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Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems

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ABSTRACT

Water scarcity in Mediterranean climate areas will be progressively aggravated by climate change, population increase and urban, tourism and industrial activities. To protect water resources and their integrity for future use and to improve biodiversity, besides following advanced deficit irrigation strategies in fruit cultivation, attention could well be directed towards what are at present underused plant materials able to withstand deficit irrigation with minimum impact on yield and fruit quality. To this end, the state of the art as regards deficit irrigation strategies and the response of some very interesting emerging fruit crops [jujube (*Zizyphus jujuba* Mill.), loquat (*Eriobotrya japonica* Lindl.), pistachio (*Pistacia vera* L.) and pomegranate (*Punica granatum* L.)] are reviewed. The strengths and weaknesses of deficit irrigation strategies and the mechanisms developed by these emerging fruit crops in the face of water stress are discussed. The response of these crops to deficit irrigation, with special attention paid to the effect on yield but also on fruit quality and health-related chemical compounds, was analysed in order to assess their suitability for saving water in Mediterranean semiarid agrosystems and to analyze their potential role as alternatives to currently cultivated fruit crops with higher water requirements. Finally, the factors involved in establishing an identity brand (*hydroSOS*) to protect fruits obtained under specific DI conditions are discussed.

1. Introduction

Mediterranean climate countries include not only those that border the Mediterranean Sea (from Spain to Turkey and Cyprus and from Morocco to Syria) but also other regions of the planet, including Southern California, Chile, South Africa and Southern Australia. All are characterized by hot dry summers, mostly rainy winters and partially wet spring and autumn. In these region, to ensure regular crop yields and for to reduce inter-annual yield variability, the scarce rainfall has to be supplemented by irrigation in order to avoid plant water deficits. Indeed, water scarcity in these sites is destined to gradually become worse because more frequent and severe droughts events driven by climate change (Collins et al., 2009). Moreover, as the population increases, leading to an increasing expansion of urban, touristic and industrial activities, tension and conflict between water users and pressures on the environment will be intensified.

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Consequently, and considering that Mediterranean agrosystems are very important consumers of fresh water, it is of paramount importance to protect water resources and their integrity for future use (Katerji et al., 2008). In this sense, to overcome the problems associated to a boost in water prices, as the discouragement of farmers and ultimately land abandonment, García-Tejero et al. (2014) indicated that an alternative could be to provide correct incentives for farmers to adopt changes in their irrigation methods by implementing strategies and tools for sustainable water saving. Among the strategies that can be applied to attain water saving are the use of improved, innovative and precise deficit irrigation (DI) management practices able to minimize the impact on crop yield and quality (Fernandez and Torrecillas, 2012). In addition, in order to contribute to water saving, fruit culture should be directed towards the use of plant materials that are less water-demanding or able to withstand deficit irrigation with minimum impact on yield and fruit quality.

In this last respect, it is important to consider that in human history, 40–100,000 plant species have been regularly used for food, fiber and for industrial, cultural and medicinal purposes. Today, at least 7000 cultivated species are in use around the world. However, in recent centuries, agricultural systems have promoted the cultivation of a very limited number of crop species. While these have been the focus of attention of commerce and scientific research world-wide, many crops have been relegated to the status of neglected or underutilized crop species, and largely ignored (Padulosi et al., 2001; Chivenge et al., 2015). In addition, this reduction in the number of crop species used for food production throughout the world has a direct effect on biodiversity, which is fundamental for ecosystem functioning, sustainable agricultural production and the attainment of food and nutritional security (Toledo and Burlingame, 2006; Chappell and LaValle, 2011). Therefore, to improve not only biodiversity but also to saving water and hence protecting the integrity of water resources for the future, it is necessary the diversification of production and consumption habits, including the use of a broader range of plant species, in particular those currently identified as underutilized and needing a low input of synthetic fertilisers, pesticides and water. This option has to be compatible with the consolidation of the cultivation of other Mediterranean traditional crops, such as olive, almond or grapevine, which are low water demanding and profitable crops. In this sense, in some countries, during recent decades there has been a certain interest in diversifying fruit tree production by cultivating species with under-exploited potential. Among these emerging crops many are characterized by their attractive fruits and health-related qualities, so that they may attract consumer attention and contribute to producer profitability

For these reasons, the aim of this review was to present the state of the art of deficit irrigation strategies and the response to them of some very interesting emerging fruit crops [jujube (*Zizyphus jujuba* Mill.), loquat (*Eriobotrya japonica* Lindl.), pistachio (*Pistacia vera* L.) and pomegranate (*Punica granatum* L.)]. To this end, the following aspects were considered: (i) the strengths and weaknesses of deficit irrigation strategies, (ii) the mechanisms developed by these emerging fruit crops to confront water stress, and (iii) the response of these crops to deficit irrigation, paying special attention not only to the effect on yield but also to the effect on fruit quality and health-related chemical compounds.

2. Deficit irrigation. Concepts and strategies

To cope with water scarcity, Mediterranean agrosystems are increasingly looking to more efficient technological innovation and irrigation management approaches. In this respect, many countries have shifted from irrigating crops in order to satisfy their evapotranspiration requirements (ETc) or full irrigation (FI), the conventional norm which seeks to maximize crop yield per unit of land, to deficit irrigation (DI) strategies, which involve reducing the amount of water provided to the crop during the growing season by the soil moisture stock, rainfall and irrigation to a level below that needed for maximum plant growth. In most of cases DI induces a gradual water deficit, due depletion of soil water reserves, accompanied by a reduction in harvestable yields, especially in soils with a significantly low water storage capacity.

When water scarcity is the consequence of uncontrolled factors and water supply is not guaranteed, farmers find it difficult to schedule any reasonable DI strategy. In contrast, if growers have a guaranteed water supply for their crops during the growing season, it is possible to improve water productivity (WP) by drawing up DI strategies based on scientific principles, attempting to produce near-maximum yields even if crops are provided with less water than they would otherwise use (maintaining crop consumptive use below its potential rate). In other words, improving the marketable yield per unit of water used rather than attaining maximum yields (Kijne et al., 2003; Zhang, 2003) Complementary advantages of the same include a reduction of nutrient loss from the root zone and a decrease in excessive vegetative vigour, accompanied by a lower risk of crop diseases linked to high humidity (Goodwin and Boland, 2002; Ünlü et al., 2006) (Table 1). However, there is a shortage of research into the risk of soil salinization as a consequence of any decrease in the leaching of salts and the use of low quality irrigation water (Boland et al., 1996; Kaman et al., 2006) (Table 2).

Three main DI strategies can be mentioned; sustained deficit irrigation (SDI), in which irrigation water used at any moment during the season is below the crop evapotranspiration (ETc) demand, and two others, both based on physiological aspects of the response of plants to water deficit – regulated deficit irrigation (RDI) and partial root-zone drying (PRD) (Fig. 1).

2.1. Sustained deficit irrigation (SDI)

At the end of 1970s, trials applying irrigation water amounts below the ETc demand but at very frequent intervals took place with encouraging results. Called deficit high-frequency irrigation (DHFI), this strategy proved unsuccessful when little water was stored in the soil. It was only possible to use DHFI and obtain maximum yields when ETc was reached through the combination of irrigation water applied and soil water depletion (Fereres et al., 1978).

In fact, the DHFI strategy is very similar to SDI (Fig. 1), which is based on the idea of allotting the water deficit uniformly over the whole fruit season, thus avoiding the occurrence of serious plant water deficit at any crop stage that might affect marketable yield or fruit quality, or distributing the irrigation water proportionally to irrigation requirements throughout the season.

2.2. Regulated deficit irrigation (RDI)

RDI works on the premise that transpiration is more sensitive to water deficit than photosynthesis and fruit growth, and water deficit-induced root-sourced chemical signals like ABA. Thus, fruit trees cope with a reduced water supply by reducing transpiration (stomata regulation or reducing leaf surface area through reducing leaf growth) (Wilkinson and Hartung, 2009). In this sense, fruit tree sensitivity to water deficit is not constant during the whole growing season, and a water deficit during particular periods may benefit WP by increasing irrigation water savings, minimizing or eliminating negative impacts on yield and crop revenue and even improving harvest quality (Chalmers et al., 1981; McCarthy et al., 2002; Domingo et al., 1996) (Table 1). Therefore, when a RDI strategy is applied, full irrigation is supplied during the drought-