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# Deficit irrigation with reclaimed water in a citrus orchard. Energy and greenhouse-gas emissions analysis

J.F. Maestre-Valero[a,*], B. Martin-Gorriz[a], E. Nicolas[b], M.A. Martinez-Mate[a], V. Martinez-Alvarez[a]

[a] *Escuela Técnica Superior de Ingeniería Agronómica, Universidad Politécnica de Cartagena, Paseo Alfonso XIII, 48, 30203 Cartagena, Spain*
[b] *CEBAS-CSIC. Campus Universitario de Espinardo, PO Box 164, 30100 Murcia, Spain*

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## ABSTRACT

Irrigated agriculture brings important socio-economic benefits, but requires high energy consumption, which in turn generates environmental problems by emissions of greenhouse gases. To maintain agricultural activity in the Segura River Basin in the face of extant water shortages, farmers are increasingly using non-conventional water resources such as reclaimed water, and implementing water conservation techniques such as regulated deficit irrigation. The present study quantified the energy consumption and production and greenhouse gas emissions of a grapefruit orchard under the implementation of two irrigation regimes (full and regulated deficit irrigation) and the alternative use of reclaimed water instead of water transferred from the Tajo-Segura Basin for irrigation. The study additionally included the novelty of performing the analyses considering four different stages of crop development. The energy and the greenhouse gas emissions assessment was performed for each study case based on an inventory of inputs of the selected plot and their corresponding energy conversion and greenhouse gas factors. The results indicate that, under the conditions studied, the use of reclaimed water and/or the implementation of regulated deficit irrigation strategies had no significant effect on energy productivity and specific greenhouse gas emissions, irrespective of the stage of crop lifecycle analysed. Moreover, in order to increase the energy efficiency of the orchard and reduce greenhouse gas emissions, the energy consumption associated with the transportation of water to the plot, the manufacture of the irrigation system and the manufacture and transport of fertilisers should be reduced.

## 1. Introduction

Since 1979, the Segura River Basin (SRB), in south-eastern Spain, has received an average of 196 $hm^3$/year from the Tajo Basin in central Spain to complement its own agricultural water resources (CHS, 2015). This complementary water allocation has meant: (i) a significant increase in the net surface area devoted to irrigation, from about 170,000 ha in 1979 to 263,000 ha in 2015 (CHS, 2015), (ii) the acquisition of water rights by > 80,000 landowners in the basin (Claver, 2016), and (iii) a significant investment in the modernisation of hydraulic and irrigation infrastructures to transform rainfed and surface irrigation based agriculture to highly efficient trickle irrigation systems (Playán and Mateos, 2006), among others.

In the case of the Region of Murcia, which covers 58.8% of the basin area, such complementary inter-basin water resources have allowed the surface area of irrigated woody trees to be increased from 63,947 ha in 1979 to 93,770 ha in 2015. For citrus, those values are 21,917 ha and 38,245 ha, respectively (CREM, 2015); with the latter representing 40.1% of the land surface occupied by irrigated woody trees in the region (ESYRCE, 2015).

Despite this complementary resource, the SRB faces a structural water deficit of nearly 400 $hm^3$/year (CHS, 2015), yet this irrigated agriculture must be maintained in order to provide food security to a population under continuous increase (WWAP, 2012; Faurès et al., 2013). Food security requires energy and water security (Bundschuh et al., 2014). Consequently, farmers, in order to partially confront such a water scarcity situation and to continue with sustainable agriculture, are usually forced to complement their share of conventional water resources with other non-conventional water resources such as reclaimed waters (RW) and with the implementation of regulated deficit irrigation (RDI) strategies (Maestre-Valero et al., 2016). It is of note that the volume of RW in the Region of Murcia is 105 $hm^3$, produced in 93 wastewater treatment plants (WWTP) (ESAMUR, 2017), and which restore about 10% of the annual renewable resources (CHS, 2015).

This development in irrigated land has brought associated important regional socio-economic benefits. However, modernisation in farm technology over time to achieve a high-productive agriculture has increased the amount of energy used in crop production (Rathke and

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* Corresponding author.
*E-mail address:* josef.maestre@upct.es (J.F. Maestre-Valero).

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Diepenbrock, 2006). That intensive energy consumption also generates environmental problems mainly attributed to Greenhouse Gas (GHG) emissions that contribute to global warming (Zaheli et al., 2015).

In this sense, energy input-output analyses represent a valuable tool that allow different production systems to be compared by investigating and assessing energy use efficiency, environmental effects and their relationship to sustainability (Khoshnevisan et al., 2014a). Enhancing energy efficiency not only helps in increasing the productivity and profitability ratio, but also results in minimised GHG emissions and environmental impacts (Alluvione et al., 2011). The relation between energy inputs and outputs has been investigated in a wide range of crops, such as citrus (Ozkan et al., 2004; Martin-Gorriz et al., 2014), apricot (Sartori et al., 2005), olive (Guzmán and Alonso, 2008), cherry (Kizilaslan, 2009), pulse (Koocheki et al., 2011), tomato (Rezvani-Moghaddam et al., 2011), plum (Tabatabaie et al., 2012), sugar beet (Asgharipour et al., 2012; Yousefi et al., 2014), cotton (Zahedi et al., 2014), and some vegetable and tree crops (Martin-Gorriz et al., 2014). Likewise, crop production GHG emissions have been calculated in some crops such as lettuce (Gunady et al., 2012), strawberry (Khoshnevisan et al., 2014b), some vegetable and tree crops (Martin-Gorriz et al., 2014), cereals (Mohammadi et al., 2014) or tomato (Ntinas et al., 2017). Overall, most of these studies analyse the energy inputs and outputs and the GHG emissions based on a general scenario, without bearing in mind the effect of other significant variables that could affect the analysis, such as (i) the implementation of water conservation irrigation techniques, (ii) the use of non-conventional water resources for irrigation, or (iii) different crop lifecycle stages.

In this context, the present study has two specific aims. On the one hand, the work analyses the energy consumption and the GHG emissions of implementing several irrigation regimes: full irrigation and RDI combined or not with RW, in a ‘Star Ruby’ grapefruit orchard. This assessment has introduced the novelty of considering four different crop lifecycles stages. On the other hand, the most relevant specific inputs that affect energy demand and GHG emissions under the different productive systems are evaluated. This will provide a valuable insight into where to focus actions to improve system efficiencies.

## 2. Materials and methods

### 2.1. Experimental cases

The assessment of energy demand and GHG emissions was carried out from 2004 to 2014 for four cases resulting from the combinations of two different water sources and two irrigation strategies. One source (TW), with an average electrical conductivity ($EC_w$) about 1 dS/m, was pumped from the “Tajo-Segura” water transfer canal. The other was tertiary saline RW, pumped from a 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 to obtain a constant $EC_w$ during the experiment (RW). The usual blending rate was 63% of water from the WWTP and 37% of TW.

Four treatments were designed, based on the water sources and the application of water deficit. On the one hand, TW and RW treatments were irrigated at 100% of the soil water lost by daily $ET_c$ during the whole season. On the other hand, the RDI treatments 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 they received 50% of the water amount applied to the control. No leaching fraction was added to the irrigation doses. Irrigation with RW and the application of RDI strategies were performed from 2008 onwards. From 2005 to 2007 the whole orchard was full irrigated with TW.

### 2.2. Functional unit and system boundary

In order to perform valuable comparisons of energy demand and GHG emissions between the different cases studied, two functional units were chosen for this study; a mass-based FU defined as 1 kg of grapefruits during one annual farming period (marketable crop yield; kg/year) and a land-based FU defined as 1 ha of farmland per year.

The system boundary was considered from raw material extraction to farm-gate based on grapefruit production. The processes and flows of the system boundary include inputs and outputs until the farm-gate phase. Energy consumption and GHG emissions derived from the treatment of sewage water to produce RW were considered in the study (Fig. 1).

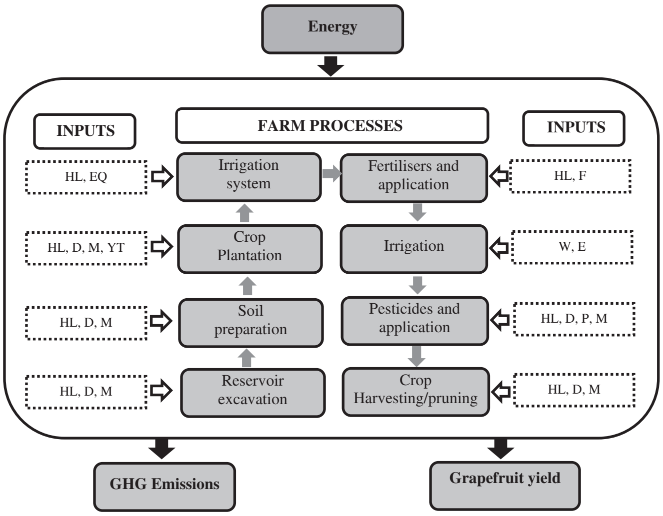

**Fig. 1.** Flow diagram for grapefruit production. HL: Human labour; D: Diesel; M: Machinery; YT: Young trees; EQ: Equipment; F: Fertilisers; W: Water; E: Electricity; P: Pesticides.

The assessment did not include: (i) nursery plantlets production, (ii) GHG emissions from the production, maintenance at the end of capital inputs life, (iii) disposal of material or waste, (iv) manufacture and construction of a shed for farm machinery storing and a plot fence.

### 2.3. Data inventory

Prior to performing the analysis, a data inventory was carried out from 2004 to 2014 considering four different crop lifecycle stages: (i) establishment of the plantation in late 2004, (ii) juvenile (unproductive) stage from 2005 to 2007, (iii) young productive stage from 2008 to 2010 and (iv) adult productive stage from 2011 to 2014. The inventory was performed according to the following aspects (Table 1):

#### 2.3.1. Orchard

For the study, a 0.5 ha commercial orchard located in Campotéjar-Murcia, south-eastern Spain (38°07′18″ N; 1°13′15″ W) was selected. The orchard was planted in 2004 with ‘Star Ruby’ grapefruit trees (*Citrus Paradisi* Macf.) grafted on Macrophylla rootstock [*Citrus Macrophylla* Wester] with a tree spacing of 6 m × 4 m.

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

#### 2.3.2. Irrigation system

The irrigation system consisted of a control head equipped with pumps, a fertigation system, electrovalves, an automatic irrigation programmer and filters. The irrigation head pumped water to the plot throughout a PVC tertiary pipe 145 m in length. A total of 17 single PE irrigation laterals each measuring 100 m in length were installed on the