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Evapotranspiration, crop coefficient and growth of two young pomegranate (*Punica granatum* L.) varieties under salt stress

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Pomegranate (*Punica granatum* L.) is a drought-hardy crop, suited to arid and semi-arid regions, where the use of marginal water for agriculture is on the rise. The use of saline water in irrigation affects various biochemical processes. For a number of crops, yields have been shown to decrease linearly with evapotranspiration (ET) when grown in salt-stressed environments. In the case of pomegranate, little research has been conducted regarding the effect of salt stress. Our study focused on the responses of ET, crop coefficient (K_c) and growth in pomegranate irrigated with saline water. Experiments were conducted using lysimeters with two varieties of pomegranate, *P. granatum* L. vars. Wonderful and SP-2. The plants were grown with irrigation water having an electrical conductivity (EC_{iw}) of 0.8, 1.4, 3.3, 4.8 and 8 dS m^{-1}. Plants were irrigated with 120% of average lysimeter-measured ET. Seasonal variation in ET, crop coefficient (K_c) and growth were recorded. Variation in daily ET was observed 1 month after initiation of the treatments. While significant seasonal ET variation was observed for the EC-0.8 treatment, it remained more stable for the EC-8 treatment. Salinity treatment had a significant effect on both daily ET ($F = 131$, $p < 0.01$) and total ET ($F = 112.68$, $p = 0.001$). Furthermore, the electrical conductivity of the drainage water (EC_{dw}) in the EC-8 treatment was five times higher than that of the EC-0.8 treatment in the peak season. Fitting the relative ET (ET_r) to the Maas and Hoffman salinity yield response function showed a 10% decrease in ET per unit increase in electrical conductivity of the saturated paste extract (EC_e) with a threshold of 1 dS m^{-1}. If these parameters hold true in the case of mature pomegranate trees, the pomegranate should be listed as a moderately sensitive crop rather than a moderately tolerant one. Fitting 30-day interval ET_r data to the Maas and Hoffman salinity yield response function showed a reduction in the slope as the season progressed. Thus using a constant slope in various models is questionable when studying crop–salinity interactions. In addition, both of the varieties showed similar responses under salt stress. Moreover, the calculated value of K_c is applicable for irrigation scheduling in young pomegranate orchards using irrigation water with various salinities.

1. Introduction

Plant water demand is described in terms of evapotranspiration (ET), which combines two important phenomena occurring simultaneously in the cropped field: evaporation and transpiration. The ET measured with lysimeter and the potential evaporative demand (E_o) measured with class ‘A’ pan evaporation are useful for estimating the crop coefficient (K_c) and scheduling irrigation. Generally, K_c is estimated as the ratio of ET to E_o, but several other approaches have also been used. ET and K_c are affected by climate, crop type and crop physiological stage (Allen et al., 1998).

As the amount of water used by plants for metabolic processes is insignificant (less than 1%), the term ET is synonymous with consumptive use (C_u) (Michael, 2006). Seasonal C_u values are useful in scheduling irrigation, and are obtained by summing the daily ET values in a cropped field throughout an entire season. Peak period C_u is particularly useful for irrigation system design, as ET, K_c and C_u are also affected by crop type, plant growth stage and weather conditions (Michael, 2006). Peak period C_u is obtained from the average of daily water use during the days of highest C_u. With the same crop type and weather conditions, the major factor affecting C_u is crop growth and development.

In the case of deciduous crops such as grapevine, the days after bud burst (DAB) play a major role in seasonal changes in ET (Shani and Ben-Gal, 2005). Towards winter, deciduous plants shed leaves and transpiration decreases to zero. However there is still some evaporation from the soil surface. This is why immediately after

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bud burst, less water is used as transpiration but in the peak season, more water is used. Netzer et al. (2009) showed a 1.46- and 3.82-fold increase in evaporation and ET, respectively, in a vineyard in the peak season relative to immediately after bud burst. ET is highly correlated to leaf area expansion (Graham et al., 2009), with leaf area increasing asymptotically with DAB. A typical hemispherical curve of leaf area index (LAI) versus DAB for apple trees shows a LAI of 0.1, 3.2 and 0.1 $m^2\ m^{-2}$ after bud burst, in the late summer and at the leaf-fall stage, respectively (Gong et al., 2007). Similarly, a rapid increase in LAI from 0.54 to 4.8 $m^2\ m^{-2}$ is evident in the vineyard from bud burst to peak season (Netzer et al., 2009). In the case of date palm, the relative ET and relative plant vegetative cover are significantly correlated (Tripler et al., 2007). At some point during the peak season, ET begins to decline. This occurs when the plant reaches its highest C_u and switches from vegetative to reproductive growth.

Incorporation of saline water in irrigation causes a reduction in transpiration (Dudley et al., 2008a), which subsequently results in reduced ET. Linear reductions in ET have been shown for several crops with varying irrigation-water electrical conductivities (EC_{iw}), including corn (*Zea mays* L.), alfalfa (*Medicago sativa* L.), melon (*Cucumis melo* L.) (Shani and Dudley, 2001; Skaggs et al., 2006), tomato (*Lycopersicon esculentum* Mill.) (Ben-Gal et al., 2003; Shani et al., 2007), grapevine (*Vitis vinifera* L.) (Shani and Ben-Gal, 2005; Shani et al., 2007), tall wheat grass [*Agropyron elongatum* (Host) P. Beauv.] (Skaggs et al., 2006), date palm (*Phoenix dactylifera* L.) (Tripler et al., 2007), onion (*Allium cepa* L.), bell pepper (*Capsicum annum* L.) and sunflower (*Helianthus annus* L.) (Shani et al., 2007; Ben-Gal et al., 2008). A good correlation between relative yield and relative ET was observed with the aforementioned crops under varying levels of EC_{iw}. In the case of cucumber, a 4.6% reduction in ET per unit increase of EC_{iw} was observed by Blanco and Folegatti (2003). Assouline et al. (2006) observed a reduction in leaf area at a electrical conductivity of 4.2 $dS\ m^{-1}$ versus 1.8 $dS\ m^{-1}$ in bell pepper, and an approximate 60% reduction in leaf area was observed upon irrigation with 171 mM NaCl versus non-salinized treatment in tomato (Maggio et al., 2004). Likewise, an approximate 86% reduction in leaf area was recorded in both Serena and Seredo varieties of sorghum at 250 mM versus 0 mM NaCl (Netondo et al., 2004). Skaggs et al. (2006) concluded that the reduction in canopy cover under high-saline treatment causes the decline in ET in alfalfa and tall wheat grass. Along with reductions in leaf area, simultaneous reductions in leaf turgor pressure were observed upon irrigation with 171 mM NaCl versus non-salinized treatment in tomato (Maggio et al., 2004).

In addition to leaf area, ET reduction under increasing EC_{iw} affects various root properties and growth environment, such as root turgor pressure, root density and root-zone salinity. Both root turgor pressure and root densities were observed to decline in tomato irrigated with 171 mM NaCl versus non-salinized treatment (Maggio et al., 2004). The EC of drainage water leaving the root zone (EC_{dw}) was 1.5–2 times higher than the EC_{iw} given at 9 $dS\ m^{-1}$ (Ben-Gal et al., 2008). Similarly, significantly higher EC_{dw} was recorded under varying EC_{iw} of 8, 18 and 28 $dS\ m^{-1}$ versus 2.5 $dS\ m^{-1}$ in the case of alfalfa and tall wheat grass (Skaggs et al., 2006). Plant roots act like a desalination factory, almost entirely avoiding the uptake of salts from the soil solution. Successive accumulation of salts in the soil leads to increasing EC_{dw} and a reduction in the osmotic potential of the soil solution (π). A reduction of π has been observed to decrease the relative yield of corn, bean and grapevine under varying EC_{iw} (Ben-Gal et al., 2009). The reduction in π reduces the symplastic pathway for water uptake by plant roots, which is driven by osmosis-induced flow (Hopmans and Bristow, 2002); conversely, the apoplastic pathway, which is driven by the matric potential gradient, should not be affected under salt stress, although this conclusion remains ambiguous. Favorable root-zone salinity can be maintained by using a suitable leaching fraction (LF) under varying EC_{iw} levels (Dudley et al., 2008a). The LF adjusts the balance between soil solution salinity and EC_{iw} by changing the amount of water percolating down from the root zone under a given EC_{iw} (Beltran, 1999). Since drainage water is not only a waste product but also a potentially valuable resource, its successful handling in irrigation can be achieved by low-flow with high-frequency irrigation along with LF adjustments (Dudley et al., 2008b).

Pomegranate (*Punica granatum* L.) is one of the oldest known edible fruits, among the seven kinds of fruit mentioned in the Bible (Blumenfeld et al., 2000). It is native to Iran and grown extensively in arid and semi-arid regions worldwide (Sarkhosh et al., 2006). Regarding the floral biology of pomegranate, Holland et al. (2009) reviewed three types of flowers: male (bell-shaped), bisexual (vase-shaped), and an intermediate type that has a short style and developed ovary which is sometimes fertile. Flowering in pomegranate occurs in three waves, and lasts for 1 month. The ratio of vase- to bell-shaped flowers determines the fruit's yield potential, and a possible reduction in this ratio is expected with increasing EC_{iw}. Pomegranate is also important in human medicine, and its components have a wide range of clinical applications (Lansky and Newman, 2007). The anthocyanins from pomegranate fruit have been shown to have higher antioxidant activity than vitamin E (α-tocopherol), vitamin C (ascorbic acid) or β-carotene (Shukla et al., 2008). Moreover, commercial pomegranate juice has been shown to have three times the antioxidant activity of green tea and red wine (Gil et al., 2000). Nevertheless, few studies have been conducted on the ET, K_c and growth of pomegranate in response to varying EC_{iw}. Pomegranate is considered to be moderately tolerant to salinity (Maas, 1993; Allen et al., 1998): cuttings from pomegranate var. Malas Shirin showed tolerance to up to 40 mM NaCl in potted cultures of 1:1 sand–perlite medium irrigated with complete Hoagland's solution. However, the performance of other pomegranate varieties, such as Alak Torsh and Malas Torsh, in the presence of salinity showed a decline from 0 mM NaCl, as indicated by number of internodes, length of main stem, length of internodes and leaf surface area (Naeini et al., 2006). Moreover, in a similar experiment with the same three pomegranate varieties, over the course of an 80-day experimental period, irrigation with concentrations of 0, 40, 80 and 120 mM NaCl resulted in increased Na, Cl and K concentrations and decreased Ca, Mg and N concentrations in the plant tissues. The amounts of soluble sugars in the plant tissues were observed to decrease with increasing NaCl concentrations (Naeini et al., 2004). In contrast, the total soluble sugar (TSS) content in melon was observed higher at EC_{iw} of 7 $dS\ m^{-1}$ (Bustan et al., 2005) and 6.1 $dS\ m^{-1}$ (Botia et al., 2005) than non-salinized treatment. Similarly, juice sugar and acid content in citrus was higher at EC_{iw} of 2.5 $dS\ m^{-1}$ versus 0.44 $dS\ m^{-1}$ (Grieve et al., 2007). Increased acids, soluble solids and sugar content have also been observed in tomato irrigated with saline water (Maggio et al., 2004). Therefore, it is possible that the use of saline water for irrigation can improve pomegranate fruit qualities such as acidity, sugar content, TSS, antioxidant value and medicinal properties. The possibility of obtaining an increase in overall fruit quality when irrigating pomegranate with saline water is of prime importance, especially with the increasing concern over sustainable management of the soil–plant–atmosphere continuum. Here, an effort was made to study the response of perennial and deciduous fruit tree, using pomegranate as a model, to varying levels of EC_{iw}. Hence, the objective of this study was to investigate the response of ET, crop coefficient and growth of young pomegranates to stress caused by irrigating with saline water.

2. Materials and methods

The plant-response study was conducted on pomegranate plants provided with increasing levels of salt in the irrigation water. Experiments were conducted using lysimeters situated at the Jacob Blaustein Institutes for Desert Research, Sede Boqer Campus, the Ben-Gurion University of the Negev, Israel. Fifty 0.2-m^3 lysimeters were filled with Sede Boqer loess soil. Single rooted cutting, prepared from two different pomegranate varieties (Wonderful and SP-2), was transplanted into each lysimeter in February 2007. The total area surrounding each plant was 3 m × 2.25 m. Water application was automated and drainage water collected manually. Each lysimeter had a highly conductive drain filled with rock wool to control the matric potential at the lysimeter bottom. A detailed description of the lysimeter system is given in Ben-Gal and Shani (2002a). The salinity of the irrigation water was brought to electrical conductivity (EC_{iw}) of 0.8 ± 0.14, 1.4 ± 0.17, 3.3 ± 0.3, 4.8 ± 1.1 and $8 \pm 1.5\,dS\,m^{-1}$ by adding NaCl, $CaCl_2$ and fertilizers. The two salts (NaCl and $CaCl_2$) were added proportionally to have an equivalent effect on solution electrical conductivity. Hereafter, these treatments are denoted EC-0.8, EC-1.4, EC-3.3, EC-4.8 and EC-8, respectively. Fertilizers (polyfeed water-soluble NPK fertilizers 14:7:28 + 1% MgO with micronutrient combination, manufactured by Haifa Chemicals, Israel) were applied with the irrigation water at a constant concentration of $0.5\,kg\,m^{-3}$. Calcium in the EC-0.8 treatment water was supplemented by the addition of $0.12\,kg\,m^{-3}$ $CaNO_3$ with $0.4\,kg\,m^{-3}$ fertilizer mix. Ten plants, five of each variety, received each salinity treatment. Salinity treatments were begun in a 1-year-old orchard in March 2008. Volcanic tuff mulch was applied on the surface of the soil to minimize evaporative losses.

Weekly water balance, generating ET (mm) data for each lysimeter, was calculated based on

$$ET = I - Dr + \Delta\theta D \tag{1}$$

where I is the irrigation (mm), Dr is the drainage (mm) and $\Delta\theta$ is the change in stored root-zone water to a root-zone depth of D (mm). Plants were irrigated with 120 ± 5% of their average back-day measured ET. Irrigation frequency varied from 1 to 5 times per day from DAB to peak season. EC_{iw} and drainage-water electrical conductivity (EC_{dw}) were recorded weekly using a EC meter (Crison Instruments S.A., Barcelona, Spain). Trunk circumference was measured near the crown-root junction with a thread and ruler. Trunk cross-sectional area (TCSA) was computed from the measured trunk circumference in November 2008, assuming a cylindrical shape. The ratio of ET to class 'A' pan evaporation (E_o) data provided the crop coefficient (K_c) values. Pan evaporation data were obtained from an adjacent meteorological station on the Sede Boqer campus.

Relative ET ($ET_r = ET/ET_p$) data were fitted to the yield reduction model as proposed by Maas and Hoffman (1977) and Maas (1990) to calculate threshold and slope:

$$\frac{ET}{ET_p}\ (\%) = \begin{cases} 100 & EC_e \le A \\ 100 - B(EC_e - A) & EC_e > A \end{cases} \tag{2}$$

where EC_e ($dS\,m^{-1}$) is the electrical conductivity of the saturated paste extract, A ($dS\,m^{-1}$) is the threshold electrical conductivity, B ($\%\,m\,dS^{-1}$) is the slope parameter and ET_p is the potential ET (mm). Seasonal changes in slope were calculated by best fitting between each ET_r measured at 30-day intervals and calculated Maas and Hoffman ET_r. The optimization was performed using the least-squares method with three different arbitrarily chosen threshold values (0.5, 1 and $1.5\,dS\,m^{-1}$). Similarly, the average slope of the accumulated seasonal data was calculated by best fit between the measured total ET_r and the calculated total ET_r with a threshold of $1\,dS\,m^{-1}$.

Values of EC_e were computed using measured data of EC_{iw} and EC_{dw} based on Eq. 93 in Allen et al. (1998) and Eq. 3 in Ayers and Westcot (1985), as shown below in (3) and (4), respectively

$$EC_e = \frac{1 + LF}{LF}\frac{EC_{iw}}{5} \tag{3}$$

$$LF = \frac{EC_{iw}}{EC_{dw}} \tag{4}$$

where LF is the leaching fraction and EC_{dw} ($dS\,m^{-1}$) is the drainage-water EC.

Statistical analyses were performed with STATISTICA software (StatSoft, Inc., Tulsa, OK, USA). Multifactor ANOVAs were used to determine the effects of species and salinity treatment on ET and TCSA using a general linear model (GLM) procedure with a fixed effect of species and random effect of salinity treatment. The end-of-season differences in the mean total ET among the various treatments were separated using post hoc Tukey HSD test (STATISTICA software). Repeated ET measurements were analyzed using a repeated measure ANOVA by a mixed-model procedure with species and time as fixed effects and salinity treatment as a random effect. A correlation between total ET and TCSA was determined by multiple regression model.

3. Results and discussion

Daily ET measurements for 'Wonderful' and 'SP-2' are shown in Fig. 1A and B, respectively. For the first month following treatment initiation, ET was nearly identical for all plants. Gradually, variations in daily ET were noted. As measured in var. Wonderful, the daily ET of the plants irrigated with the highest salinity water (EC-8) changed from 0.2 to $2.1\,mm\,day^{-1}$, while the daily ET of plants receiving the lowest salinity treatment (EC-0.8) changed from 0.23 to $5\,mm\,day^{-1}$ from bud burst to peak season, respectively; similar data were measured for 'SP-2' plants. For comparison, the daily measured ET values for citrus range from 1.3

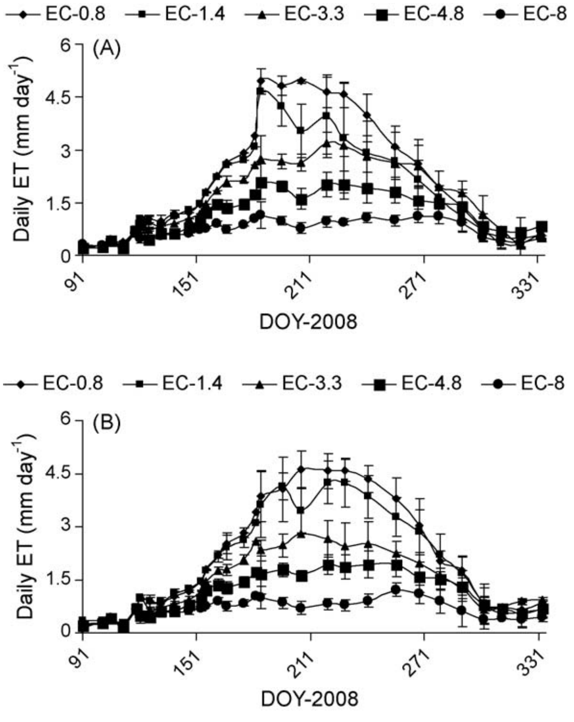

Fig. 1. Means ± SD of temporal fluctuation in daily ET ($mm\,day^{-1}$) throughout the year under various irrigation-water electrical conductivities (EC_{iw}) for 'Wonderful' (A) and 'SP-2' (B).

Table 1
Source of variation, related *F*-ratios and *p*-values calculated from STATISTICA software for the monthly ET (L), total ET (L) and trunk cross-sectional area (TCSA) (cm^2).

Repeated measures ANOVA for monthly ET (L)				GLM ANOVA for total ET (L)				GLM ANOVA for TCSA (cm^2)			
Source of variation	DF	*F*-Value	*P*-Value	Source of variation	DF	*F*-Ratio	*P*-Value	Source of variation	DF	*F*-Ratio	*P*-Value
EC ($dS\,m^{-1}$)	4	131.82	0.001**	EC ($dS\,m^{-1}$)	4	112.78	0.001**	EC ($dS\,m^{-1}$)	4	4.93	0.076
Variety	1	0.00	0.98	Variety	1	0.55	0.46	Variety	1	0.21	0.65
Months	8	1052.11	0.001**	EC ($dS\,m^{-1}$) × variety	4	1.51	0.22	EC ($dS\,m^{-1}$) × variety	4	1.75	0.16
Months × EC ($dS\,m^{-1}$)	32	68.79	0.001**								
Months × variety	8	2.52	0.012*								
EC ($dS\,m^{-1}$) × variety	4	2.04	0.11								
Months × EC ($dS\,m^{-1}$) × variety	32	2.62	0.001**								

* Values are significant at 5%.
** Values are significant at 1%.

to 5 mm day^{-1} in Sao Paulo, Brazil (Alves et al., 2007), and for grapevine from 2.7 to 4.3 mm day^{-1} in the semi-arid environment of northeastern Brazil (Azevedo et al., 2008). The daily ET demand for apple trees in northwest China ranges from 2.25 to 6.53 mm day^{-1} (Gong et al., 2007). Similarly, daily ET of 3.47–6.65 mm day^{-1} and 3.33–4.02 mm day^{-1} was measured in Pisa, Italy for willow and poplar, respectively (Guidi et al., 2008). In pecan, daily ET changed from 0.55 to 8.4 mm day^{-1} in Las Cruces, New Mexico (Wang et al., 2007), and a daily ET of 1.72–6.56 mm day^{-1} was recorded in a vineyard located in southern Israel (Netzer et al., 2009). Nonetheless, reduction in daily ET under varying EC_{iw} levels has only been reported sporadically for fruit trees. In our experiment, the daily ET of the EC-8 plant was shown to be half that of the EC-0.8 plant, a phenomenon which can be both beneficial and harmful. During the experimental period, E_o changed from 3.06 to 9.16 mm day^{-1}. The ET values measured under all treatments were lower than E_o throughout the entire experimental period, possibly due to the plants' age. However, the ET during peak season in the EC-0.8 and EC-8 treatments was greater by a factor of 22 and 11, respectively, than the ET measured immediately after bud burst. Analyzing the monthly ET data using repeated measures ANOVA for 9 months (March–November) showed that the single effects of months ($F = 1052$, $p < 0.01$) and treatment ($F = 131$, $p < 0.01$) are highly significant but that of variety ($F = 0$, $p = 0.98$) is not (Table 1). Similarly, the interactive effects between months and treatment ($F = 68$, $p < 0.01$), months and variety ($F = 2.5$, $p = 0.01$) and months, treatment and variety ($F = 2.64$, $p < 0.01$) were highly significant, but the interaction between treatment and variety ($F = 2.04$, $p = 0.11$) was not (Table 1). Performance of the two varieties of pomegranate was similar under existing environmental conditions for all EC_{iw}. Moreover, the daily ET for all treatments (Fig. 1) was dependent on the daily fluctuations in environmental conditions but the amplitude of the fluctuation decreased dynamically with DAB and EC_{iw} levels.

Evolution of cumulative ET (ET_{cum}) for 'Wonderful' and 'SP-2' is shown in Fig. 2A and B, respectively, by aggregating their respective daily ET values (Fig. 1A and B). The cumulative E_o is also shown in Fig. 2A and B. From DAB to peak season, ET_{cum} increased at an escalating rate, and from peak season to leaf-fall stage, its rate of increase dropped. The stepwise change in amplitude of the ET_{cum} curve with increasing EC_{iw} was similar for 'Wonderful' and 'SP-2'. The shape of the ET_{cum} curve was sigmoidal over time, like the cumulative E_o curve. The convexity of the ET_{cum} curve is due to increasing values of ET from March to August, and its concavity is due to decreasing values of ET from September to November. The total ET demand for 'Wonderful' was 544, 461, 420, 302 and 186 mm $year^{-1}$, and for 'SP-2', 557, 516, 376, 294 and 171 mm $year^{-1}$ for treatments EC-0.8, EC-1.4, EC-3.3, EC-4.8 and EC-8, respectively. By comparison, in pistachio, changes in ET from 1024 to 784 mm $year^{-1}$ were observed with a change in irrigation from full to deficit conditions (Iniesta et al., 2008). Over 6 years of experimentation in grapevine, the maximum seasonal ET varied from 1087 to 1348 mm $year^{-1}$ (Netzer et al., 2009). In our experiment, the cumulative ET measured in the EC-0.8 treatment was approximately three times lower than the cumulative E_o (1521 mm $year^{-1}$). In other treatments, the rate of decrease in ET_{cum} versus E_o was higher than in the EC-0.8 treatment. The ET_{cum} of cotton grown under an irrigation threshold (IT) of 40% showed a curve similar to that of the cumulative E_o, but under an IT of 20%, the ET_{cum} curve was lower than that of E_o, and under an IT of 90%, the ET_{cum} was higher than the cumulative E_o curve (Suleiman et al., 2007). This means that the potential evaporative demand of the cotton plant decreases with decreasing water availability for plant growth and development. Similar reports of declining ET_{cum} versus cumulative E_o have been published for increasing irrigation-water salinity in a number of crops, such as corn, alfalfa, melon (Shani and

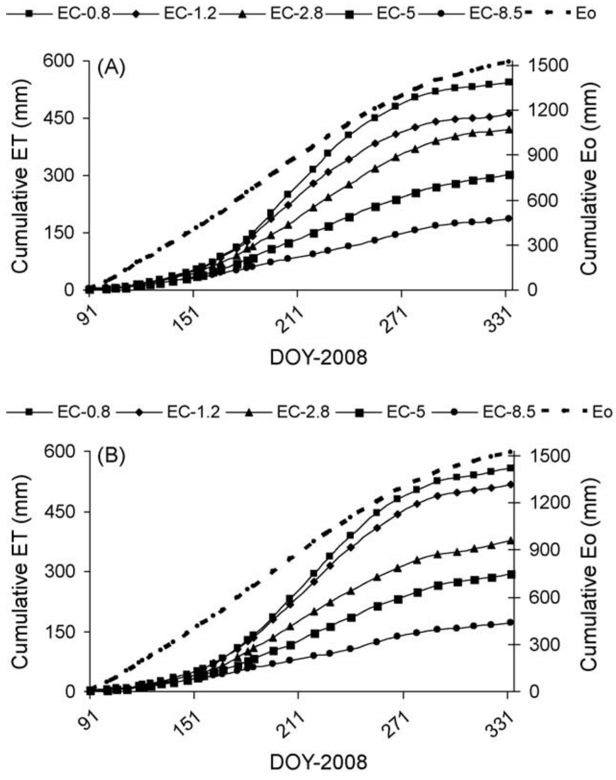

Fig. 2. Evolution of cumulative ET (mm) and cumulative class 'A' pan evaporation data (E_o) (mm) throughout the year under various irrigation-water electrical conductivities (EC_{iw}) for 'Wonderful' (A) and 'SP-2' (B).

Dudley, 2001; Skaggs et al., 2006), tomato (Ben-Gal et al., 2003; Shani et al., 2007), grapevine (Shani and Ben-Gal, 2005; Shani et al., 2007), tall wheat grass (Skaggs et al., 2006), date palm (Tripler et al., 2007), onion, bell pepper and sunflower (Shani et al., 2007; Ben-Gal et al., 2008). In agreement with the daily ET, ET_{cum} changed dynamically for each month after bud burst with increasing EC_{iw}. The total ET demand under freshwater-irrigated conditions for a 1-year-old pomegranate tree is around 550 mm year^{-1}, but this value decreases significantly with increasing irrigation-water salinity. Generally, there are practices of using more water under saline than freshwater irrigation. However, the use of more water under saline-water irrigation may increase the LF even more than needed. Consequently, this increase of LF may enhance percolation of drainage into groundwater and cause a problem of secondary salinization (Beltran, 1999). In such a case, using low-flow or high-frequency irrigation could be advantageous (Dudley et al., 2008b).

Both total ET and TCSA decreased linearly with increasing level of EC_{iw} (Fig. 3A and B, respectively). The total amount of water required for a 'Wonderful' plant varied from 3671, 3116, 2838, 1974 and 1255 L year^{-1} under the EC-0.8, EC-1.4, EC-3.3, EC-4.8 and EC-8 treatments, respectively. The total water demand for 1 year in the EC-0.8 treatment was three times higher than that in the EC-8 treatment. A tentatively similar result was shown with var. SP-2. In agreement with the above results, Shani and Ben-Gal (2005) showed that seasonal demand of water in grapevine decreases with increasing concentrations of chloride in the irrigation water from 3.8 to 149 mM. Moreover, a similar phenomenon of declining seasonal water demand has been recorded in various crop species, such as tomato (Ben-Gal et al., 2003) and bell pepper (Ben-Gal et al., 2008). An identical trend of decreased size as a function of increased EC_{iw} was recorded for TCSA. The TCSA values were 40 and 25 cm^2 in EC-0.8 and EC-8 treatments, respectively, in var. Wonderful (Fig. 3B). In addition, TCSA increased linearly with increasing ET. Linear relationships between ET and biomass production have been previously reported in bell pepper (Ben-Gal et al., 2008), tomato (Ben-Gal et al., 2003), melon, corn, alfalfa (Shani and Dudley, 2001), and grapevine (Shani and Ben-Gal, 2005). The linear yield–ET relationship was found to hold true when boron salinity interactions were studied in tomato by Ben-Gal and Shani (2002b) and in date palm by Tripler et al. (2007). Analyzing the total ET data by GLM ANOVA showed that salinity treatment has a significant effect on total ET (F = 112.68, p = 0.001) (Table 1). However, neither the interactive effect between salinity treatment and variety (F = 1.51, p = 0.22) nor the single effect of variety (F = 0.55, p = 0.46) were significant (Table 1). Accordingly, the two varieties followed the same trend for total ET under the Sede Boqer campus climatic conditions with varying EC_{iw}. Moreover, a comparison of the means of total ET among the various treatments by post hoc Tukey HSD test showed that EC-0.8 and EC-1.4 do not differ significantly from each other, but that all other treatment levels – EC-3.3, EC-4.8 and EC-8 – differ significantly from one another and from the EC-0.8 and EC-1.4 treatments. The use of desalinated water (EC-0.8) versus tap water (EC-1.4) in pomegranate irrigation has been shown to be statistically meaningless for a 1-year-old tree. Similarly, using the same procedure to analyze the TCSA data, neither the single effects of variety (F = 0.21, p = 0.65) or salinity treatment (F = 4.93, p = 0.076), nor the interaction between salinity treatment and variety (F = 1.75, p = 0.16) were significant (Table 1). In our experiment, a weak but significant correlation between TCSA and total ET was discovered by using the multiple regression model of the STATISTICA software and can be described by TCSA (cm^2) = 0.0062 total ET (L) + 15.51 with R^2 = 0.40, F(1,48) = 31.15, p = 0.0001 (figure not shown). This result is probably due to the younger age of the plant; several years of experimentation with fruit trees might produce a better correlation. Summarizing the results presented in Figs. 1, 2 and 3, ET and growth showed a pronounced decrease with increasing EC_{iw}, due to reduced π (Ben-Gal et al., 2009). As already mentioned, the reduction in π reduces the symplastic pathway for root water uptake in plants driven by osmosis-induced flow (Hopmans and Bristow, 2002). Root water uptake is driven mainly by soil matric and osmotic potentials, which independently control the apoplastic and symplastic pathways, respectively. As the root is the only source for water, nutrients and minerals, more research into the root's water-uptake mechanism would serve to advance such studies. We believe that research into ways of combining drought and salinity stresses should focus on means of combining symplastic and apoplastic pathways for root water uptake, rather than on above-ground reductions in growth, biomass and yield.

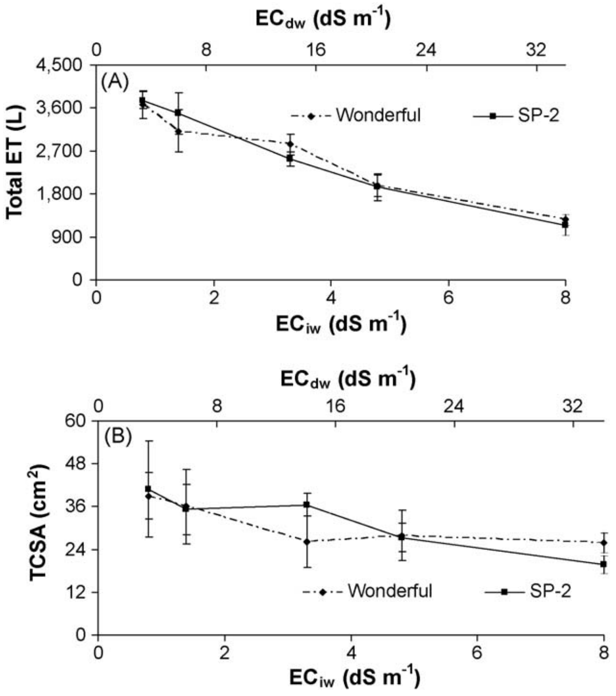

Fig. 3. (A) Means ± SD of total ET for 1 year (L), and (B) Means ± SD of trunk cross-sectional area (TCSA) (cm^2) under various irrigation-water electrical conductivities (EC_{iw}) and drainage-water electrical conductivities (EC_{dw}) for 'Wonderful' (A) and 'SP-2' (B).

The EC_{dw} from the EC-8 treatment was significantly higher than that from the EC-0.8 treatment throughout the year for both 'Wonderful' (Fig. 4A) and 'SP-2' (Fig. 4B). EC_{dw} from the EC-8 treatment increased from March to August and decreased from September to November. In contrast, EC_{dw} from the EC-0.8 treatment decreased with treatment initiation and then remained constant for the rest of the year. Variations in EC_{dw} values as a function of treatment were observed 2 weeks after treatment initiation. Salt accumulated in the soil as the trees selectively took up water, as reflected by the increased EC_{dw}, which was generally found to be four times higher than EC_{iw} and continued to fluctuate with the seasons. In an experiment with bell pepper, a 1.5- to 2-fold higher EC_{dw} than EC_{iw} was recorded at an EC_{iw} of 9 dS m^{-1} (Ben-Gal et al., 2008). In another experiment, Skaggs et al. (2006) showed 1.5 times higher EC_{dw} than EC_{iw} at EC_{iw} of 8, 18 and 28 dS m^{-1}. Here, during the peak season, more than five times higher EC_{dw} than EC_{iw} values were recorded in the EC-8 treatment for both varieties. At times, sudden increases in the plant's ET demand (due to highly fluctuating weather conditions) negated our assumption of a constant LF of 0.2. In this case, EC_{dw} jumped to

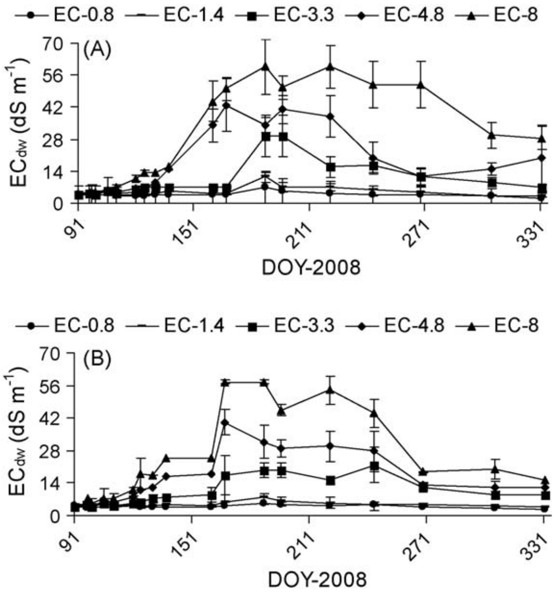

Fig. 4. Means ± SD of temporal fluctuation in drainage-water electrical conductivities (EC$_{dw}$) throughout the year under various irrigation-water electrical conductivities (EC$_{iw}$) for 'Wonderful' (A) and 'SP-2' (B).

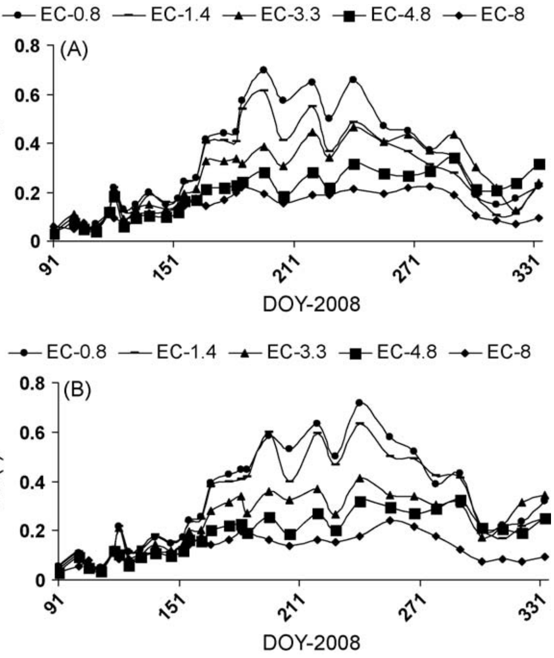

Fig. 5. Temporal fluctuation in the crop coefficient (K_c) throughout the year under various irrigation-water electrical conductivities (EC$_{iw}$) for 'Wonderful' (A) and 'SP-2' (B).

very high levels and disturbed the steady-state condition of the ratio between irrigation-to-drainage amounts as well as the ratio of EC$_{dw}$ to EC$_{iw}$, as suggested by Shani et al. (2007). Monitoring the interplay between EC$_{iw}$ and LF is therefore highly recommended when irrigating plants with saline water.

Calculated K_c values for 'Wonderful' and 'SP-2' are shown in Fig. 5A and B, respectively. These values are also presented in Table 2 relative to DAB. K_c values calculated from the experimental data varied from 0.03 to 0.64 in the EC-0.8 treatment and from 0.03 to 0.21 in the EC-8 treatment in the case of 'Wonderful' (Fig. 5A and Table 2). Calculated K_c was higher for EC-0.8 than EC-8-treated plants throughout the year. Similarly, a successive decline in K_c values was recorded in cucumber under EC$_{iw}$ 1.5, 3.2 and 5.1 dS m^{-1}, respectively (Blanco and Folegatti, 2003). In pistachio, changing irrigation from full to deficit conditions decreased the K_c value from 1.15 to 0.8 (Iniesta et al., 2008). The yearly change in K_c value was recorded in citrus, from 0.57 in a 1-year-old plant to 1.12 in a 4-year-old plant (Alves et al., 2007). In the case of grapevine, K_c changed from 0.4 to 1.0 from bud burst to peak season under freshwater irrigation (Netzer et al., 2009). At ITs of 40, 60 and 90%, the K_c of cotton changed, respectively, from 0.51, 0.9 and 0.99 in the initial stage to 0.92, 1.2 and 1.2 in mid-season and to 0.1, 0.38 and 0.58 at the end of the season under freshwater irrigation (Suleiman et al., 2007). In our experiment, the K_c values followed the same trend as the daily ET for both varieties. K_c was affected mainly by type of crop, salinity, climate and plant growth stage. Lower K_c values represent slower plant growth and lower canopy cover, indicating lower ET. More or less the same K_c throughout the year indicates a small and stressed plant under high-saline irrigation. Pomegranate, a deciduous fruit tree, starts sprouting in the spring and sheds its leaves in the winter, and its K_c values therefore vary a great deal from one season to the next. A strong correlation between K_c and LAI has been observed ($R^2 = 0.89$) in apple (Gong et al., 2007), and a second-order polynomial curve between K_c and LAI ($R^2 = 0.90$) has been observed in grapevine (Netzer et al., 2009). A good correlation has also been found between the relative K_c ($K_c/K_{c\,max}$) and the effective canopy cover for various deciduous fruit crops (Wang et al., 2007).

Another possible method of inferring K_c values under stressed conditions is the FAO-56 crop coefficient procedure (Allen et al., 1998). In that approach, K_c under nonstressed conditions is reduced to a new K_c for any level of salinity stress. The FAO-56 crop coefficient procedure for estimating K_c was accurate under ITs of 40, 60 and 90% in cotton for three different phenological stages—initial, mid and end, under freshwater irrigation (Suleiman et al., 2007). To facilitate salinity-induced reduction in the FAO-56 crop coefficient procedure, Allen et al. (1998) used the crop-response model of Maas and Hoffman (1977) with constant values of B and A. One of the limitations of this approach is the assumption of a constant slope in the Maas and Hoffman model throughout the season. Calculated values of B for 30-day interval ET$_r$ data are shown in Fig. 6. This chart also shows the average B

Table 2
List of crop coefficients (K_c) under various irrigation electrical conductivities (EC$_{iw}$) with days after bud burst (DAB) for 'Wonderful' and 'SP-2'.

DAB	EC-0.8		EC-1.4		EC-3.3		EC-4.8		EC-8	
	Wonderful	SP-2	Wonderful	SP-2	Wonderful	SP-2	Wonderful	SP-2	Wonderful	SP-2
30	0.16	0.15	0.15	0.15	0.14	0.14	0.12	0.09	0.09	0.09
60	0.19	0.19	0.19	0.19	0.16	0.15	0.13	0.13	0.09	0.09
90	0.49	0.44	0.45	0.41	0.33	0.31	0.23	0.21	0.13	0.13
120	0.64	0.58	0.52	0.53	0.38	0.35	0.25	0.24	0.12	0.11
150	0.53	0.60	0.42	0.54	0.43	0.37	0.29	0.29	0.17	0.17
180	0.39	0.45	0.32	0.44	0.41	0.32	0.30	0.30	0.21	0.17
210	0.22	0.28	0.19	0.27	0.32	0.23	0.25	0.25	0.16	0.12
240	0.20	0.28	0.17	0.23	0.18	0.33	0.28	0.22	0.15	0.15

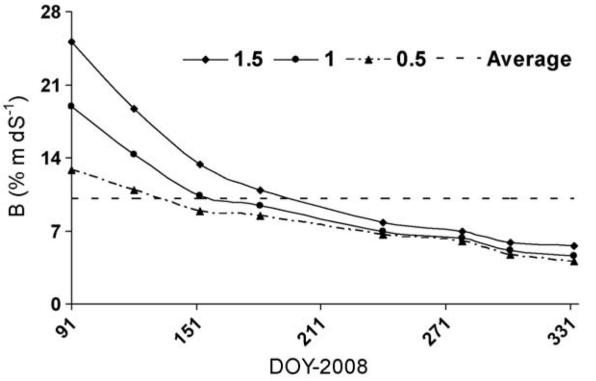

Fig. 6. Estimated seasonal variation in the slope (B) (% m dS^{-1}) from 30-day interval ET$_r$ data at three different threshold electrical conductivities (A) of 0.5, 1 and 1.5 dS m^{-1} and the average B for the year obtained from the total ET$_r$ data.

calculated from the total ET$_r$ data. The reduction in B during the experimental period could be due to increasing crop tolerance to salinity. Since the accuracy of the optimization of B is highly dependent in the early season on threshold A, we calculated B using $A = 0.5$, 1 and 1.5 dS m^{-1}. In all cases, there was a clear reduction in B over time. Thus, using a constant slope in various crop–salinity models is questionable. If irrigation is scheduled using the average slope, under-irrigation at the beginning of the season and over-irrigation late in the season may occur. Hence, while studying plant response to salinity, seasonal variation in the slope needs to be considered because the impact of salinity on ET and growth is a time-integrated, dynamic process. Nonetheless, $A = 1$ dS m^{-1} and $B = 10\%$ were computed with the total ET$_r$ data, a result similar to that found by Naeini et al. (2006) who measured leaf surface, length of internode, length of the main stem and number of internodes on the main stem in an experiment on 'Alak Torsh' and 'Malas Torsh' pomegranate cuttings (Naeini et al., 2006). If the threshold and slope values determined in this study hold true in the case of mature trees, the pomegranate should be listed as a moderately sensitive crop rather than a moderately tolerant one as in Maas (1993) and Allen et al. (1998).

4. Conclusions

Under saline-water irrigation, the daily ET of pomegranate is significantly lower than under freshwater irrigation. This is why due attention should be paid to delivering the correct amount of water for irrigation. As the ET of plants is highly influenced by prevailing weather conditions, judicious use of water for saline- and freshwater irrigation is possible using experimentally computed K_c values. Fitting the total ET$_r$ to the Maas and Hoffman yield salinity response function showed a 10% decrease in ET per unit increase in EC$_e$ with a threshold of 1 dS m^{-1}. If these parameters hold true in the case of mature trees, the pomegranate should be listed as a moderately sensitive crop rather than a moderately tolerant one. Fitting each 30-day ET$_r$ value to the Maas and Hoffman yield salinity response function resulted in a reduction in the slope as the season progressed. Thus, using a constant slope in various crop–salinity models is questionable. Moreover, an increase in root-zone salinity is the prime factor reducing plant ET and growth, as the measured EC$_{dw}$ in the EC-8 treatment was much higher than that in the EC-0.8 treatment. The two varieties followed the same trends for all of the data recorded during the experiment. While there was a reduction of ET during this study the antioxidant value could be increased. Thus, future study of the antioxidants ingredients of these varieties under salt stress should be examined using well-controlled water and solutes flux experimental system.

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