Precision irrigation or the need to join forces

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ABSTRACT

Precise irrigation is one of the most promising approaches to manage irrigation in fruit tree orchards, but it is challenging to the user. In this work we use examples of the work carried out in our group (www.irnas.csic.es/rec) to outline and illustrate the need for a combined work of physiologists and agronomists to develop more efficient irrigation strategies and irrigation scheduling methods. We also consider the need of their contribution, together with that of specialists on economics, for a wise choice of the production target.

INTRODUCTION

Precision irrigation (PI) is a holistic approach for a rational use of water in agriculture (Smith and Baillie, 2009). Within the PI framework, the aim is to irrigate each plant with the right amount of water and at the right time. The base for PI is an optimum combination of the irrigation system, the irrigation strategy and the irrigation scheduling method, as well as a correct choice of the production target. The complexity behind a rational use of water in agriculture (Geerts and Raes, 2009, Fernández, 2014a) advices for a joint work of specialists on hydraulics, physiology, agronomy, electronics, data processing and transmission, and economy, among other disciplines (Fernández, 2014b).The aim of this work was to outline the need for a multidisciplinary approach to overcome the challenges inherent to PI.

THE IRRIGATION STRATEGY

A number of irrigation strategies have been developed, from full irrigation to supplementary, or complementary, irrigation. Both sustained deficit irrigation and regulated deficit irrigation are recommended for fruit tree orchards (Ruiz-Sanchez et al., 2010; Fernández, 2014a). At the beginning of 2010 we started a research line focused to irrigation management in hedgerow olive orchards with high plant densities. By that time we made a literature review to design an irrigation strategy suitable for our experimental orchard (cv Arbequina, 1667 trees ha^{-1}). The irrigation strategy was published in a paper in which we showed results from the first three experimental years (Fernández et al., 2013). In the Discussion of that paper we suggested the need for changes in our irrigation strategy, based on recent findings by Hammami et al. (2011), among others, on olive fruit development. Basically, the group of Hammami, led by Prof. Hava Rapoport, studied the influence of water stress on cell division and growth of different olive fruit tissues, which have marked consequences on the fruit size and, consequently, on the net incomes of the grower. The right irrigation strategy for olive is still a matter of debate, since there uncertainties remain on the crop sensitivity to water stress at different stages of the productive cycle (Fernández, 2014a).

IRRIGATION SCHEDULING

Uncertainties

The need of physiological knowledge to understand how plants use water applies to even basic processes, e.g. how plants take up water from the soil. Zimmermann et al. (2004) questioned the cohesion-tension theory (C-T theory) and proposed the multi-force theory of water ascent in trees. Basically, they claimed the tension generated by leaf transpiration is not the only force involved in water lifting from the roots to the leaves. Instead, several forces of physical and chemical origin act together. This proposal by Zimmerman was criticized in a letter to the Editor by 45 top scientists on plant hydraulics (Angeles et al., 2004). Recent evidence, summarized by Bentrup (2016), suggests that the C-T theory does not give a satisfactory explanation of how water travels from the roots to the leaves, and gives credit to the multi-force theory. One of the aspects of Zimmermann's theory is that readings with the Scholander chamber are misleading. He claimed that the actual xylem tension is much lower than that recorded with the Scholander chamber, and that the chamber measures relative changes in turgor pressure, but not absolute values. Strikingly enough, therefore, the information provided by the widely used Scholander chamber is still questioned.

Another key feature of plant hydraulics related to water uptake is vulnerability to cavitation. Here, again, there is a lack of consensus in the scientific community. Xylem cavitation is characterized by vulnerability curves (VC), which relate xylem pressure with the percentage of cavitation. The literature provides two types of VC, "sigmoidal" (s-type) and "exponential" (r-type), the shape depending on the method used to generate it (Cochard et al., 2013). The problem is that there is a lack of consensus on the method that should be used. Exponential curves largely overestimate the vulnerability to cavitation as compared to sigmoidal curves, so there is not a consensus on something as basic as the effect of xylem tension on the loss of hydraulic conductivity. In olive, we compared different methods to generate VC and found that the "sigmoidal" type seems to be more representative for the species (Torres-Ruiz et al., 2014), which is in accordance with its high resistance to cavitation (Fernández, 2014a).

Errors in irrigated agriculture also come from a wrong choice of the production target. Many believe that full irrigation (FI) increases water use efficiency (WUE), i.e. the amount of biomass produced per unit of water consumed by the crop. But the standard curve of WUE vs. g_s, applicable to most crops, shows that the greatest values of yield per unit of water consumed are achieved when the crop water consumption is far below the maximum (Cifre et al., 2005). Another factor often forgotten is the influence of irrigation in quality. Our regulated deficit irrigation (RDI) treatments, in fact, led to oils with greater quality than those from the FI trees. Actually, oils from the RDI treatments had higher contents of pigments and phenolic compounds, a higher oleic/linoleic ratio and greater oxidative stability, among other characteristics affected by irrigation (García et al., 2016). In these cases in which the quality of the marketable product counts, the water productivity (WP), defined as the net income achieved per unit of water consumed by the crop, could be a more appropriate production target than WUE.

Physiology to the rescue

Precise irrigation requires an effective irrigation scheduling method based on the continuous and precise monitoring of the plant water stress. Stomatal conductance (g_s) is considered as one of the most reliable indicators of water stress (Jones, 2007), mainly because of the early response of stomata to stressing conditions and because it regulates both transpiration and carbon uptake, two processes highly related to water productivity. But we are still far from knowing in detail how stomata work (Chaves et al., 2016). In addition, the continuous recording of g_s is not easy under field conditions, which explains why g_s is not widely used to schedule irrigation in commercial orchards. Recently, however, Hernandez-Santana et al. (2016) suggested a method for the assessment of g_s in fruit tree orchards from continuous and automatic records of sap flux density (J_s) in the outer rings of the sapwood.

Other examples on how physiological advances lead to improvements on irrigation scheduling have been provided by researchers working with other plant-based methods to schedule irrigation, such as those based on sap flow, trunk diameter and leaf turgor related measurements. These three methods have a high potential to schedule irrigation in commercial orchards, and are useful for precise irrigation because they allow for continuous and automatic data recording and transmission, and because. In addition, they can be combined with remote imagery, to schedule irrigation in zones within the orchard with different sensitivity to water stress. None of the methods, however, has been widely adopted by the growers, likely because environmental and crop conditions have an influence on the recorded data, such that interpreting the collected information requires training (Fernández 2014b). The most recent of these three methods is that based on leaf turgor potential measurements. Until recently, leaf turgor measurements were possible in the laboratory, but difficult under field conditions. This changed with the Leaf patch clamp pressure probe, named as LPCP or ZIM probe, developed by Zimmermann et al. (2008). Our group was the first to test the ZIM system in a commercial olive orchard, as part of the experiments starting in 2010 (Fernández et al., 2011). Since then, we have published a number of papers, some from a joint work with the group that developed the system. Comparisons with the Scholander chamber and with the cell turgor pressure probe (Fernández et al., 2011; Ehrenberger et al., 2012) allowed us to propose an approach suitable to irrigate high density olive orchards just from a visual analysis of the daily curves recorded by the probes. The approach, tested by Padilla-Díaz et al. (2016), is an example of how the combination of physiological and agronomical studies can provide useful tools for the precise irrigation of commercial fruit tree orchards.

CONCLUSIONS

New irrigation approaches, such as precise irrigation, advices for a joint work of physiologists and agronomists. Advances on both disciplines must be combined to increase the rationale of water use in agriculture. Despite of their high potential, widely accepted tools and methods to monitor water stress and to schedule irrigation still have dark aspects that must be elucidated, both for improving our understanding on how plants use water and to increase their applicability to commercial orcchards.

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