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Assessment of yield and water productivity of clementine trees under surface and subsurface drip irrigation

M.A. Martínez-Gimeno[a,*], L. Bonet[b], G. Provenzano[c], E. Badal[b], D.S. Intrigliolo[a,b], C. Ballester[d]

[a] Departament of Irrigation, Center for Applied Biology and Soil Sciences (CEBAS-CSIC), Murcia, Spain
[b] Valencian Institute for Agricultural Research (IVIA), Unidad Asociada al CSIC "Riego en la agricultura mediterránea" Valencia, Spain
[c] Department of Agricultural, Food and Forest Sciences, University of Palermo (UNIPA), Palermo, Italy
[d] Centre for Regional and Rural Futures (CeRRF), Deakin University, Griffith, NSW, Australia

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ABSTRACT

Irrigation systems aimed to optimize water use efficiency in agriculture have become essential due to the increasing water limitations that agriculture is currently facing. Assessment of crop responses to different irrigation systems and strategies are therefore encouraged to find the most efficient options for each specific case. The main objective of this study was to assess the performance of a citrus crop under a surface (SI) and subsurface drip irrigation (SSI) with 7 (SI_7, SSI_7) or 14 emitters (SI_{14}, SSI_{14}) per plant, as well as a third SS treatment (SSI_A), identical to SSI_7 but equipped with and additional drip line buried between the tree rows. Evaluations were made in terms of yield, fruit composition, irrigation water productivity (IWP) and water savings. Results showed that, on average, water savings were 23.0% in the SSI treatment compared to the SI treatment without significant differences in either yield or fruit composition. IWP was higher in SI_{14}, SSI_{14} and SSI_A than in SI_7 and SSI_7 treatments. SSI_A was the treatment with the lowest irrigation volumes and the highest yield and compared to SI_7 allowed, over the three years, water savings in the range between 22.4 and 27.9%. Results from this study illustrate that there is opportunity to substantially save water in citrus production and that further research in this direction is needed to contribute to better optimize the water resources in agriculture.

1. Introduction

According to data from the Food and Agriculture Organization (www.fao.org), two-thirds of the world population are expected to live in regions with water stress conditions by 2025 (between 500 and 1000 m^3 per year per capita). Agriculture, which is the largest water-consuming sector, has to adopt methods and strategies to improve crop sustainability (Provenzano et al., 2014). Using irrigation techniques that allow water savings without significantly reducing crop yield, maximizing economic benefits and protecting environmental quality, has been proposed as a possible strategy to approach this challenge (Rodriguez-Sinobas et al., 2016).

Spain is one of the largest citrus producers in Europe, with annual productions higher than 5 million tonnes during the last decade (www.fao.org). The main citrus producing region is the Valencian Community with nearly 3 million tons per year, which is equivalent to 60% of the Spanish citrus production (http://gipcitricos.ivia.es/citricultura-valenciana). Because of the semi-arid climate of the area and the high crop water requirements, there is a growing interest among farmers in implementing strategies aimed to improve the sustainability of the citrus production. Adoption of efficient irrigation systems associated to water saving strategies, based on either simple periodic estimations of the soil water balance terms or precise assessments of temporal and spatial distribution of water exchange processes within the soil-plant-atmosphere system (Provenzano et al., 2013), may lead to improve crop sustainability.

Compared to other irrigation methods, drip irrigation systems provide the possibility to apply lower volumes of water, more frequently and efficiently. If well designed, these systems make it possible to apply slow, steady and uniform amounts of water and nutrients within the plant's root zone, while minimizing deep percolation and maintaining high productivity levels (Rallo et al., 2011).

During the last decades, the interest in the use of subsurface drip irrigation (SSI) in woody perennial crops has increased. SSI has been suggested as a promising strategy for a sustainable water management in semiarid regions (Consoli et al., 2014). In this irrigation system, water can be uniformly applied directly to the root zone while maintaining a dry soil surface, thus, minimizing the water loss from evaporation and preventing weeds' growth (Provenzano, 2007). SSI has been shown to preserve water in comparison to surface drip irrigation

* Corresponding author.
E-mail address: magimeno@cebas.csic.es (M.A. Martínez-Gimeno).

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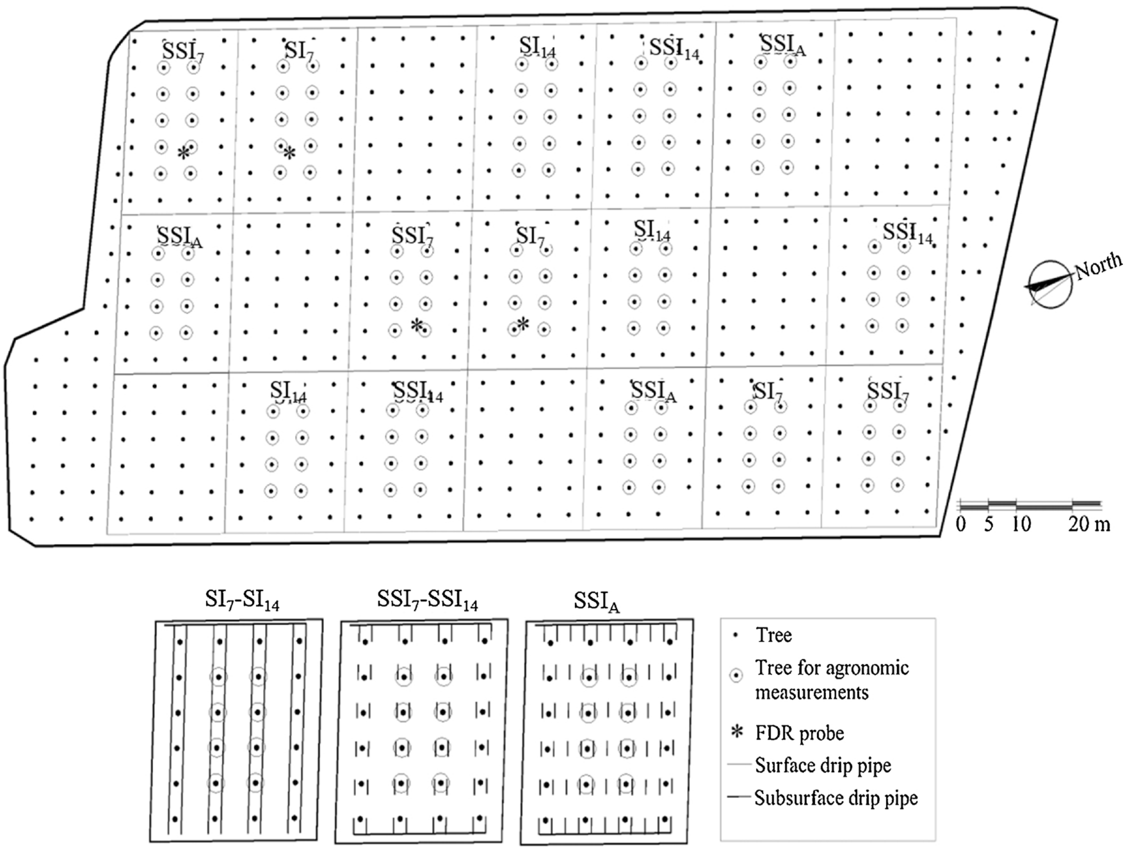

Fig. 1. Experimental layout showing the distribution of treatments in the field and the location of FDR probes and sampled trees. "SI" and "SSI" mean surface and subsurface drip irrigation, respectively, and the subscripts indicate the number of emitters used per tree. "SS_A" refers to the treatment with an additional dripline between tree rows.

(SI) without compromising yield, increasing then water use efficiency (Consoli et al., 2014; Robles et al., 2016; Zhang et al., 2017).

Nevertheless, the adoption of SSI has been also associated to some inconveniences such as a high initial cost, potential for rodent damage, salt accumulation between the drip lines and soil surface, and particularly, high potential for emitter plugging (Phene et al., 1986, 1993; Phene, 1995).

In drip irrigation systems, the number of emitters per plant determine the number and dimensions of the wetted bulbs, in which roots are mainly concentrated. Root growth conditions inside the wetting bulbs are considered close to the optimum, as water and nutrients are readily available to the plant as result of the high-frequency irrigation (Pereira et al., 2010). In tree crops, the number of emitters per plant and the spacing between them can be flexible, as long as an adequate volume of root zone is provided with enough water to meet canopy water requirement (Evans et al., 2007). Smaller the emitter spacing, bigger the soil wetted volume and higher is the crop water availability (Shan et al., 2011). Recently, García-Tejera et al. (2017) concluded that under deficit irrigation, the wetted area on the soil surface should be reduced in order to decrease soil evaporation while under full irrigation, at least 30–40% of the allotted soil per tree should be wetted to maximize trees' transpiration. A reduced volume of wetted soil implies that a greater fraction of the root system is in dry soil, particularly towards the end of the season. This is the reason why in horticultural studies, lower midday stem water potential (ψ_{stem}) values have been often observed under drip irrigation (Lampinen et al., 2001; Intrigliolo and Castel, 2005) than under furrow irrigation (McCutchan and Shackel, 1992; Fereres and Goldhamer, 2003).

The main objective of this work was to assess the performance of citrus trees in terms of plant water status, yield, fruit quality and irrigation water productivity when: i) trees were grown under SI and SSI; ii) soil wetted volume was modified by doubling, from 7 to 14, the number of emitters per plant in both irrigation systems, and; iii) an additional third line was added in the SSI treatment between tree rows.

2. Materials and methods

2.1. Experimental plot

The study was conducted during 2014, 2015 and 2016 in a commercial citrus orchard planted with *Citrus clementina*, Hort. ex Tan. 'Arrufatina', located in Alberique (39° 7′ 31.33″ N, 0° 33′ 17.06″ W), Valencia, Spain. Trees were grafted onto Citrange Carrizo (*Citrus sinensis*, Osb. x *Poncirus trifoliata*, Raf.) and planted at spacing of 5.50 m x 4.25 m. At the beginning of the experiment, the canopy ground cover (GC) was equal, on average, to 39.4 ± 4.1%.

The soil was loam to sandy clay loam texture with percentages of sand, silt, and clay ranging from 34.4 to 51.6%, 22.6 to 38.4% and 21.8 to 33.8%, respectively, within the orchard. Soil organic matter was on average 1.25% and total organic carbon 0.73%. Irrigation water had, on average for the three seasons, an electrical conductivity of 1.33 dS m^{-1} and pH equal to 7.9 at 25 °C.

The irrigation system was installed in March 2014. This included, automatic control valves for each treatment and flow meters to monitor the amount of water applied in each sub-plot during an irrigation event. Trees were provided with 2–3 drip lines depending on the treatment, located either above (on surface, SI treatments) or below the soil surface (subsurface, SSI treatments) at 0.30 m depth, one meter apart from the tree rows. In order to avoid possible differences between SI and SSI treatments due to root damage while installing the drip lines in treatment SSI, one trench at each side of the tree rows was also excavated and filled in the SI treatment simulating what was done to install the SSI