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Controlled deficit irrigation for orange trees in Mediterranean countries

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A B S T R A C T

Orange tree cultivation is widespread throughout the world, and the Mediterranean Basin is an important producer. The Mediterranean climate is characterised by scarce water resources that limit crop sustainability. In this study, controlled deficit irrigation is evaluated as a water conservation strategy with the aim of improving crop sustainability. To accomplish this objective, a trial is conducted in southern Spain for nine months with four treatments (five repetitions each): normal irrigation (the control variable), deficit irrigation and two treatments of controlled deficit irrigation. In relation to the crop, physiological parameters, production and fruit quality were analysed, all with respect to water usage. Finally, an efficiency curve was established for water usage, which determined the optimum water usage to be between 700 and 800 mm. It has been experimentally determined that controlled deficit irrigation reduces water used by 5% compared with constant deficit irrigation and improves productivity by 4%. The primary conclusion is that controlled deficit irrigation strategies present certain advantages to crop management and are an alternative to reducing water inputs with minimal effects on production and fruit quality, thus contributing to crop sustainability.

1. Introduction

Sustainability is related to ecology (Cama et al., 2013), economics (Dias et al., 2017) and energy (Fernández-García et al., 2015); each may be maintained for long periods without exhausting resources or causing severe damage to the environment. Sustainability is based on three pillars: economic, social and environmental, with an occasionally fragile and difficult balance among the pillars (Clift, 1995). Sustainable agriculture represents an economically viable, environmentally safe and socially acceptable system of food, fibre and fuel production, with a set of post-material values that emphasises the preservation of agriculture and food production, livestock wellbeing and economic assistance to farmers (Singh et al., 2016).

Given a world population that will continue to grow and cultivated land that cannot increase at a similar rate, this concept is of vital importance, considering that the impacts from climate change can cause the degradation of natural resources with adverse agricultural consequences (Dhillon et al., 2010). In the world, 18% of the arable and permanent cropped area is irrigated, contributing as much as 40% of the gross agricultural output (Ritzema, 2016). Irrigated agriculture is the largest user of freshwater and makes up 70% of total freshwater withdrawals worldwide (Christ and Burritt, 2017). In Mediterranean countries as Spain, this can be up to 80% (Montoya et al., 2016). Environmental problems are associated to irrigation as salinization/alkalinisation (Rahman et al., 2015) or sterility (Notarnicola et al., 2012), where around 30% of irrigated land is moderately or severely affected (Dregne, 1983), related to this concern the irrigated area is being reduced by approximately 1–2%. Irrigated agriculture impacts the environment (Zhang et al., 2011, 2016; Raucci et al., 2015; Ali et al., 2015; Manfredi and Vignali, 2014); thus, it must be managed sustainably (Ceccarelli, 2014), especially because there are an estimated two million people who lack access to safe and affordable water. Recently proposed irrigation and water management strategies include the best performance possible with regards to cost effectiveness and sustainability (Vico and Porporato, 2011; Mehmeti et al., 2016).

The cultivation of citrus fruits, especially the orange tree (*Citrus sinensis* (L.) Osbeck), is globally widespread, and for agronomic

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reasons, the Mediterranean region is especially suitable for this type of production (Torres et al., 2016). The sweet orange (*C. sinensis* (L.) Osbeck) is used in juices and drinks that are consumed in several countries and represents approximately 60% of global citrus fruit production. Domesticated in Southeast Asia (Wu et al., 2014), *C. sinensis* belongs to the genus *Citrus*, subfamily Aurantioideae and family Rutaceae. As its principal properties, *C. sinensis* contains a large variety of potent antioxidants, carotenoids, vitamin C, flavonoids and phenolic compounds with properties that promote health (Pons et al., 2014; Sharma et al., 2014). The global production of oranges in 2013 was approximately 71.7 million metric tons (Tm) (FAOSTAT, 2016); Spain ranked sixth (2013), with 3.39 million Tm, behind Brazil, the United States, China, India, Mexico and the Mediterranean Basin, the latter being the primary producer.

Orange production is determined by the number and size of fruits, depending on three processes: flowering, appearance of fruits and their growth. However, this species is sensitive to the alternate bearing phenomenon (Germanà and Sardo, 2004; De Souza Prado et al., 2007). In areas classified as having a semiarid climate, water scarcity is the factor that contributes most to limiting crop production (Yang et al., 2010); thus, it is essential to establish the timing and amount of water to be applied (Germanà and Sardo, 2004). To precisely achieve this target, it is essential to use drip irrigation, which can control the amount of irrigation and fertilisers applied as well as produce a certain level of energy savings.

Drip irrigation and underground irrigation (Coltro et al., 2017) are two types of localized irrigation, which apply water only where it is needed with several advantages. In addition to water saving, there is also the use of urban wastewater that can contribute to the net saving of water (Barbosa et al., 2017) and in some cases, increase productivity through the input of fertilizers (Lu et al., 2016a,b). On a large scale, when there are different kinds of crops, optimization techniques can be used to make a more efficient water use (Liu et al., 2017; Márquez et al., 2011; Manzano-Agugliaro and Cañero-Leon, 2010). For specific crops, controlled water deficit strategies, also known as deficit irrigation, can be adopted (Stagno et al., 2015a,b).

In oranges trees, several experiments were worked out. Thus, for young orange orchard, Consoli et al. (2014) found that the deficit irrigation (DI) strategies (75% of ETc) were successfully applied allowing water saving without significant detrimental physiological effect on trees. But also found that the impact of the imposed deficit on trees depends mainly on its degree of severity (i.e. lowering of stem water potential above the threshold of −1.3 MPa for citrus orchards). Following their studies in young orange trees (Consoli et al., 2017), they found that compared with the full irrigation treatment, partial root-zone drying (PRD) at 50% of crop water demand (ETc) increased the fruit yield by 20% in 2013 and 10% in 2014.

The effects of deficit irrigation (DI) treatments applied on mature orange trees, were studied by several authors. Stagno et al. (2015a,b) studied in Sicily (Italy), during three consecutive summer seasons (2009–2011) in a sandy loam texture soil. Two different DI strategies supplying 70 and 50% of crop evapotranspiration (ETc) were compared with irrigation at the full rate of ETc. They found that the orange trees became less sensitive to moderate water restrictions (DI = 70% ETc) permitting approximately 80 mm of water saving. As main conclusion of their works was that a moderate water restriction can be applied in commercial orange orchards because it saved water and improved fruit quality. Similar results were found by Shahabian et al. (2012), they studied two deficit irrigation strategies on mature orange trees: conventional deficit irrigation (DI) and partial root-zone drying (PRD). The study was carried out during two consecutive years (2008 and 2009) in a semi-arid climate on a silty–clay–loam soil in the north of Iran. Both DI and PRD trees were irrigated at two levels, 75 and 50% of the full irrigation (FI). Results showed that DI treatments reduced fruit yield by around 30% compared with FI, but PRD treatments caused no reduction in fruit yield, furthermore, no negative impact was detected in fruit quality after applying DI and PRD treatments.

For longer period of study, Gasque et al. (2016) studied the effects of long-term (2007–2011) summer deficit irrigation (DI) strategies in a deep sandy-loam soil in Valencia (Spain). the RDI treatments received 40% and 60% of the full irrigation dose during the deficit period. They achieved that summer DI treatments did not cause negative effects on either the amount or on the quality of the yield if the threshold value of −2.0 MPa was not surpassed. According to the results, it can be concluded that long-term DI strategies may be applied successfully on orange trees during summer without negatively affecting the studied parameters while allowing water savings between 12% and 27%. Also, in Spain, García-Tejero et al. (2010) at the Guadalquivir river basin, studied four strategies of deficit irrigation based on a different water-stress ratio. They conclude that deficit irrigation affects yield and fruit quality, while enabling water savings of up to 1000 m^3 ha^{-1}. Therefore, yield declined on average 10–12% but boosted water productivity 24% with respect to the fully irrigated treatment.

The objective of this study is to determine the minimum irrigation threshold in orange trees where the production and crop quality is least affected, thus increasing the sustainability of orange tree crops in Mediterranean climates and estimate the water saving for the Mediterranean area.

2. Materials and methods

The experimental component of the study was developed in the facilities of the Institute of Agricultural Research and Training (Instituto de Investigación y Formación Agraria y Pesquera – IFAPA) of La Cañada, Almería, Spain (36° 50′ 09″ N, 2° 24′ 13″ W). The location of the experimental farm in the western Mediterranean is depicted in Fig. 1.

2.1. Climate and soil

There is a complete weather station on the farm itself, located in Almeria (Spain) at coordinates: 36° 50′ 09″ N, and 2° 24′ 13″ W, the average climatic values are presented in Table 1. The climate of the area is semi-arid Mediterranean (De Frutos et al., 2015), characterised by mild, moderately rainy winters and dry, warm summers.

The crop is situated on soil whose values and characteristics are presented in Table 2. The soil is of alluvial origin, is very homogeneous, has a depth greater than 1 m and is a *Eutric Fluvisol* type soil of loamy texture. The soil has been analysed at depths of z = 0.30 and z = 0.60 m. Moisture at field capacity (θ_{fc}) was calculated for a tension of $\psi = 0.1$ Bar, and the permanent wilting point (θ_{pwp}) was determined for $\psi = 15$ Bar. Adjustment of the Van Genuchten equation was performed using the measured data to immediately relate the soil moisture to measured tensions in the field, using Watermark tensiometers. The measured data and adjustment curve are depicted in Fig. 2.

2.2. Crop management and irrigation system

The studied crop is a fully developed orange tree plantation of the 'Newhall' variety and Cleopatra mandarin pattern, with a plantation frame of 6 m × 4 m (416 trees ha^{-1}) and more than 85% soil surface coverage.

The plantation at the time of the study had been drip irrigated and managed by tensiometers installed at z = 0.30 and 0.60 m for