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Effects of three irrigation systems on ‘Piel de Sapo’ melon yield and quality under salinity conditions

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Abstract

The melon crop is moderately sensitive to soil salinity and, as a consequence, its yield decreases under saline conditions. Nevertheless, the exposure to moderate salinity also influences the melon quality by improving it, which offers compensation to the farmer. As a consequence, in moderately salt-affected lands, like the traditional irrigation area of the ‘Vega Baja del Segura’ (Alicante, Spain), melons are being grown. In this area the modernization of the secular irrigation system through the replacement of flood by drip systems, is currently being fostered. This fact, however, is generating some controversy, due to the known salt leaching effect that flood irrigation followed by drainage makes in the soil. In this study, the effects of three irrigation systems, namely, drip (DI), subsurface drip (SDI) and flood (FI), on soil salinity and thus, on the yield and quality of the melon, were compared. According to the results, the FI system kept the soil salt levels during the growth period at 4.1 ± 0.3 dS/m, that is, significantly lower than the 4.7 ± 0.2 dS/m attained with the DI and SDI systems. Nevertheless, the DI and, overall, SDI, provided higher and more homogenous soil moisture completely counteracting the effect of salinity as revealed by the soil water potential calculations. As a result, the SDI gave 27 ± 5 Mg/ha of total yield in comparison to 23 ± 2 Mg/ha (DI) and 20 ± 6 Mg/ha (FI). Besides, the SDI system reduced the number of damaged melons, thus additionally contributing to the significant higher marketable yield of the SDI (25 ± 4 Mg/ha) in comparison to the DI (20 ± 1 Mg/ha) and the FI (19 ± 7 Mg/ha). On the contrary, in the SDI treatment the fruit soluble solids content, titratable acidity and pulp firmness decreased a bit, however, in the sensory evaluation no differences among irrigation treatments were observed.

Keywords

drip; subsurface drip; flood irrigation; trickle; Cucumis melo; postharvest

1. Introduction

Salinity is an abiotic stress factor that reduces crop yield and affects a World percent of irrigated land between 10 and 25% (Metternicht and Zinck, 2003; Tanji and Wallender 2012; AQUASTAT, 2018). In areas with arid to dry sub-humid climates, high water tables and/or with low-quality irrigation waters, these salinity-prone conditions have to be taken into account for agricultural development. To minimize the adverse effects of salinity in agriculture, many techniques are used. These range from the traditional installation of drainage systems that ease the leaching of soil salts (Rhoades 1974) to water desalination (Martínez-Beltrán and Koo-Oshima, 2006) and, even, to the increase of the salt-tolerance of rootstocks and/or varieties by using plant breeding (Ashraf and Foolad, 2013) and biostimulants (Plaut et al., 2013). However, in few instances salinity is considered as an enhancement factor for harvest quality, economically making up for yield losses. Therefore, in areas where salinity constrains the diversity of crops to those that are from tolerant to moderately tolerant to salts, such as cotton, barley or globe artichoke, others more salt-sensitive, such as melon or tomato, could also be grown as long as salinity is not excessive (Colla et al., 2006a, b; Botía et al., 2005; Mendlinger, 1992).

In the area of the irrigators community of ‘Carrizales’ (Alicante, SE Spain) the salinity of the irrigation waters measured as the electrical conductivity at 25 °C (EC₂₅) is generally between 2.5 and 6 dS/m. These salt contents constrain its agricultural production to crops between tolerant and moderately tolerant to salinity such as alfalfa, globe artichoke and pomegranate and, also, moderately salt-sensitive such as broccoli and melon but with yield losses. Losses that, by using the decision support system based on the SALTIRSOIL_M model (DSS-SALTIRSOIL, <http://agrosal.ivia.es/>), have been estimated up to 36% for melon. As a consequence, under saline conditions the harvest quality is critical for agricultural sustainability. Bearing this objective in mind, the irrigators community of ‘Carrizales’ is promoting a proprietary brand, which features a ‘Piel de Sapo’ (skin of toad) melon with a pleasant sweet taste and a high market price (Illescas, 2016). The quality of this melon is attributed to the specific environmental conditions of silty-clay soils and semi-arid climate of the area, as well as, to the salts of its available irrigation waters, which are a consequence of the area location on the final reaches of the traditional irrigation zone of the ‘Vega Baja del Segura’.

In the ‘Carrizales’ area, 25 out of 997 ha of irrigated land (CHS, 2015) are nowadays cropped with melon, which is generally flood irrigated, as most of the traditional zone

of the ‘Vega Baja del Segura’ still is. Despite its low water and nutrient use efficiencies, the water application over crop requirements that is characteristic of flood irrigation followed by drainage has a beneficial effect of soil salt leaching of which farmers in the area are aware since ancient times (Cavanilles, 1797). This flushing-out of salts allows the farmer some control over soil salinity that, in the conditions of the ‘Carrizales’ area, is critical to obtain acceptable agricultural yields.

All melon crop varieties are classified as moderately sensitive to soil salinity (Mangal et al., 1988; Turini, 2011; Tedeschi et al., 2011; Grieve et al., 2012) and, therefore, melon yields in the ‘Carrizales’ area can decrease by up to 36% regarding its agronomic potential. In general, the implementation of drip irrigation increases agricultural yields because these systems improve the water and fertilizer distribution in the soil, while minimizing the impact on the environment because of their characteristic lower agricultural losses of water and nutrients. Therefore, the current irrigation modernization plans in the ‘Vega Baja del Segura’ (GVA, 2016) aim at the installation of drip irrigation systems. However, the possible impact of the abandonment of flood irrigation on the soil salinity of the area is not being taken into account.

Although drip and flood irrigation systems have been previously compared, to our best knowledge there is not any comparison of drip and subsurface drip against flood irrigation. Furthermore, a comparison of drip irrigation systems against flood under salinity conditions in real commercial horticultural plots has never been done up to date. In this study, we compare the effects of three different irrigation systems: the traditional by flood and two drip, in particular drip and subsurface drip, on soil salinity, and on melon yield and quality, in a salt-prone irrigation area.

2. Materials and methods

2.1. Plot location

The irrigation area of ‘Carrizales’ is located in the Alicante province (SE Spain). It is bounded by two wetlands: the ‘Fondó d’Elx-Crevillent’ to the north and northwest and the ‘Salines de Santa Pola’ to the northeast, while the traditional irrigation zone of the ‘Vega Baja del Segura’ extends to the west and southwards. The irrigation water in the ‘Carrizales’ area is constituted by the irrigation return flows from two other irrigation areas that take their water from the Segura River. In Mediterranean Spain, including the ‘Carrizales’ area, melon is cultivated in the same plot once every, at least, four years,

alternating with plants from other families and a fallow season (Alarcón and Fuentes, 2017). By using rotations like these, the farmers effectively avoid the soil-borne fungal diseases this plant is prone to in Mediterranean countries (Chilosi et al., 2008). In 2016 a representative commercial melon plot of $110 \times 26 \text{ m}^2$ with coordinates $38^\circ 8' 31'' \text{ N}$ and $0^\circ 42' 31'' \text{ W}$ and average altitude of $1 \pm 1 \text{ m a.s.l.}$ was selected for the trial (Fig. 1).

[Figure 1]

2.2. Soil

The soil in the plot was classified as aquic xerofluvent according to the Soil Taxonomy (Soil Survey Staff, 1999) and Calcaric Fluvisol following the FAO (IUSS Working Group WRB, 2006) with these characteristics: silty-clay texture, 50% of calcium carbonate equivalent, 3% of organic matter content in the Ap horizon which decreases to 1% at depth and bulk density in the range of 1.16 to 1.37 g/cm^3 (Table 1). Regarding salinity before the onset of irrigations, the average electrical conductivity at 25°C and chloride concentration in the soil saturation extract (EC_{se} and $[\text{Cl}^-]_{\text{se}}$) in the plot from the surface down to 60 cm were $3.2 \pm 0.5 \text{ dS/m}$ and $6.5 \pm 1.5 \text{ mmol/L}$ (Table 1). Since only sensitive and moderately sensitive crops present yields below 90% for EC_{se} between 2 and 4 dS/m (Maas and Hoffman, 1977) the soil can be considered moderately saline and chloridated. The water table was kept at 0.9 m from the soil surface throughout the season by means of buried drain pipes at that depth.

[Table 1]

2.3. Climate

The climate is classified as hot semi-arid (BSH) according to the Köppen-Geiger classification (Rodríguez-Ballesteros, 2016) with annual average reference evapotranspiration (ET_0) and rainfall of, respectively, $1180 \pm 50 \text{ mm}$ and $240 \pm 40 \text{ mm}$ (95% CI), reason why irrigation becomes necessary for agriculture.

2.4. Cropping and fertilization

The plot was cropped with *Cucumis melo* L., ssp. melo Ibericus Group var. ‘Piel de Sapo’, formerly classified as *Cucumis melo* L., Inodorus Group var. ‘Piel de Sapo’ (Pitrat, 2017), to a plant spacing of $1 \times 2 \text{ m}^2$. Non-grafted seedlings were transplanted on 23rd April to the plot on raised beds 15 cm high and 50 cm wide, which have been previously covered with black plastic films. The harvest was collected from 25th July to

25th September of the same year. All the plants were given the same fertilization treatment which, according to the usual melon fertilizing practices in the area and the farmer's experience, consisted in one basal application of 250 kg/ha of an NPK complex containing 10% N, 5% P₂O₅ and 10% K₂O on the rows and three more applications of 3 kg/ha of a 66% humic extract (15% K₂O) diluted in the irrigation water.

2.5. Irrigation treatments

The irrigation treatments were two drip: surface drip (DI) and subsurface drip (SDI), and the traditional one by flood (FI) with three repetitions each, which were arranged alternately along the plot (Fig. 1). Each repetition was formed by four rows of plants leaving in all cases two rows of guard plants in order to protect the trial from possible edge effects between different treatments.

The DI system was composed of one drip tube for each row of plants with drip emitters of 4 L/h each half a meter. This same composition was chosen for the SDI treatment but with the drip tube buried at 4 cm beneath the soil surface. The FI repetitions were irrigated from one side with a 10 cm radius pipe. The irrigation amounts were similar for the three irrigation treatments. The irrigation schedules were decided by the farmer based on water availability, especially for flood, which is subjected to rotation in the traditional irrigation area of 'Vega Baja del Segura', and his experience. During the entire trial period, no significant rain events were recorded on the farm, so all the water came from irrigation.

In the DI and SDI, the water amounts were determined by means of flow meters. Therefore, in the drip systems the irrigations began on the day of planting, 23rd April 2016, with long applications of 5 h with 5 – 7 mm/week, of low frequency, every 5 days, until 2nd June 2016, subsequently increasing the frequency to 6 days/week until 5th August 2016 (irrigations of 2 h/day with a total of 25 mm/week), to subsequently reduce the amount (from 11 to 3 mm/week) and the frequency (3 – 2 days per week) during the senescence of the crop, from 5th August 2016 onwards, reaching a total amount of 332 mm at the end of the season (Fig. 2).

[Figure 2]

In the FI, the irrigation water amount (I) was determined on the basis of volumetric flow rate of the water entering the subplots (q), the subplot area (S) and the irrigation length (t) by means of $I = q t/S$. Since $q \approx 11$ L/s and $S = 8 \times 26 = 206$ m² (Fig. 1), in the FI, an

irrigation of about 25 min, i.e., 80 mm, was given the day before planting and then, four more of about 22 min, i.e., 70 mm, per irrigation were applied every 20 – 30 days following the standard management in the area. In total there were five irrigations from the planting until the beginning of the crop senescence that accounted for 360 mm.

2.6. Irrigation water quality

The electrical conductivity at 25 °C (EC_{25}) of the irrigation water was monitored with an ES/2 probe (METER Group, Inc., Pullman, Washington, USA). Additionally, several water samples were taken throughout the growing season. They were analyzed in the laboratory using potentiometry to measure pH and determine alkalinity (Gran, 1952), coulometric-amperometric argentometry to determine chloride (Cl^-) (Cotlove, 1963) and atomic emission spectroscopy by inductively coupled plasma (ICP – AES) to determine the rest of main ions (Na^+ , Ca^{2+} , Mg^{2+} , etc.) as well as boron (B). Then, the water quality was assessed on the basis of calculated sodium adsorption ratio ($SAR = [Na^+]/([Mg^{2+}] + [Ca^{2+}])^{1/2}$) along with adjusted SAR (SAR_{adj}) (Lesch and Suarez, 2009) for sodicity, and the residual sodium carbonate ($RSC = Alkalinity - 2([Mg^{2+}] + [Ca^{2+}])$) for alkalinity. The amount of water applied with the drip (DI & SDI) systems was monitored with digital meters and rainfall with an ECRN-50 pulse gauge (METER Group). The amount of water applied with the FI was monitored on the basis of date, length and water flow into the plot.

2.7. Soil water content and salinity

Since the root system of the melon plants consists of a very extensive shallow portion and a poorly developed deeper part, i.e., below 45 cm (Weaver and Bruner, 1927), only the soil depth down to 60 cm was studied for water content and salinity by means of probe measurements along with sampling and laboratory analyses.

The field soil water content (θ) was monitored at two depths (20 and 40 cm) in only one repetition per treatment (Fig. 1) with the capacitance-conductance 5TE probes (METER Group). To convert the values of the probe-measured bulk soil dielectric permittivity (ϵ_b) to θ , the semi-empirical simplified dielectric mixing model with b_0 and b_1 coefficients calibrated for a nearby soil was used (Visconti et al., 2014).

Throughout the growing season the soil salinity and chloride content were determined by taking soil samples from 0 to 60 cm at 20 cm intervals in the rooting depth (between 5 and 10 cm from the plant's stem) of two zones per repetition (Fig. 1). The soil

samples were sealed in plastic bags and taken to the laboratory where they were air dried and then gently deagglomerated to pass a 2-mm mesh. The soil-to-water 1:1.5 (w/w) extracts were prepared by adding deionized water ($EC_{25} < 1 \mu S/cm$) to the soil samples, shaking for 30 min and centrifuging. In the aqueous extracts the EC_{25} was measured with a Basic 30 conductimeter equipped with a Pt 1 cm^{-1} 5070 conductivity cell (Crison Instruments, Barcelona, Spain) and, the chloride content determined with the above-mentioned coulometric-amperometric argentometry method (Cotlove 1963). The soil salinity and chloride content were finally expressed as their values in the saturation extract (EC_{se} and $[Cl]_{se}$) by multiplying the EC_{25} and $[Cl]$ in the 1:1.5 extracts by an adequate transformation coefficient (Visconti and de Paz 2018) which depends on the soil clay content and whose values ranged from 1.60 to 1.67 in this case.

2.8. Soil water potential

The soil water potential (ψ) at 20 and 40 cm depth was estimated by adding the matric potential (ψ_m) to the osmotic potential (ψ_o) of the soil solution at those depths ($\psi = \psi_m + \psi_o$). The ψ_m was estimated from θ using the van Genuchten soil water retention curve with parameters expressed as functions of textural fractions, organic matter content and bulk density and calibrated for European soils (Wösten et al., 1999). The ψ_o was estimated from EC_p by means of the following empirical equation $\psi_o = -0.36 + 0.55 EC_p$, where EC_p is the soil pore water electrical conductivity at 25 °C. The EC_p had been previously calculated from θ , EC_{se} and the soil water content at saturation (θ_{sat}), in turn calculated from the application of the van Genuchten retention curve at $\psi_m = 0$, using $EC_p = EC_{se} \theta/\theta_{sat}$. The soil water potential was calculated in head units (cm) and then reported as $pF = \log(-\psi)$ because the use of logarithmic units eased the comparisons and presentation of data on graphs.

2.9. Crop development

The canopy cover was monitored by taking zenithal photographs followed by image analysis.

2.10. Crop chloride and nutrient contents

Leaf chloride and nitrogen contents in the leaf blades and petioles were determined at various times spaced from three to four weeks throughout the growing season. The leaves were chosen at random within each treatment repetition and then sealed in plastic bags and taken to the laboratory. There, they were dried at 65 °C, grounded in a mill and

saved for analysis. The analytical methods were the extraction of Miller (1998) with final coulometric-amperometric argentometry (Cotlove, 1963) for chloride, and the micro Kjeldahl technique for nitrogen (Horneck and Miller, 1998).

2.11. Fruit yield evaluation

Melons were harvested by means of 4 fruit cuts leaving at least one week between them following the commercial procedure. All the melons from the same repetition and treatment were weighed and then, four representative melons per repetition were taken to the laboratory for a fruit quality evaluation.

2.12. Fruit quality evaluation

In the laboratory all melons were longitudinally cut in order to evaluate their quality. First of all, external and internal colour was measured using a Chroma Meter CR-300 (Minolta Co. Ltd., Osaka, Japan). For the skin colour measurement, 'L*', 'a*', 'b*' values were recorded from the equatorial zone of three replicates per fruit and then, the hue angle (h) and chroma (C*) were calculated as $h = \arctan(a^*/b^*)$ and $C^* = ((a^*)^2 + (b^*)^2)^{1/2}$.

Soluble solids content (SSC), titratable acidity (TA) and flesh firmness in three parts of the fruit: the blossom-end, the stem-end and the equatorial area were also evaluated. The SSC and TA were assessed in the juice obtained from the squeezing of three cylinders 8 mm in diameter. The SSC was determined with a PR-1 refractometer (Atago Co., Ltd., Tokyo, Japan), while the TA so was by neutralization with NaOH 0.1 N, using phenolphthalein as indicator of the titration final point. Flesh firmness was determined in a 1-cm thick slice as the load in kg needed to break the fruit flesh. A texturometer Universal Testing Machine 4301 (Instron Corp., Canton, Massachusetts, USA), with an 8-mm flat plunger was used for this task.

The analytical assessment of the fruit quality was complemented with a sensory evaluation that was carried out by a panel of eight to ten semi-trained judges. The fruit samples consisted of four balls 1.5 cm in diameter which had been carved from the equatorial area of the melons. Three replicates per treatment were evaluated. The samples were presented to the panellists on trays labelled with random three-digit codes and at room temperature. Water and unsalted crackers were provided for mouth rinsing between samples. The tasters were asked to assess the following sensory attributes in a

10-point scale from 1 (very low) to 10 (very high): flesh firmness, juiciness, sweetness and flavour and aroma intensities

2.13. Data analyses

All the data generated in this research are available from the corresponding author upon request. To study the effects of the three irrigation treatments on the various yield and quality components several one-way analyses of variance (ANOVA) were done. Then, the different treatments were compared by means of orthogonal contrasts (Webster and Lark, 2018). The orthogonal contrast comparison scheme is the most appropriate because of the structure the irrigation treatment variable presents in our experimental design: both DI and SDI systems are closely related and are remarkably different from the traditional FI which is the standard or control treatment. Accordingly, we planned the following two orthogonal contrasts in advance: both DI and SDI against FI, and DI against SDI. In this study the statistical significance level was set at 5% while all means are reported as the 95% confidence interval.

3. Results

3.1. Irrigation water quality

According to the mean water $EC_{25} = 4.1$ dS/m and composition (Table 2) this presented $SAR = 7.3$ along with $SAR_{adj} = 8.6$ (mmol/L)^{1/2}, $RSC = -18$ mmol_C/L, $[Cl^-] = 22$ mmol/L and saturation indexes (SI) for calcite and gypsum equal to, respectively, 0.13 and -0.55. Following the agricultural water quality classifications of Ayers and Westcot, (1985) for EC_{25} , SAR and $[Cl^-]$, Wilcox (1958) for RSC and the criteria in Visconti et al. (2010) for the SI, the irrigation water in the plot was classified as severely saline, non-sodic, non-alkaline, severely chloridated, non-saturated at all for gypsum and barely for calcite. Additionally, the boron concentration was found well below 2 mg/L (Table 2), which is the toxicity threshold for melon (Grieve et al., 2012). In general, the water presents limitations for agricultural use due to salinity and, especially, chloride, but not sodium. According to the SIs the water is barely prone to clog the drip emitters. For melon irrigation the water does not present limitations of use because of boron.

[Table 2]

Throughout the season, the EC_{25} of the water varied within a fairly wide range between 3 and 5 dS/m (Fig. 3). The highest salinity occurred during the irrigation intensification period (June – August, Fig. 3).

[Figure 3]

3.2. Soil water content

The irrigation system had an important effect on the distribution of water in the soil profile according to the sensor measurements. The SDI system gave rise to a homogeneous distribution of soil water content (θ), reaching values between 0.35 and 0.40 both at 20 and 40 cm during the period of highest evapotranspiration (Fig. 2). In the other two irrigation systems (DI and FI) this homogeneous distribution of moisture was not observed (Fig. 2).

In the DI the shallower layer (20 cm) showed θ values below 0.30 until late May, and then around 0.40. However, θ at 20 cm was much lower than at depth (40 cm) where it kept between 0.45 and 0.55 quite consistently throughout the season (Fig. 2).

In the FI system the soil water content remained more constant both in the shallow layer and in depth. In the superficial layer (20 cm), θ kept very close to 0.30 throughout the whole season. Besides, peaks due to irrigation events barely showed up which may be a consequence of the lack of uniformity in the water application. At depth (40 cm) θ remained between 0.45 and 0.50 until June and then fell during the period of highest evapotranspiration to 0.40.

3.3. Soil salinity and chloride content

The mean EC_{se} and $[Cl]_{se}$ from 0 to 60 cm depth throughout the cropping season in the plot were, respectively, 4.5 ± 0.2 dS/m and 14.0 ± 0.6 mmol/L. These are remarkably higher than the mean EC_{se} and $[Cl]_{se}$ within the same depth interval before the onset of irrigations, which were, respectively, 3.2 ± 0.5 dS/m and 6.5 ± 1.5 mmol/L (Table 1). Since irrigation was the main source of salts and, specifically, chloride, to the plot, this soil salinity increase was due to irrigation. There were, however, significant differences among treatments. In the drip systems (DI & SDI) the EC_{se} increased from the beginning and then kept steady at 4.8 ± 0.2 dS/m until September. In the FI the EC_{se} concurrently increased at the beginning but, then, it decreased a bit and kept significantly below the drip systems at 4.0 ± 0.3 dS/m during the summer (Fig. 4). Interestingly, there were no EC_{se} differences between DI and SDI. The $[Cl]_{se}$ qualitatively reproduced the same EC_{se} evolution and also the differences between treatments, however, these were less significant (Fig. 4).

[Figure 4]

In the soil moisture graphs at 40 cm, more peaks were observed in the SDI system in comparison to the DI one and, overall, to the FI one (Fig. 2). This fact indicates that in the SDI system water reached 40 cm depth more often than in the DI one and, naturally, much more often than in the FI system.

3.4. Soil water potential

The soil water potential (pF) at 20 cm was higher and more dependent on the irrigation treatment than at 40 cm (Fig. 5). At 20 cm the SDI system presented a mean pF of 3.76 with few variations throughout the cropping season. The pF was higher for DI with a mean value of 4.14, although it was remarkably over 4.2, i.e. the wilting point, until early June. The pF was even higher for FI with a mean of 5.19. At 40 cm, all the systems presented very similar and constant pF, which was well between the field capacity and wilting point limits, specifically, the DI presented a mean pF of 3.40, while it was 3.51 for FI and 3.67 for SDI.

[Figure 5]

3.5. Canopy cover

The final canopy cover kept well below 50% in all treatments. There were, however, significant differences among the three irrigation treatments (Table 3). The drip systems allowed a greater canopy development with joint $38 \pm 2\%$ of final cover. This was significantly higher than the canopy cover of $32 \pm 5\%$ attained with FI, while there were no significant differences between both drip systems (Fig. 6a).

[Table 3]

[Figure 6]

3.6. Crop chloride and nutrient contents

Leaf chloride contents differed a lot between blades and petioles and remarkably throughout the season, overall in petioles (Fig. 7). Chloride preferentially accumulated in the petioles of the leaves reaching mean values as high as $13.5 \pm 0.4\%$ in July, whereas chloride in the blades kept always below 4% on average (Fig. 7). The remarkable difference of chloride contents between petioles and blades that was observed during the growing and fruit set stages, attenuated during growth and maturation: in August and September chloride in the blades increased a bit, while in the

petioles abruptly dropped below 5% on average. Contrary to chloride, nitrogen contents did not differ among treatments (Fig. 8).

[Figure 7]

[Figure 8]

3.7. Fruit yield

There were significant differences in total yield among the irrigation treatments (Table 3). These differences arose primarily between both drip systems and FI and secondarily also between DI and SDI (Fig. 6b). The average yield of ‘Piel de Sapo’ melons in open irrigated cultivation in Spain is 31 ± 1 Mg/ha (MAPA, 2018). In the trial plot, however, only the SDI could approach that value with 27 ± 5 Mg/ha. In the other two irrigation systems the average production was 23 ± 2 Mg/ha (DI) and 20 ± 6 Mg/ha (FI), that is, respectively, 15 and 26% lower than SDI on average (Fig. 6b).

Contrary to the number of fruits, significant differences were not observed for the average melon weight (Table 3). In terms of fruit length, differences were neither observed between treatments (Table 3), however, diameter did seem to be reduced a bit by the drip systems (Table 3 and Fig. 6c). What is more important is the significant differences observed in terms of number of damaged pieces, i.e. malformed, cracked, sunstroke and, remarkably, perforated by *phragmites*, which led to a higher relative number of marketable pieces for the FI compared to both drip systems (Fig. 6d). Fruit damages were observed specifically in the DI, which exhibited 9% fewer marketable pieces than FI and 7% fewer than SDI (Fig. 6d).

3.8. Fruit quality

The internal colour did not change among irrigation treatments (Table 4). The external colour did not change either (data not shown). Regarding the SSC, TA and flesh firmness, slight but significant differences were observed among irrigation treatments (Table 4). Specifically, the drip systems exhibited 6% lower SSC than FI (Fig. 6e). TA was also significantly lower by 9% in the SDI treatment but not in the DI one, which presented the highest acidity (Fig. 6f). The SDI fruit also showed the lowest flesh firmness (Fig. 6g). All these differences were observed in the three tested melon parts, i.e., stem-end, equatorial area and blossom-end (data not shown).

[Table 4]

Sweetness, characteristic and overripe aromas, juiciness, flavour intensity, flesh firmness and overall quality as assessed by the sensory evaluation were not affected by the irrigation treatments (Table 5). All samples were evaluated by the tasters with high firmness and juiciness (scores over 7 – 8), high aroma intensity (scores of 6.5 – 7.8) and also high flavour intensity and sweetness with scores over 7 in all cases.

[Table 5]

4. Discussion

There were no soil salinity differences between DI and SDI, but there were between these and FI. Since salinity was remarkably lower in the whole plot before the onset of irrigations, both drip systems contributed the same amount of salts to the soil, and significantly 0.6 dS/m more than the FI.

The salt-tolerance of melons (*Cucumis melo* L.) in the Inodorus group, within which the variety ‘Piel de Sapo’ was classified until recently (Escribano and Lázaro, 2009; Pitrat, 2017), is characterized, according to the threshold-slope model, by a maximum EC_{se} for 100% yield between 1.05 and 1.73 dS/m and, a yield loss between 8.9 and 14.0% for each additional 1 dS/m increment (Mangal et al., 1988; Tedeschi et al., 2011). Considering the average values of soil salinity attained in each irrigation system, i.e., 4.1 ± 0.3 dS/m for FI and 4.7 ± 0.2 dS/m for both DI and SDI, melon yields would have been expected to decrease to 62 ± 7% in both drip systems and to 69 ± 6% in the FI to produce, respectively, 19 ± 2 and 21 ± 2 Mg/ha.

In the FI the observed melon yields agreed with the theoretical calculations based on EC_{se}, however, in the DI and, overall, the SDI, did not, they were significantly higher in that order. Given that soil salinity was higher in the drip systems, and adding that nutrition was equal in all three systems, this higher productivity can only be explained because of the higher and more homogeneous distribution of soil water that was achieved with the SDI compared to the DI and, overall, the FI (Fig. 2).

The SDI kept the θ high and homogenous at both 20 and 40 cm depth (Fig. 2). As a consequence, in the SDI the pF at both depths was well below 4.2, i.e. the wilting point, throughout most of the cropping season, thus barely causing stress on the plant because of drought (Fig. 5). The other two systems did not perform the same way: the DI kept the pF at 20 cm over 4.2, i.e., the wilting point potential, until early June, whereas the FI

kept the pF over 4.2, constantly throughout the cropping season. At 40 cm all the irrigation treatments kept the pF well below 4.2 throughout the whole cropping season.

Since the melon rooting depth is very shallow (Weaver and Bruner, 1927) and, additionally, fruit yields decrease as pF increases (Oster et al., 2012 and references therein), these differences in pF at 20 cm could explain that the SDI gave rise to significantly higher melon yields than the DI, and that both drip systems were also more significantly productive than the FI (Fig. 6b).

The important factor that increased the pF in the DI compared to the SDI was the lower θ at 20 cm in the DI until early June. It has been previously shown that the DI systems give rise to important heterogeneities in soil water content compared to SDI because of higher evaporation rates, runoff and preferential flow (Hardie et al., 2018), and that the SDI systems decrease soil surface evaporation and runoff in various horticultural crops such as potato, tomato and eggplant, thus eventually increasing their yields (Najafi and Tabatabaei, 2007). In this trial, since evaporation was approximately equally restricted in all treatments due to the plastic cover, surface runoff downslope the raised beds is the process that could explain, the most, the lower θ that was observed at 20 cm in the DI compared to the SDI. The burying of the drip emitters seems to have been effective in enhancing water infiltration, with remarkable consequences on pF and, eventually, yield. This burying of the drip emitters could lead to clogging problems, however, the melon in the area is an annual crop and, therefore, since the drip lines are reinstalled every season, clogging does not pose the same trouble as in permanent installations.

Then, in the drip systems, overall in the SDI, the higher and better distribution of soil water completely counteracted the harmful effect of salts, improving, on the one hand, the vegetative development, as revealed by the significant differences in the canopy cover between treatments and, on the other, the fruit set, as revealed by the significant differences observed in the number of fruits per plant among the irrigation treatments (Table 3). These differences arose primarily between the drip systems and the FI and, secondarily, between both drip systems (Fig. 6h).

The differences in chloride concentration that were observed between leaf petioles and blades, point to the existence of a buffering mechanism against chloride toxicity in the melon plant. This protective mechanism seems to have been more successful in the FI compared to the drip systems, especially during the summer months where leaf chloride was significantly lower in the FI compared to both DI and SDI, while there were no

differences between these (Fig. 7). This effect can be interpreted as a consequence of the lower soil chloride content in the FI compared to DI and SDI (Fig. 4). However, it had no consequences on melon yield. Therefore, the melon plants did not show the effects of Cl^- toxicity.

The average weight of ‘Piel de Sapo’ melons under non-saline irrigation conditions in Eastern Spain is 3.4 kg (Baixauli et al., 2008), i.e., equal to the average value obtained in this trial under salinity conditions (3.44 ± 0.05 kg). Therefore, the number of fruits but not their weight was the yield component affected by the irrigation treatment. Interestingly, this reduction effect on the number of melons but not on their weight has been observed to be caused by irrigation water salinity itself (Pereira et al., 2017).

Another interesting effect of the direct moistening of the soil surface characteristic of the DI is that it eased the sprout of the *phragmites* typical of the nearby wetland areas. These grasses in their development from beneath the melon fruits were able to drill their crust. This deleterious effect of DI was barely observed in the SDI and FI treatments. The burying of the drip emitters in the SDI at only 4 cm seems to have sufficed to limit the sprout of the *phragmites* and thus, contribute to significantly keep the average melon marketable yield with this system as high as 25 ± 4 Mg/ha (Fig. 6i), therefore, attaining an irrigation water productivity (IWP) of 7.4 ± 1.1 kg/m³, i.e. significantly over DI (5.9 ± 0.2 kg/m³) and FI (5 ± 2 kg/m³).

Finally, regarding the melon fruit quality, it has been repeatedly reported that as the salinity of irrigation waters increase, the SSC and TA of melon fruits (Franco et al., 1993; Mendlinger and Fossen, 1993), as well as their pulp firmness (Navarro et al., 1999; Colla et al., 2006b) also increase, while yields decrease. In our study this trade-off between quantity and quality characteristics was also observed to be caused by the irrigation management due to its effect on the pF. Therefore, it is pF, as a lumped parameter of θ and EC_{se} , that explains not only the effects of irrigation on melon yield, but also quality. Whatever the case, with 13.5 ± 0.2 °Bx (DI and SDI) and 14.3 ± 0.3 °Bx (FI), the SSC in all three treatments kept well above the standard SSC contents found in ‘Piel de Sapo’ melons in Spain and abroad, which lays between 10 and 13 °Bx (Ribas et al., 2003; Cabello et al., 2009; Dalastra et al., 2016). Similarly to SSC, the TA in all treatments with means between 1.17 and 1.29 mg/L, was still well within the standard range for ‘Piel de Sapo’ melons, which runs from 1.05 to 1.34 mg/L (Artés et al., 1993; Lázaro et al., 2012). This fact explains that the significant lower SSC values

of the melons from the drip treatments and, also, the lower TA and firmness values of the melons from the SDI treatment, did not lead to practical differences as revealed by the sensorial scores.

5. Conclusions

Soil salinity is an important worldwide problem for irrigated agriculture that is often counteracted by flood irrigation and drainage of water excesses. However, the application of water surpluses for salt leaching clashes with the increasing need for water saving. In our experimental trial, the advantageous soil salt leaching effect of FI over the water-saving DI and SDI systems was clearly seen, however, melon yield was significantly the highest in the SDI treatment. This occurred because the SDI improved the magnitude and distribution of water in the soil profile, thus keeping the soil water potential in the rooting depth homogeneous, constant and always between the field capacity and wilting point limits. In comparison, the DI and, overall, FI, had less homogeneous, less constant and higher soil water potentials, on average further from field capacity. Additionally, in the SDI fewer melons were lost due to, remarkably, crust perforation by *phragmites*, thus further leading to higher marketable yields. Regarding quality, the SDI and DI treatments significantly reduced analytical fruit quality parameters, however, fruit quality still kept well above usual ‘Piel de Sapo’ standards and thus, quality differences did not show up in the sensory evaluation. The advantageous effects of drip irrigation systems and, overall, SDI at just 4 cm depth, over flood systems, on melon yield and hence, water productivity, under salinity conditions have been shown. However, here only one season was studied, and as it has been also shown, the drip systems led to significantly higher soil salinity in just that season. Whether the effects of the scarce autumn and spring rainfalls that feature the climate in the area are enough to leach the excessive soil salinity caused by the drip systems should be studied to know the real, i.e., medium to long term, sustainability of drip systems under salinity conditions. These results can be extended to other areas similar to those under Mediterranean climate that are also featured by contrasting wet and dry seasons, e.g., monsoonal.

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Table captions

- Table 1** Average main characteristics of the soil in the experimental plot just before the onset of irrigations
- Table 2** Average main characteristics of the irrigation water in the experimental plot during the irrigation season
- Table 3** Analyses of variance of the effect of the different irrigation treatments on the canopy cover and several melon yield components
- Table 4** Analyses of variance of the effect of the different irrigation treatments on several melon quality analytic components
- Table 5** Analyses of variance of the effect of the different irrigation treatments on several melon quality sensory components

Figure captions

- Fig. 1** Map of the experimental plot and irrigation trial design with the location of the soil water content sensors and the sampling areas
- Fig. 2** Cumulated irrigation water amount in the three irrigation systems along with the soil water content at 20 and 40 cm depth as measured with the sensors and using a calibrated simplified dielectric mixing equation
- Fig. 3** Electrical conductivity at 25 °C of the irrigation water throughout the cropping season according to sensor measurements (continuous line) and samples analysed in the laboratory (diamonds)
- Fig. 4** Comparison of the effects on the electrical conductivity at 25 °C (top) and on the chloride content (bottom) of the soil saturation extract from 0 to 60 cm depth of the

drip (DI & SDI) and flood systems (FI) and of both drip systems. Error bars are 95% confidence intervals for the orthogonal contrasts

Fig. 5 Soil water potential estimated at 20 and 40 cm depth in each of the three irrigation treatments: drip (DI), subsurface drip (SDI) and flood (FI), throughout the cropping season. The wilting point (WP) and field capacity (FC) potentials are provided for comparison

Fig. 6 Comparison between, on the one hand, both drip (DI & SDI) and flood (FI) systems, and on the other hand, between drip (DI) and subsurface drip (SDI) systems on several yield and quality melon characteristics. Error bars are 95% confidence intervals for the orthogonal contrasts

Fig. 7 Comparison throughout the cropping season between the effects on the chloride content in the leaf blades (top), and petioles (bottom) of, on the one hand, both drip (DI & SDI) and flood (FI) systems and, on the other hand, drip (DI) and subsurface drip (SDI) systems. Error bars are 95% confidence intervals for the orthogonal contrasts

Fig. 8 Comparison throughout the cropping season between the effects on the nitrogen content in the leaf blades (top row), and petioles (bottom row) of, on the one hand, both drip (DI & SDI) and flood (FI) systems and, on the other hand, drip (DI) and subsurface drip (SDI) systems. Error bars are 95% confidence intervals for the orthogonal contrasts

719 **Figure 1.**

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Figure 3.

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762 **Figure 5.**

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Figure 7.

789 **Figure 8.**

Table 1.

Depth (cm)	Texture USDA				Org. Mat. (%)	Ca. Carb. Eq. (%)	BD/ g cm ⁻³	EC _{se} / dS m ⁻¹	[Cl] _{se} / mmol L ⁻¹	pH
	Clay (%)	Silt (%)	Sand (%)	Class						
0-10	50.7	42.8	6.5	Silty clay	3.03	48.3	1.16	1.46	4.62	8.05
10-30	55.3	40.7	4.0	Silty clay	2.22	47.5	1.29	2.28	6.03	8.02
30-60	54.5	41.0	4.5	Silty clay	1.84	52.8	1.37	4.23	7.52	7.64
60-90	52.7	42.8	4.5	Silty clay	1.08	59.5	nd	2.45	7.33	7.82

*Org. Mat.: organic matter content; Ca. Carb. Eq.: calcium carbonate equivalent; BD: bulk density; EC_{se}: electrical conductivity at 25 °C of the saturation extract; [Cl]_{se}: chloride concentration in the saturation extract; nd: no data

Table 2.

EC ₂₅	pH	Alk	[Ca ²⁺]	[Cl]	[K ⁺]	[Na ⁺]	[Mg ²⁺]	[NO ₃ ⁻]	[SO ₄ ²⁻]	[B]
4.10	7.4	5.7	5.9	22.2	0.48	24.5	6.0	0.29	11.4	0.44

*EC₂₅: electrical conductivity at 25 °C in dS/m; Alk: alkalinity in mmol/L; all other concentrations are in mmol/L except for boron, which is in mg/L

Table 3.					
Source of variance	Sum of squares	Degrees of freedom	Mean squares	F	p-value
<i>Canopy cover (%)</i>-----					
Irrigation treatment	291.3	2	145.7	4.84	0.014
Residual	994.1	33	30.1		
Total	1285.4	35			
<i>Total yield (Mg/ha)</i>-----					
Irrigation treatment	73.1	2	36.5	10.3	0.012
Residual	21.3	6	3.6		
Total	94.4	8			
<i>Number of fruits per plant</i>-----					
Irrigation treatment	0.226	2	0.113	10.5	0.011
Residual	0.065	6	0.011		
Total	0.291	8			
<i>Fruit weight (kg/fruit)</i>-----					
Irrigation treatment	0.7	2	0.337	0.392	0.676
Residual	1052.2	1225	0.859		
Total	1052.9	1227			
<i>Fruit length (cm)</i>-----					
Irrigation treatment	26.3	2	13.2	0.979	0.376
Residual	16419.3	1221	13.4		
Total	16445.7	1223			
<i>Fruit diameter (cm)</i>-----					
Irrigation treatment	27.0	2	13.5	4.48	0.012
Residual	3407.5	1130	3.0		
Total	3434.5	1132			
<i>Marketable yield (%)</i>-----					
Irrigation treatment	125.6	2	62.8	8.45	0.018
Residual	44.6	6	7.4		
Total	170.2	8			

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Table 4.					
Source of variance	Sum of squares	Degrees of freedom	Mean squares	F	p-value
<i>Soluble solids content (°Bx)</i>-----					
Irrigation treatment	50.1	2	25.1	15.6	<0.001
Residual	514.8	321	1.6		
Total	564.9	323			
<i>Titrateable acidity (mg/L)</i>-----					
Irrigation treatment	0.783	2	0.392	11.2	<0.001
Residual	11.250	321	0.035		
Total	12.034	323			
<i>Firmness (kg)</i>-----					
Irrigation treatment	1.53	2	0.763	3.4	0.034
Residual	71.89	321	0.224		
Total	73.42	323			
<i>Internal color (chroma)</i>-----					
Irrigation treatment	11.0	2	5.50	1.7	0.193
Residual	1067	321	3.33		
Total	1078	323			
<i>Internal color (hue)</i>-----					
Irrigation treatment	35.3	2	17.6	1.8	0.165
Residual	3126	321	9.7		
Total	3161	323			

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Table 5.					
Source of variance	Sum of squares	Degrees of freedom	Mean squares	F	p-value
<i>Sweetness</i> -----					
Irrigation treatment	10.93	2	5.47	2.53	0.084
Residual	272.70	126	2.16		
Total	283.63	128			
<i>Characteristic aroma</i> -----					
Irrigation treatment	3.11	2	1.55	0.40	0.668
Residual	484.18	126	3.84		
Total	487.28	128			
<i>Overripe aroma</i> -----					
Irrigation treatment	26.70	2	13.35	2.65	0.075
Residual	634.92	126	5.04		
Total	661.62	128			
<i>Juiciness</i> -----					
Irrigation treatment	3.76	2	1.88	1.31	0.272
Residual	180.34	126	1.43		
Total	184.10	128			
<i>Flavour intensity</i> -----					
Irrigation treatment	5.83	2	2.92	1.07	0.346
Residual	337.70	124	2.72		
Total	343.53	126			
<i>Flesh firmness</i> -----					
Irrigation treatment	1.24	2	0.62	0.29	0.750
Residual	269.50	126	2.14		
Total	270.74	128			
<i>Overall quality</i> -----					
Irrigation treatment	2.17	2	1.09	0.88	0.418
Residual	144.70	117	1.24		
Total	146.87	119			