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Economic feasibility of implementing regulated deficit irrigation with reclaimed water in a grapefruit orchard

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ABSTRACT

This study, conducted from 2005 to 2014, assessed the long-term economic viability of irrigating a commercial grapefruit orchard with saline reclaimed water (RW) combined or not with a regulated deficit irrigation (RDI) strategy. During the first three years after plantation, trees were full irrigated (100% of the crop evapotranspiration; ET_c) with fresh surface water (TW; electrical conductivity about 1 dS m^{-1}) pumped from the "Tagus-Segura" water transfer canal. Then, from the fourth year onwards, two water sources, TW and RW (electrical conductivity of 3.0 dS m^{-1}) were used, and two irrigation treatments, a control treatment (TW and RW irrigated 100% of ET_c) and a RDI treatment (TW-RDI and RW-RDI irrigated 50% of ET_c during the 2nd stage of fruit growth) were performed. A discounted cash flow analysis (DCFA), which considered an orchard life period of 20 years, was performed to determine the profitability of different irrigation strategies. It evidenced that irrigation with TW was the most economically feasible option up to a TW price of 0.16 € m^{-3}, whereas from this water value, RW began to be the most profitable treatment. In a context of water scarcity where water availability is limited and RDI strategies must be performed, the use of TW-RDI was advised up to a water price of 0.38 € m^{-3}, but from this threshold, RDI with RW became the most profitable option due to its lower irrigation water cost. The grapefruit selling price had a clear effect on the profitability of the different treatments and showed full irrigated treatments as the most profitable. A fruit selling price below 0.08 € kg^{-1} produced negative net present values for all the treatments.

1. Introduction

Spain is the largest producer and exporter of grapefruits in Europe, with 73% (58,800 Tm) of the grapefruit production, from which, 93.4% is exported. The main area of production is located in the southeast region, characterized by a semiarid climate and a high evaporative demand. Consequently, although grapefruit is well adapted to dry, warm, semi-tropical humid and tropical climatic conditions, the amount of irrigation necessary for fresh fruit production is very high, forcing citrus growers to find ways to maximize water savings and improve final fruit yield and quality (Pérez-Pérez et al., 2014). Under this unfavorable scenario, an increased pressure on water resources ruled by the competition for water between agriculture, industry and population (Iglesias et al., 2007) and also by the climate change (Faurès et al., 2013) is latent, leading to an urgent need to explore new alternative water sources and also strategies to cope with crop water requirements in order to maintain or enhance sustainable agricultural production.

In that regard, the use of non-conventional reclaimed water (RW) in agriculture has gained importance during the last decades. In addition, although it has usually been viewed in a negative light as a product commonly requiring disposal, as it may contain high concentrations of salt leading to undesirable effects on soils and plants (Ayers and Westcot, 1985), with appropriate management, RW has great potential to become a valuable irrigation water source. The main reasons are that (i) it is free-of-charge when the "polluter pays" policy is implemented (Mounzer et al., 2013) and (ii) it contains high organic matter and many nutrients such as N, P and K, which are essential for plant growth and might allow reducing fertilizer application rates (Nicolás et al., 2016).

Besides using RW, one well-known way to optimize water resources is to employ regulated deficit irrigation (RDI) strategies, which consists of cutting-off or reducing partially the irrigation during low water stress sensitivity periods of the crop cycle, when

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adverse effects on productivity are minimized (Chalmers et al., 1981; Mitchell et al., 1986).

Some studies carried out on grapefruits have proved the technical and agronomical advantages of: (i) reusing RW (Maurer and Davies, 1993; Romero-Trigueros et al., 2014; Pedrero et al., 2015), (ii) implementing RDI strategies (Levy et al., 1978; Ballester et al., 2011, 2014; Pérez-Pérez et al., 2014; Gasque et al., 2016) or (iii) implementing RDI combined with RW (Pedrero et al., 2015). However, little research focused on the profitability of RDI or the implementation of RW strategies has been conducted, although all studies point out RDI or the use of RW as a profitable alternative for irrigation in arid and semiarid areas. Most financial and economic studies have been conducted in almond orchards, such as García et al. (2004) and Romero et al. (2006), who evaluated RDI in a four-year period, and Alcón et al. (2013a), who studied regulated and sustained deficit irrigation during 6 years taking in consideration three different growth phases; i.e. non-productive, transition and fully productive trees. In the case of citrus, others have evaluated the economic performance of RDI in adult orange trees (Pérez-Pérez et al., 2010) or the effect of irrigation with RW on adult mandarin orchard (Alcón et al., 2013b). In spite of these studies, the analysis of the economic feasibility of RDI combined with RW in citrus trees remains unknown.

In this context, this study aims to evaluate the long-term economic feasibility of implementing several irrigation regimes, full irrigation and RDI combined or not with RW, in a '*Star Ruby*' grapefruit orchard, introducing the novelty that this approach overcomes the temporal limitations of previous studies as it considers three different lifecycles of the crop.

2. Material and methods

2.1. Field conditions and irrigation treatments

The experiment was conducted from 2005 to 2014 at a 0.5 ha commercial orchard located in Campotéjar-Murcia, south-eastern Spain (38°07′18″ N; 1°13′15″ W). This area is characterized by a Mediterranean semi-arid climate with warm, dry summers and mild winter conditions. The annual reference evapotranspiration (ET_0) and rainfall are on average 1,330 and 280 mm, respectively. The soil within the first 90 cm depth had a loamy texture (24% clay, 33% loam and 43% sand) with an average bulk density of 1.41 g cm^{-3}. It was classified as a Typic Haplocalcid according to Soil Survey Staff (2014).

The study was performed on 'Star Rubyí grapefruit trees (*Citrus Paradisi* Macf) grafted on Macrophylla rootstock [*Citrus Macrophylla*] which was planted in 2004 with a tree spacing of 6 m × 4 m. Three different lifecycle stages were considered in this study: (i) juvenile (unproductive) stage from 2005 to 2007, (ii) young productive stage from 2008 to 2010 and (iii) adult productive stage from 2011 to 2014.

A total of 192 trees were used in this study. The experimental design was a randomized complete design with four blocks and four experimental plots per block. The standard plot was made up of twelve trees, organized in three adjacent rows with four trees per row. The two central trees "inner trees" of the middle row were used for measurements and the other ten trees were guard trees so as to eliminate potential edge effects.

The irrigation system consisted of a single lateral drip line laid on the soil surface next to the tree trunk. It provided three self-pressure compensating on-line emitters per tree discharging 4 L h^{-1} each, placed at 1 m from the trunk and spaced 1 m apart. The irrigation doses were scheduled based on the daily crop evapotranspiration (ET_c) accumulated during the previous week. ET_c values were estimated as reference evapotranspiration (ET_0), calculated with the Penman–Monteith methodology (Allen et al., 1998), and month-specific crop coefficients (K_c). From January to December K_c were 0.40, 0.50, 0.50, 0.55, 0.55, 0.60, 0.60, 0.60, 0.55, 0.50, 0.45 and 0.40, respectively (Castel et al., 1987). In order to correct K_c during the juvenile and young productive stages (from 2005 to 2010) a reduction coefficient of 0.50 and 0.75, respectively was considered, which accounted for eventual decrease in evapotranspiration because of the partial soil covering by the crop canopy (young grapefruit trees) (Fereres et al., 1982).

Trees were irrigated daily during the ten-year experiment. The total amounts of water applied were measured with inline water flow meters, placed on the four replicates of each treatment. The irrigation was controlled automatically by a head-unit programmer and electro-hydraulic valves.

All treatments received the same amounts of fertilizer applied through the drip irrigation system. In 2005, fertilizer amounts were 89–45–64 kg ha^{-1} year^{-1} (N–P_2O_5–K_2O) and it increased by about 15% each year until adult productive stage. Pest control practices and pruning were those commonly used by growers in the area, and no weeds were allowed to develop within the orchard.

The experiment involved two different water sources. One source (TW), with an average electrical conductivity (EC_w) about 1 dS m^{-1}, was pumped from the "Tagus-Segura" water transfer canal, which is a canal that supplies a large part of the surface water used in the southeast of Spain for both human consumption and irrigation practices. The other was tertiary saline reclaimed water (RW) pumped from a wastewater treatment plant (WWTP). This source was automatically blended at the irrigation control-head with water from the canal to reduce its EC_w value down to ≈3 dS m^{-1} in order to obtain a constant EC_w during the experiment. The usual blending rate was 63% RW and 37% TW.

For each water source (TW and RW), two irrigation treatments were carried out. The control treatments involved irrigation with TW or RW during the whole season at 100% of the soil–water lost by daily ET_c. The RDI treatment consisted of irrigation at 100% ET_c, except during the second stage of fruit growth, 55–65 days between late-June and mid-September, when it received 50% of the water amount applied to the control. No leaching fraction was added to the irrigation doses. Irrigation with RW and application of RDI strategies began to be performed from 2008 onwards. From 2005 to 2007 the whole orchard was full irrigated with TW.

Table 1 shows the irrigation water applied, the rainfall and the ET_0 for the experimental period.

Table 1 Mean annual values of the water applied (mm) for each irrigation treatment for the juvenile (2005, 2006, 2007 and

Table 1
Mean annual values of the water applied (mm) for each irrigation treatment for the juvenile (2005, 2006, 2007 and 2005–2007), young productive (2008, 2009, 2010 and 2008–2010) and adult productive (2011, 2012, 2013, 2014 and 2011–2014) stages. Annual rainfall (mm) and reference evapotranspiration (ET_0; mm) at the experimental site during are also presented.

	Irrigation Water Applied (mm)		Rainfall (mm)	ET_0 (mm)
	Control treatment	RDI treatment		
2005	127	–	168	1,266
2006	142	–	359	1,276
2007	181	–	335	1,299
2005–2007	150	–	287	1,280
2008	224	193	271	1,332
2009	379	331	306	1,384
2010	356	309	330	1,254
2008–2010	320	278	302	1,323
2011	585	515	264	1,258
2012	599	521	260	1,407
2013	570	496	249	1,395
2014	614	518	258	1,431
2011–2014	592	513	258	1,373