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Melon crops (*Cucumis melo* L., cv. Tendral) grown in a mediterranean environment under saline–sodic conditions: Part II. Growth analysis

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ABSTRACT

An irrigation experiment using saline–sodic waters was carried out in 2004 in the Volturno river plain (southern Italy) to investigate the growth of the melon cultivar Tendral under saline–sodic conditions. Four salinity irrigation treatments (C, $T_{0.5}$, T_1 and T_2) were tested using water with electrical conductivities of 0.9, 8.7, 15.3 and 28.2 dS m^{-1}, respectively. At the end of the crop cycle the electrical conductivity (EC_e^d) of the saturated paste in the soil profile between 0.0 and 0.9 m reached values of 0.9, 3.2 4.2 and 6.6 dS m^{-1}, respectively, for the C, $T_{0.5}$, T_1 and T_2 treatments. Increasing salinity led to a rise in specific leaf area (SLA; cm^2 g^{-1}) while it reduced leaf area (LA, m^2 per plant), leaf area ratio (LAR, cm^2 g^{-1}), the unit leaf rate (ULR, g m^{-2} per day) and water use efficiency (WUE g kg^{-1}). The relative growth rate (RGR, g g^{-1} per day) and the biomass produced (W, g plant^{-1}) decreased. The reduction in RGR was closely related to the reduction in relative leaf area growth rate (RLAGR, cm^2 of leaf cm^{-2} per day), the relative leaf weight growth rate (RLWGR, g of leaf g^{-1} per day) and the relative fruit weight growth rate (RFWGR, g of fruit g^{-1} per day). A highly significant positive correlation was found between RGR and LAR (R^2 = 0.9847***), while between RGR and ULR the determination coefficient was also significant but lower (R^2 = 0.6808***). The most visible effect of the salinity treatment was on LA reduction. In $T_{0.5}$, T_1 and T_2 the LA was respectively 10%, 34% and 45% less than in the C treatment. W and the crop evapotranspiration (ETc) also decreased with increasing salinity. The reduction in W for $T_{0.5}$, T_1 and T_2 (respectively, 2%, 28% and 40% less than treatment C) was greater than the reduction in ETc (respectively, 2%, 22% and 32% less than treatment C). Therefore also the WUE significantly decreased as salinity increased. The Tendral cv. responded to salinity mainly with morphological adaptations, first with a LA reduction that was followed by decreases in the W and ETc. There may well also be functional adaptations associated with ULR reduction.

1. Introduction

Plant growth can be inhibited under saline conditions by low external water potential, ion toxicity and ion imbalance (Greenway and Munns, 1980). The intensity with which these factors affect growth depends on the plant genotype and the environmental conditions. Low external water potential can cause morphological and/or functional plant adaptations. Morphological plant adaptations include a reduction in leaf area (LA, m^2 per plant), with a consequent reduced leaf area duration (LAD, m^2 day) and a subsequent reduction in water use (Richards, 1992). Functional adaptations include reductions in the photosynthetic assimilation rate per unit of leaf area (ULR, g dry weight m^{-2} leaf area per day), or changes in water use efficiency (WUE, g kg^{-1}). Whatever adaptations the plant activates under salinity conditions, the result is a reduction in plant growth that can be evaluated by measuring the relative growth rate (RGR, g dry weight g^{-1} dry weight per day) (Hunt, 1982). RGR is a function of the leaf area ratio (LAR, cm^2 leaf area g^{-1}), which is an index of plant leafiness. The ULR is an index of the photosynthetic-assimilatory capacity of the plant that is measured per unit of leaf area. It is therefore possible to ascertain whether salinity has led to morphological, functional or combined adaptations by examining whether the RGR index is correlated to the LAR, to the ULR, or to both.

To date, few studies have used the functional approach to plant growth analysis to determine the effects of salinity on plant growth processes (Shannon and Francois, 1978; Curtis and Läuchli, 1986; Wickens and Cheeseman, 1988; Schachtman et al., 1989; Cramer et al., 1990; Glenn et al., 1998; Wahid et al., 1999; Bayuelo-Jiménez et al., 2003; Ewe and da Silveira Lobo Sternberg, 2005; Shi and Sheng, 2005; Saied et al., 2005). These studies have been conducted on several species, including arboreal and native species,

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and are very often restricted to a short growing season. Given the lack of experimental results from targeted studies on the tolerance of the Tendral melon cultivar to salinity, an agronomic open field trial was carried out in a Mediterranean environment. In the companion paper Tedeschi et al. (2011) documented the effects of irrigation with saline–sodic waters at different concentrations on the response of the total and marketable yield in melon. The fruit quality parameters that were investigated included flesh hardness, sugar content and fruit preservability. In the previous study, the tolerance of the melon to salinity was also evaluated by using the Maas–Hoffman model.

The aim of the present study was to evaluate the effects of irrigation with saline–sodic water on the entire plant growth cycle. Growth analysis was used to identify the changes in the parameters that were direct responses to salinity; special attention was given to shoot dry matter, leaf expansion, water use and the likely mutual relationships among them.

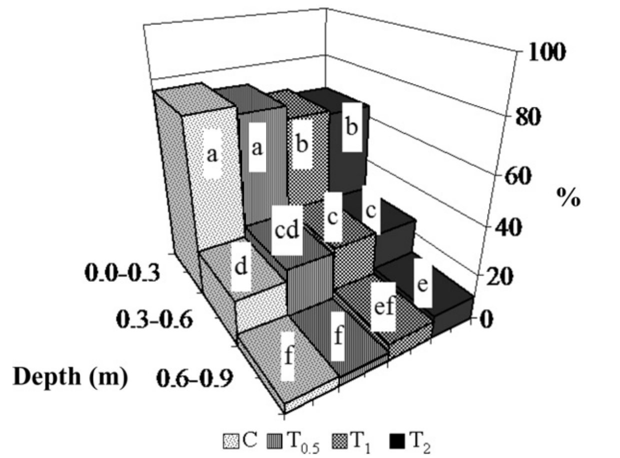

Fig. 1. Water consumed at three depths (0.0–0.3, 0.3–0.6 and 0.6–0.9 m) expressed as % of the total water consumed in each treatment. Interaction saline treatments (C = well water, $T_{0.5}$ = water at 0.5% of NaCl, T_1 = water at 1% of NaCl, T_2 = water at 2% of NaCl) × depth. Values followed by different letters are significantly different at $P \le 0.05$.

2. Materials and methods

The study was carried out at an experimental farm in Vitulazio (southern Italy). A full description of the site conditions, experimental protocol, crop and irrigation information can be found in the companion paper Tedeschi et al. (2011). For all the interval of the crop cycle reported in Table 2 of Tedeschi et al. (2011) ET_0 was calculated according to the Hargreaves and Samani equation (1985). This equation is particularly suited to the Volturno river plain and more generally to southern Italy, provided it is used for intervals which are not too short (15 days or more) (Ravelli and Rota, 1994; Ravelli, 2009). Observations collected during the trial relate to six periods: 17, 14, 14, 14, 14, and 8 days in length. The water balance, reported in Table 1, is determined using the vertical profiles of soil water content for the layers 0.0–0.3; 0.3–0.6 and 0.6–0.9 m. The crop evapotranspiration (ETc) of each period was divided by the number of days in each period and used to calculate the average daily ETc.

At transplanting and after each saline irrigation, the electrical conductivity (EC_e) in the saturated paste was determined according to Rhoades (1996) for the soil layers at depths of 0.0–0.3, 0.3–0.6 and 0.6–0.9 m. The EC_e and soil water content (averaged over the replicates) were used to calculate:

(1) the osmotic soil potential for each soil layer and date using the empiric equation given by Romano and Mecella (1982) and Saxton and Rawls (2006);

$$\psi_\omega = \frac{\theta_s}{\theta} \times ECe \times 0.036 \quad (1)$$

ψ_ω is the osmotic potential of the soil solution on the date considered in MPa; θ_s is the saturated soil moisture: % of the dry weight; θ is the soil moisture on the date considered: % of the dry weight; EC_e is the dS m^{-1} measured after each irrigation; and

(2) the matric potential of each soil layer and date, using the following equation;

$$\psi_m = 0.00083\theta^3 - 0.06716\theta^2 + 1.8109\theta - 16.308 \quad (2)$$

ψ_m is the matric potential in MPa; θ = see [Eq. (1)]

Eq. (2) (R^2 = 0.9227) is the water retention curve of the experimental site as determined in the spring of 2004. The equation is valid for the potential range between −0.01 and −1.5 MPa.

Since there is experimental evidence that plants will extract additional soil water from the less-stressed portions of the root zone to compensate for reduced root water uptake in the stressed root zone regions (Letey et al., 2011), we decided to use the EC_e values to estimate the EC_e^d, that is the weighted average of the observed EC_e for each soil layer with weights equal to water uptake in each layer. Moreover, ψ_ω^d and ψ_m^d (weighted mean osmotic and matric potential) were calculated in the same manner. We believe that a weighted average considering the water uptake from each layer was more accurate than a simple linear average.

Using four plants per plot and replicate, according to a previously determined schedule (see Tedeschi et al., 2011), the shoot dry weight, W (stems + leaves + fruit) and leaf area, LA, were determined. The average of the four plants was then used to determine the indexes reported in Table 2 according to equations found in the literature (Williams et al., 1965; Cooper, 1966; Radford, 1967; Snyder, 1974; Causton and Venus, 1981; Hunt, 1982). By measuring the cumulative shoot dry weight (W g m^{-2}) against the crop cumulative evapotranspiration (ETc, kg m^{-2}) used to produce W, we estimated the biomass-water use efficiency described by Steduto (1996), hereafter referred to as WUE.

All of the data obtained were analysed using ANOVA and the mean values of all variables were compared using Tukey's multiple range test.

3. Results

3.1. Root water uptake and total water potential

Low percolation (estimated from the data in Table 1) was due to the determination of water volume on the basis of observed soil water content prior to each irrigation, using drip irrigation (Tedeschi et al., 2011), and to careful control of the applied volumes. Five small rainfall events (1.8, 7.4, 2.8, 2.6 and 5 mm) occurred during the crop season. Table 1 shows how the change in soil water content and irrigation water retained over several treatments contributed to the plant water requirements. As regards the relative consumption of each soil layer (Fig. 1), considering the total crop evapotranspiration (ETc) for the soil profile (0.0–0.9 m) of each treatment, the results show that the plants took up water throughout the soil profile in different quantities in relation to the saline concentration of the irrigation water (ECw). Increased salinity resulted in a gradual but significant relative reduction in the water consumption from the soil surface layer (0.0–0.3 m), while water consumption increased in the deepest layer. The highest soil