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Yield response of seedless watermelon to different drip irrigation strategies under Mediterranean conditions

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ABSTRACT

Water is an essential resource for food production, as agriculture consumes close to 70% of the total freshwater, and its shortage is becoming critical in arid and semiarid areas of the world. Therefore, it is important to use water more efficiently. The objectives of this project are to determine the productive response and the irrigation water use efficiency of seedless watermelon to three irrigation management strategies over two growing seasons. This was done by applying 100, 75 and 50% of the irrigation water requirements (IWR) the first year, in the second year added six additional treatments, of which three treatments were regulated deficit irrigation with 75% IWR during the vegetative growth, fruit development and fruit ripening stages, and the other three treatments were with 50% IWR during the same stages. The exposure of watermelon plants to severe deficit irrigation resulted in a reduction in dry biomass, total and marketable yield, average fruit weight, fruit number and harvest index, and without improvement of marketable fruit quality. The fruit ripening was the less sensitive stage to water deficits. Relative water content and cell membrane stability index decreased as the water deficit increased. Irrigation water use efficiency decreased to a lesser extend during the fruit ripening stage than when water restriction were applied during different growth stages. If water is readily available, irrigating with 100% of water requirements is recommended, but in the case of water scarcity, applying water shortage during fruit ripening stage would be advisable.

1. Introduction

Watermelon [*Citrullus lanatus* (Thun.) Matsum. and Nakai] is an important crop around the world, with a production approximately 117 million Mg from 3.5 million ha (FAO, 2017). Currently, the leading watermelon-producing countries are China, Turkey and Iran. Spain is the main producer of watermelon for the European community, with 969,327 Mg from 17,360 ha (FAO, 2017).

Irrigation water is an essential element for crop production (Howell, 2001; Steduto et al., 2012). Agriculture uses approximately 70% of freshwater; in Spain, agriculture utilizes approximately 68% of total water use (FAO, 2016). During recent years, freshwater shortage is becoming critical in arid and semiarid areas of the world with increasing competition for water across agricultural, industrial and urban consumers (Chai et al., 2016). Rapid population growth, other human activities and the greater incidence of drought, particularly in the Mediterranean area, are increasing the demand for fresh water (Fereres, 2008). This water scarcity and the incremental increase in irrigation costs have led to heightened interest in improving the productivity of water use in crop production (Bessembinder et al., 2005; Fereres and Soriano, 2007; Steduto et al., 2012; Reddy, 2016).

Irrigation water-use efficiency (IWUE) is a common indicator employed to assess the efficiency of the use of irrigation water in crop production (Bos, 1980; Tolk and Howell, 2003; Pascual-Seva et al., 2016). At present, there are challenges in maximizing IWUE and increasing crop productivity per unit of water applied. Within this context, the use of deficit irrigation (DI) strategy is a technique of applying irrigation less than the optimum crop water requirements with a result to improve water use efficiency (Pereira et al., 2002; Costa et al., 2007; Capra et al., 2008; Evans and Sadler, 2008; Chai et al., 2016). The real challenge is to establish DI on the basis of maintaining or even increasing crop productivity while saving irrigation water and, therefore,

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Table 1
Percentages of clay, loam and sand, and soil texture according to the USDA for each irrigation rate (IR: T1, T2 and T3), at a 0.15 and 0.30 m depth in the 2016 and 2017 growing seasons.

	IR	Depth (m)	Clay (%)	Silt (S)	Sand (%)	Texture
2016	T1	0.15	25	51	24	Silt loam
		0.30	27	50.5	22.5	Clay loam
	T2	0.15	25	51	24	Silt loam
		0.30	27	49	24	Clay loam
	T3	0.15	26	50	24	Silt loam
		0.30	27	49	24	Clay loam
2017	T1	0.15	17.5	32.5	50	Loam
		0.30	20	32	48	Loam
	T2	0.15	17.5	32.5	50	Loam
		0.30	20	28	52	Loam
	T3	0.15	17	30.5	52.5	Loam
		0.30	18	30	52	Loam

increasing the IWUE (Chai et al., 2016). For this reason, DI requires precise knowledge of the crop yield response to water applied (Fereres and Soriano, 2007). Currently, DI is a common practice throughout the world, especially in dry regions, where it is more important to maximize crop water productivity rather than the harvest per unit land (Ruiz-Sanchez et al., 2010). Regulated deficit irrigation (RDI) is the treatment of water stress during certain crop developmental periods (Fereres and Soriano, 2007).

Water content and water potential have been used as indicators of leaf water status. The use of water content has been replaced by the relative water content (RWC) which are measurements based on the maximum amount of water a tissue can hold (Yamasaki and Dillenburg, 1999). RWC reflects the metabolic activity in tissues, and it is used as a meaningful index for dehydration tolerance (Anjum et al., 2011; Kalariya et al., 2015). RWC correlates closely with a plant's physiological activities, soil water status (Tanentzap et al., 2015) and is a parameter used for screening the drought tolerance of different genotypes (Tanentzap et al., 2015). On the other hand, the cell membrane stability index (MSI) is also widely used as an indicator of leaf desiccation tolerance (Chai et al., 2010), which detects the degree of cell membrane injury induced by water stress (Bajji et al., 2002).

Watermelon grows in the summer, when evapotranspiration (ET) demands are high and rainfall is scarce, particularly in a Mediterranean-type climate, where irrigation is needed for any significant summer cropping (Turner, 2004). Watermelon is considered to be very sensitive to water stress with larger yield reductions when water use is reduced (Steduto et al., 2012). The timing and extent of water deficit irrigation are important for efficient water use and maximizing yield (Erdem and Yuksel, 2003; Yang et al., 2017). Currently, there is little available data of DI for seedless watermelon, especially for developed hybrids.

Therefore, it is important to identify the best practices for the water management of watermelon using DI techniques. The objective of this study is to evaluate response of watermelon growth, fruit yield, fruit quality, IWUE, and plant water status under DI in open field conditions.

2. Materials and methods

2.1. Experimental site

Field experiments were carried out in two plots at the Cajamar Experimental Center in Paiporta, Valencia, Spain (39.4175 N, 0.4184 W), during the 2016 and 2017 growing seasons. The soils are deep, with a coarse texture (Table 1), and are classified as Anthropic Torrifluvents according to the USDA Soil Taxonomy (Soil Survey Staff, 2010). Although the soil of the two plots was apparently similar, soil analyses indicated that the soil in 2017 was sandier than in 2016. In addition, while the soil texture in 2017 was uniform throughout the profile (loam), the soil in 2016 presented a higher percentage of clay (clay loam) at 0.30 m compared to that at a 0.15 m depth. The analyses indicate that the soils have a slightly alkaline pH (on average 7.4), are fertile (1.89% organic matter content; EC 0.39 dS m^{-1}), and present high available phosphorous (43 mg kg^{-1}; Olsen) and potassium (340 mg kg^{-1}; ammonium acetate extract) concentrations. Irrigation water was pumped from a well, with EC 2.53 dS m^{-1} and 77 mg kg^{-1} N-NO^{3-} content.

According to Papadakis's agro-climatic classification (Verheye, 2009), the climate is subtropical Mediterranean (Su, Me) with hot dry summers and an average annual rainfall of approximately 450 mm, irregularly distributed throughout the year, with approximately 40% falling in autumn. Fig. 1 shows the most significant climatological data of the growing seasons expressed as average monthly values: temperature (ºC), precipitation (mm), and reference evapotranspiration (ET$_o$; mm) obtained from a Class A evaporation pan adjacent the experimental plots.

2.2. Plant material and management

Plants of the triploid watermelon cv. *Stellar F1* (Nunhems®) grafted on the hybrid '*Shintoza*' (*Cucurbita maxima* x *Cucurbita moschata*) were transplanted when plants had reached the two-leaf stage in an open field at a spacing of 1.0 m by 3.0 m apart in plastic mulched rows, following traditional practices used in the area, on 19 May 2016 and 15 May 2017. Shortly afterwards, plants were de-topped to force the growth of four tertiary vines per plant, as described by López-Galarza et al. (2004). The row length was 10.0 m, and the width of the raised bed covered by the plastic mulch was approximately 0.60 m.

The cv. *Premium,* also grafted on the hybrid '*Shintoza*', was used as a pollinator with a proportion of 33% to ensure a sufficient pollen amount for the pollination of the triploid cv. The incorporation of nutrients (250-100-250 kg ha^{-1} N-P$_2$O$_5$-K$_2$O) was performed by fertigation, following the recommendation described by Pomares et al. (2007). Fruit harvest started on 25 July 2016 and lasted until 1 August 2016 and again on 20 July 2017 until 3 August 2017, with three recollections each year.

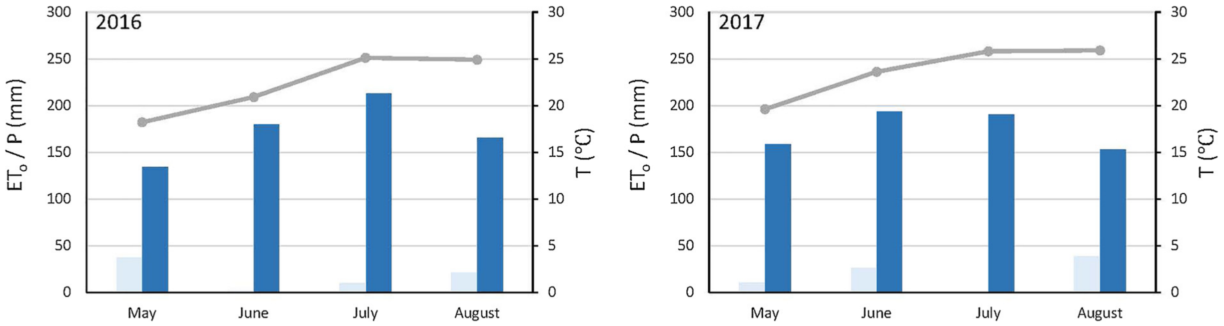

Fig. 1. Average monthly reference evapotranspiration (ETo; mm; ■), precipitation (P; mm; □) and temperature (ºC; —●—) from May to August 2016 and 2017.