices of the sensors and related systems decrease. Others, however, find these methods too complicated to install and maintain, and their records too difficult to interpret, to be used in commercial orchards. No detailed studies, however, have been published on the reasons for these methods not being adopted by farmers and orchardists. I hypothesized that methods based on SF, TDV and LPT records are useful both for monitoring water stress and scheduling irrigation in commercial orchards, provided they are used in combination with new technologies and approaches that make them inexpensive and user-friendly. When used alone, or by non-trained users, they are expensive and errors can easily arise from difficulties on installation and maintenance, as well as on the analysis and interpretation of the data.

To test my hypothesis, in this work I review the potential of SF, TDV and LTP related records to monitor water stress in commercial orchards. I first identify main limitations on the performance of each method imposed by the plant response to environmental water conditions. I then address difficulties to the requirements of each method for installation, maintenance, and data processing and interpretation. Eventually I explore solutions that are being developed to overcome such limitations.

2. Experimental details and data collection

I have reviewed main findings on the use of SF, TDV and LPT related measurements reported by other authors for a variety of species and conditions. In addition, most of the figures and experimental approaches commented below are derived from the work on the topic made by my research group. We worked at three different olive (*Olea europaea* L.) orchards, all within a radius of 30 km from Seville, southwest Spain. La Hampa orchard had 'Manzanilla de Sevilla' trees (from now on 'Manzanilla') planted at 7 m × 5 m in 1969 (Cuevas et al., 2010). La Nava orchard had 'Arbequina' trees planted at 7 m × 6 m in 1998 (Fernández et al., 2011b). In both cases trees had a round canopy and a single trunk with 2–4 main branches from 0.7 to 1.2 m above ground. The Sanabria orchard had 'Arbequina' trees planted at 4 m × 1.5 m in 2007 (Fernández et al., 2013). In this case the trees had a monoconic canopy, with a single trunk and main branches from 0.6 to 0.7 m above ground. Both at La Hampa and La Nava the soil had a useful depth of 1.5–2 m, and a moderate-to-high water retention capacity. At the Sanabria orchard the soil was sandy, with a low soil water retention capacity and a maximum depth of 0.6 m. Climate in the area is Mediterranean, with a wet, mild season from October to April and a dry, hot season from May to September. Average potential evapotranspiration (ET_o) and rainfall (R) are ca. 1250 mm and ca. 500 mm, respectively. The three orchards were irrigated during the dry seasons, normally from May to early September (La Hampa) or late October (La Nava and Sanabria). Drip irrigation was applied in all cases, with one lateral per tree row and 4–5 drippers per tree. A variety of irrigation strategies were tested in the orchards, as detailed in the mentioned publications. Basically, we applied several deficit irrigation (DI) strategies, including low frequency irrigation (LFI), sustained deficit irrigation (SDI) and regulated deficit irrigation (RDI). We also had fully irrigated trees, with daily water supplies to replace the crop evapotranspiration (ET_c) minus the effective rainfall.