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REGULAR ARTICLE

Five-year growth and yield response of two young olive cultivars (*Olea europaea* L., cvs. Arbequina and Empeltre) to soil salinity

R. Aragüés · Mónica Guillén · A. Royo

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Abstract Olive is considered moderately tolerant to salinity, but most studies are short in duration and report its tolerance on the basis of targeted irrigation water salinity (ECiw) rather than on measured root zone soil salinity (ECe). We evaluated the growth (tree height and trunk diameter) and yield (fruit and oil weights) response of two drip-irrigated young olive cultivars (Arbequina and Empeltre) subject to three ECiw treatments (2, 4 and 10 dS m^{-1}). The ECe of 23 Arbequina and 20 Empeltre trees was intensively monitored during the 2003–2007 study period using an EM38 sensor and converting its readings into ECe through sensor calibration. For growth, the slopes of the linear regression equations (−3% to −5%) and the ECe_{50} estimates (12.5–14.0 dS m^{-1}) were similar in both cultivars and vegetative traits. Likewise, for yield the slopes of the linear regression equations (−4% to −7%) and the ECe_{50} estimates (7.9–9.6 dS m^{-1}) were similar in both cultivars and yield traits. Based on mean ECe_{50} estimates, olive vegetative growth was ranked as moderately tolerant (mean ECe_{50}=13.2 dS m^{-1}), whereas olive and oil yields were ranked as moderately sensitive (mean ECe_{50}=8.7 dS m^{-1}).

Keywords Salinity tolerance · Growth · Yield · Fruit characteristics

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Introduction

Irrigated olive orchards have expanded in the last decades in many areas of the world and in particular in the Mediterranean region, where 98% of the world's olive oil is produced. An increasing proportion of these orchards is being irrigated with low-quality waters due to the growing competition of freshwater by other users, population growth and climate change (Cimato et al. 2010; Chartzoulakis 2005).

Due to the expansion of olive orchards irrigated with saline waters, a proper knowledge of response of olive to salinity is essential. However, existing data on the effects of salinity on growth and yield of olive are scarce, especially for long-term experiments under field conditions (Aragüés et al. 2005; Cimato et al. 2010; Gucci and Tattini 1997; Melgar et al. 2009; Wiesman et al. 2004). Olive is considered moderately tolerant to salinity, with threshold ECe values (dS m^{-1}) that vary among authors: 4–6 (Bernstein 1964), 3–6 (Maas and Hoffman 1977), 1.2–2.5 (Hassan et al. 2000), 2.7 (Soltanpour and Follet 2001), and 4.0 (Aragüés et al. 2004). Based on the absolute slope of the response functions, Aragüés et al. (2004) provided a value of 12% for the growth of young Arbequina olive, whereas Hassan et al. (2000) reported values from 3.4% to 5.2% for fruit yield of three olive cultivars. These authors also concluded that vegetative growth was more tolerant to salinity than fruit yield production.

The response of olive to salinity varies with cultivar (Benlloch et al. 1994; Chartzoulakis 2005; Marín et al. 1995; Perica et al. 2008). Marín et al. (1995) studied the response of 26 olive cultivars by measuring the shoot length of rooted olive cuttings grown in a 100 mM NaCl solution. Forty-nine days after the initiation of the trial, the growth of the salt-treated plants ranged from 16 to 70% of the non-saline control. However, these results should be interpreted with caution because the use of pure NaCl solutions may result in ion toxicities, imbalances and nutritional disorders. Chartzoulakis (2005) classified 36 young olive cultivars as being tolerant (13 cultivars), moderately tolerant (12 cultivars) and sensitive (11 cultivars). Arbequina was classified as tolerant in both studies, whereas Empeltre was not reported. However, as pointed out by Chartzoulakis (2005) the tolerance of these young plants grown in pots for a limited period of time could be different from that obtained with adult plants grown under field conditions.

Based on the published information on the effects of salinity on growth and yield of olive, Chartzoulakis (2005) proposed the following guidelines for the salinity of irrigation water based on the degree of problem: None for EC<2.5 dS m^{-1}, increasing for EC 3–5 dS m^{-1}, and severe for EC>5.5 dS m^{-1}. However, these guidelines depend on olive cultivar, water management (i.e., leaching fraction) and climatic conditions (i.e., precipitation, potential ET, etc.). Thus, Melgar et al. (2009) reported that mature trees of the tolerant cultivar Picual drip-irrigated under Mediterranean climate (mean annual precipitation around 700 mm) allowed using high saline irrigation waters (up to 10 dS m^{-1}) for a long time (9 years) without affecting growth and yield. Winter leaching by rainfall of the salts accumulated in the root zone during the irrigation seasons was the main reason for the absence of negative effects with such high saline waters. This result clearly shows that the establishment of the salinity tolerance of olive (or any other crop) should be based on root zone soil salinity rather than irrigation water salinity.

The objective of this work was establishing the principles by which the response of olive to salinity should be evaluated. To this aim, the two most important olive cultivars in the Ebro Valley (Arbequina and Empeltre) were subject during 5 years to different irrigation water salinities using a high-frequency drip irrigation system, and the root zone soil salinity of each tree was monitored intensively in order to establish the soil salinity-growth and soil salinity-yield response functions of these olive cultivars.

Materials and methods

Field conditions, plant material and irrigation management

The study was conducted from 2002 to 2007 in a field with a sandy loam soil (average soil saturation percentage = 37%) located at the CITA experimental station (41° 44′ N latitude, 0°49′ W longitude, altitude 225 m) in the middle Ebro River Basin (NE Spain). The climate is semiarid Mediterranean continental, with average annual values of 330 mm (precipitation), 14.6°C (air temperature), and 1,230 mm (FAO Penman-Monteith reference evapotranspiration). For the study period, average annual values were 417 mm (precipitation) and 14.2°C (temperature)

One-year old olive cuttings of cvs. Arbequina and Empeltre were planted in spring 2002 with an intra-row distance of 2.5 m. and an inter-row distance of 5.5 m. A randomized block design was initially designed with two blocks (replications) and five saline treatments (EC irrigation water = 2, 4, 6, 8 and 10 dS m^{-1}). Each experimental plot consisted of four trees, and the field was bordered by a guard row.

Olive trees were irrigated during the April to October growing season with three drip lines, one located close to the trees and the other two at each side of the trees at a distance of 0.5 m. Each tree was irrigated by 6 emitters (4 L h^{-1} each) located at a distance of 0.35 m between them. With this system, a wetted surface higher than 1-m wide was created. This wetted area was appropriate to obtain consistent ECa readings with a Geonics EM38 electromagnetic sensor (Geonics Limited, ON, Canada).

Irrigations were given three times per week with high and similar volumes of water in all treatments to maintain high and constant soil water contents and to impose leaching fractions of around 50% or higher (non-saline treatment basis) in order to reach as quickly as possible the target soil salinity values in the root zone with a uniform soil salinity profile. The annual number of irrigations varied between 65 in 2003 and 59 in 2006, and the annual volumes of applied water varied between 3,100 L/tree in 2005 and 2,265 L/tree in 2007.

The trial was irrigated with freshwater during 2002 in order to obtain a good and uniform plant establishment. The differential saline treatments were initiated in spring 2003. In winter 2005 a serious, unusual and persistent frost (mean air temperatures below 0°C and minimum air temperatures close to −11°C for more than a week) damaged an important number of trees. All the trees were irrigated with freshwater during 2005 for recovering purposes. Since a substantial portion of the trees subjected to irrigation water salinities of 6 and 8 dS m^{-1} were still damaged at the end of the 2005 growing season, it was decided to eliminate these saline treatments from the trial. Thus, results are presented for the rest of healthy trees irrigated during 2003–2007 (except in 2005) with saline waters of 2 (treatment T2), 4 (treatment T4) and 10 (treatment T10) dS m^{-1}. The number of trees of each cultivar monitored in the trial was 24 (4 trees per experimental plot × 2 replications × 3 saline treatments). Since some trees died during the study period, the final number of trees per saline treatment was 8 in Arbequina T2 and T4, 7 in Arbequina T10 and Empeltre T2 and T4, and 6 in Empeltre T10.

Saline irrigation treatments were prepared by diluting a stock solution of 20 dS m^{-1} stored in a 6,000-L tank. This solution was made up by adding the appropriate amounts of NaCl and $CaCl_2$ salts to obtain concentrations about 200 mM (Cl^-), 80 mM (Na^+) and 60 mM (Ca^{2+}), and a sodium adsorption ratio of about 10 $mmol^{1/2}\ L^{-1/2}$. The T2 treatment was the regular irrigation water of the CITA experimental farm diverted from the Gállego River. T4 and T10 treatments were prepared by means of a Progress-6000 irrigation computer that diluted the stock solution with freshwater in the appropriate proportions. A water sample was taken in each irrigation event and salinity treatment for measuring its EC. The average EC ± standard deviation (dS m^{-1}) of each saline treatment for years 2003, 2004, 2006 and 2007 was: $T2 = 1.9 \pm 0.4$, $T4 = 4.1 \pm 0.8$, and $T10 = 8.8 \pm 2.8$. These values were close to the target EC values and relatively uniform during the study period. Year 2005 was not included in these averages because, as indicated before, freshwater was only applied in this year.

Soil salinity

The apparent soil electrical conductivity (ECa) was periodically measured in each monitored tree during the 2003–2007 growing seasons by placing a Geonics EM38 sensor on the ground close to the trunk in the horizontal dipole position. With this dipole configuration, the depth of exploration for a 70% sensor response is 0.75 m (Rhoades et al. 1999). The readings were taken weekly, 1 day after irrigation. Soil temperatures were also measured with a digital soil thermometer at 0.3 and 0.6-m depths to convert the ECa readings to a reference temperature of 25°C.

The sensor was calibrated against soil salinity by taking soil samples along the field at 0–0.6 m depth in points evenly distributed along the ECa intervals. Each sample was a composite of two sub-samples taken in the planting row at 0.25 m at both sides of each monitored tree. The number of points for calibration varied between 9 and 29, depending on dates. The number of dates for calibration was one in 2003 and 2007 and two in 2004, 2005 and 2006. The soil samples were air dried, ground and sieved (<2 mm), and the EC was measured in the 1:5 soil: water extract (EC_5). Based on the ECe (soil saturation extract)-EC_5 relationship previously obtained for this soil (ECe=12.5 EC_5; R^2=0.98; number of observations = 40), the EC_5 values were converted into ECe and the annual ECa-ECe calibrations were obtained. The annual mean ECe was estimated in each tree from the corresponding annual mean ECa readings and the annual ECa-ECe calibrations. The 2003–2007 mean ECe estimates were calculated from the individual annual means.

Vegetative growth, yield and fruit characteristics

The height of each monitored tree was measured at time of planting (May 2002) and at the end of the study period (December 2007). The trunk diameter, an easier and more precise measure than tree height, was measured several times during the growing periods of each year with a digital electronic caliper placed over a permanent-ink mark located at about 0.2 m above the soil surface. The olive's vegetative growth was obtained from the difference in tree height between the last and first measurements and from the difference in trunk diameter between measurements.

Yield (i.e. weight of fruits per tree) was measured annually at harvest (around November or December of each year) and a representative sample of 1 kg of fruits per treatment was taken to determine fruit characteristics. The weight of 20 fruits and its length and width were measured. After pitting the fruits, pulp weight, stone weight, stone length and width, and pulp:stone ratio were also measured. Fruits were ground in a 5-mm mesh mill and the oil was extracted by the Abencor system following Royo et al. (2005).

Data analysis

Data were subjected to analyses of variance (ANOVA) and regression analyses. Arbequina and Empeltre vegetative growth, yield and fruit characteristics measured in treatments T2, T4 and T10 were compared running an ANOVA using the GLM procedure of SAS (version 9.1) statistical package (SAS 2002). Cultivar, trait and treatment means were separated using a Duncan's test with a 5% rejection level. The relative salinity tolerance of each of the above traits was obtained by comparing its values for the T4/T2 and T10/T2 treatment ratios.

Arbequina and Empeltre relative vegetative growths and yields measured in each monitored tree were regressed against the corresponding mean ECe estimates for the 2003–2007 study period. Relative values were calculated as the value of the trait at a given ECe divided by its maximum value. Since the minimum ECe values were close or above the threshold ECe of 4 dS m^{-1} for olive (Aragüés et al. 2004), a linear regression was performed of the olive's traits against ECe. The salinity tolerances of Arbequina and Empeltre traits were assessed through the parameters ECe_{50} (ECe at which the trait decreases by 50% from its maximum value) and slope (% decline per unit increase in ECe).

Results

Soil salinity

The total number of ECa readings taken during the study period was 5,418 (average of 126 reading per tree), and the average coefficients of variation of the 2003–2007 treatment means were 33% (T2), 33% (T4) and 42% (T10) (Table 1). All the R^2 values of the ECa-ECe calibration equations were significant at $P<0.001$, except the R^2 of 2006, significant at $P<0.01$ (Table 2).

Based on the yearly mean ECa values measured in each tree and the corresponding yearly calibration equations shown in Table 2, the 2003–2007 mean ECe estimates and their standard deviations were obtained for each of the 23 Arbequina and 20 Empeltre trees (Fig. 1). In Arbequina, trees n° 1–8 belong to T2, n° 9–16 to T4 and n° 17–23 to T10. In Empeltre, trees n° 1–7 belong to T2, n° 8–14 to T4 and n° 15–20 to T10. For each treatment of both cultivars, the CV values were 38% (T2), 19% (T4) and 28% (T10).

For each saline treatment and olive cultivar, the 2003–2007 mean ECe estimates are given in Tables 3 to 5. For a given treatment, the ECe values of Arbequina and Empeltre were not different ($P>0.05$). For a given cultivar, ECe was significantly different among treatments ($P<0.05$) and increased with salinity in the irrigation water.

Vegetative growth (tree height and trunk diameter)

Average tree height at time of planting was significantly higher ($P<0.05$) in Arbequina (1.03 m) than in

Table 1 Yearly mean ± standard deviation of ECa (EM38 sensor readings in the horizontal-dipole position) in saline treatments T2, T4 and T10. N = number of ECa readings per tree

Year	ECa (dS m^{-1} at 25°C)			
	N	T2	T4	T10
2003	23	0.20±0.04	0.29±0.05	0.58±0.13
2004	27	0.16±0.06	0.28±0.08	0.61±0.18
2005	29	0.24±0.04	0.28±0.05	0.33±0.06
2006	24	0.23±0.05	0.29±0.06	0.49±0.14
2007	23	0.23±0.04	0.38±0.07	0.65±0.19
Average	126	0.21±0.07	0.30±0.10	0.52±0.22

Table 2 Calibration equations between ECa (EM38 sensor readings in the horizontal-dipole position) and ECe (soil saturation extract EC of samples taken at 0–60 cm soil depth) obtained in each study year (2003–2007). N = number of observations; R^2 = coefficient of determination

Year	$\mathrm{ECe\ (dS\,m^{-1}) = a\ ECa\ (dS\,m^{-1}) + b}$			
	a	b	N	R^2
2003	22.1	−1.6	29	0.83
2004	26.0	−0.6	24	0.84
2005	21.8	0.7	17	0.77
2006	13.8	2.9	18	0.50
2007	16.4	−0.8	22	0.88

Empeltre (0.62 m), but average tree height at the end of the study period was higher in Empeltre (2.64 m) than in Arbequina (2.20 m). The average height growth in the 2002–2007 period was 2.02 m in Empeltre and 1.17 m in Arbequina.

Average trunk diameter at time of planting was significantly higher ($P<0.05$) in Arbequina (0.062 m) than in Empeltre (0.049 m), but average trunk diameter at the end of the study period was higher in Empeltre (0.74 m) than in Arbequina (0.58 m). The average diameter growth in the 2002–2007 period was 0.61 m in Empeltre and 0.44 m in Arbequina. Within each cultivar, tree height and trunk diameter at the beginning of saline treatments (spring 2003) were not different among the tested trees. Hence, the differential saline treatments were initiated with homogeneous trees in each tested variety. For this reason, analyses performed on the basis of relative instead of absolute vegetative growth gave similar conclusions.

Table 3 shows Arbequina and Empeltre 2003–2007 average growths in tree height and trunk diameter in treatments T2, T4 and T10, and the corresponding treatment ratios T4/T2 and T10/T2. Arbequina and Empeltre height growths were similar in T2 and T4, and higher than in T10. In contrast, Arbequina and Empeltre diameter growths were significantly different in T2 and T4, whereas in T10 and T4 they were similar in Arbequina and different in Empeltre.

Figure 2 shows the Arbequina and Empeltre relationships between relative growths in tree height and trunk diameter and soil salinity (mean ECe) during the 2003–2007 study period. The coefficients of determination of the corresponding linear regressions were significant at $P<0.001$. The Arbequina and Empeltre slopes for relative height growth were not significantly different ($P>0.05$) and the values were −5.3% in Arbequina and −4.5% in Empeltre. The ECe_{50} estimates were 11.6 dS m^{-1} in Arbequina and 13.3 dS m^{-1} in Empeltre. Arbequina and Empeltre slopes for relative diameter growth were not significantly different ($P>0.05$), and the values were −3.1% in Arbequina and −4.6% in Empeltre. The estimated ECe_{50} values were 14.7 dS m^{-1} in Arbequina and 13.3 dS m^{-1} in Empeltre.

Olive and oil yields

Empeltre started producing fruit 1 year later (2004) than Arbequina (2003). Yield in 2005 was negated by frost damage in winter that also affected yield in 2006. For these reasons, although yields were measured on an annual basis, only the 2003–2007 mean accumulated olive and oil yields are presented (Table 4). Olive and oil yields were higher in Arbequina than in Empeltre. For both cultivars, treatments T2 and T4 had similar olive and oil yields but treatment T10 had lower values than T2

Figure 3 shows the Arbequina and Empeltre relationships between relative olive and oil yields, and soil salinity. Data scattering was high and the coefficients of determination were lower than those for vegetative growth (Fig. 2), although significant at

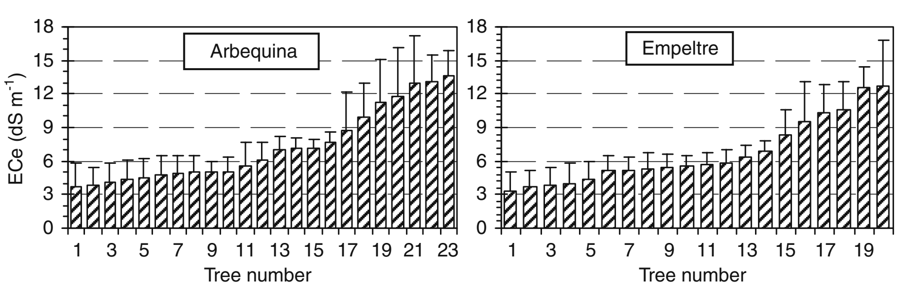

Fig. 1 2003–2007 mean soil ECe in each Arbequina and Empeltre monitored olive tree. Vertical bars represent one standard deviation of the mean

Table 3 Arbequina and Empeltre 2003–2007 mean soil ECe and mean tree height and trunk diameter growth in saline treatments T2, T4 and T10. T4/T2 and T10/T2 are treatment ratios. For each cultivar, means followed by the same letter are not significantly different (P>0.05)

Treatment	ECe (dS m^{-1})		Tree height growth (m)		Trunk diameter growth (m)	
	Arbequina	Empeltre	Arbequina	Empeltre	Arbequina	Empeltre
T2	4.4 a	4.2 a	1.43 a	2.36 a	0.53 a	0.72 a
T4	6.3 b	5.9 b	1.12 ab	2.09 a	0.42 b	0.62 b
T10	11.6 c	10.7 c	0.85 b	1.73 b	0.36 b	0.47 c
T4/T2	1.4	1.4	0.78	0.89	0.80	0.87
T10/T2	2.6	2.5	0.60	0.73	0.69	0.66

P<0.001 for olive yield and P<0.01 for oil yield. The effect of the 2005 winter frost on olive and oil yields in 2005 and 2006, and the alternate bearing in these young trees could be responsible of these relatively low coefficients of determination.

Arbequina and Empeltre olive yield slopes were not significantly different (P>0.05) although numerically the Arbequina slope (−4.5%) was higher than the Empeltre slope (−6.7%). The ECe_{50} values for olive yield were 8.6 dS m^{-1} for Arbequina and 7.5 dS m^{-1} for Empeltre. Arbequina and Empeltre oil yield slopes were not significantly different (P>0.05), although numerically the Arbequina slope (−4.0%) was higher than the Empeltre slope (−5.2%). The ECe_{50} values for oil yield were 10.5 dS m^{-1} for Arbequina and 8.4 dS m^{-1} for Empeltre.

Fruit characteristics

Olive, stone and pulp weights were higher in Empeltre than in Arbequina (Table 5), and Empeltre fruits were larger than Arbequina fruits. The shape of Empeltre olives were elongated (average length:width =1.5), in contrast to the spherical shape in Arbequina (average length:width=1.1). Stones were longer than olives, with average length:width ratios of 1.6 in Arbequina and 2.3 in Empeltre. Olive and pulp weights were the same in T2 and T4 and lower in T10 (Table 5). Arbequina fruit sizes were not significantly different in T2 and T4, whereas Empeltre fruit sizes were different in these treatments. Stone fruit sizes were similar in the three treatments in both cultivars (data not given). Based on treatment ratios, decreases in fruit weight and size with increasing salinity were small.

Discussion

Soil salinity

The mean soil ECe in each monitored tree was quite uniform during the 2003–2007 study period, as shown by the relatively low standard deviations in Fig. 1. The relatively high CV of the ECe means in each treatment and the ECe values shown in Fig. 1 indicate that the individual soil salinity values for a given irrigation water salinity treatment were in some cases quite different. For this reason, it is essential to analyze the response of crops on the basis of measured soil salinity (ECe) rather than on the basis of targeted irrigation water salinity (ECiw). However, many studies dealing with olive salinity tolerance are based on ECiw rather than on ECe or other soil salinity attributes (Aragüés et al. 2004; Chartzoulakis 2005; Gucci and Tattini 1997), raising concerns on

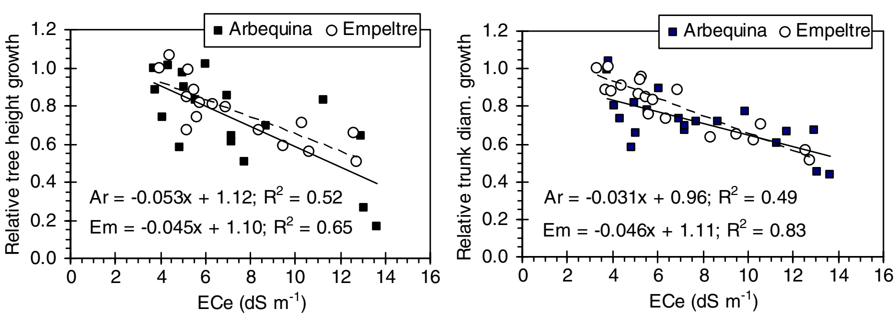

Fig. 2 Arbequina and Empeltre relationships and linear regression equations between relative growth in tree height and trunk diameter, and mean soil salinity (ECe) for the 2003–2007 study period

Table 4 Arbequina and Empeltre 2003–2007 mean soil ECe and mean olive and oil yields in saline treatments T2, T4 and T10. T4/T2 and T10/T2 are treatment ratios. For each cultivar, means followed by the same letter are not significantly different ($P>0.05$)

Treatment	ECe (dS m^{-1})		Olive yield (kg tree^{-1} year^{-1})		Oil yield (kg tree^{-1} year^{-1})	
	Arbequina	Empeltre	Arbequina	Empeltre	Arbequina	Empeltre
T2	4.4 a	4.2 a	2.29 a	1.65 a	0.43 a	0.29 a
T4	6.3 b	5.9 b	1.86 ab	1.23 ab	0.36 ab	0.19 ab
T10	11.6 c	10.7 c	1.17 b	0.65 b	0.26 b	0.14 b
T4/T2	1.4	1.4	0.81	0.75	0.84	0.66
T10/T2	2.6	2.5	0.51	0.39	0.60	0.48

the validity and extrapolation of results. In our work, the mean ECe in T10 (11.2 dS m^{-1}) was relatively close to the target ECiw of 10 dS m^{-1}, whereas the mean ECe values in T4 (6.1 dS m^{-1}) and T2 (4.3 dS m^{-1}) were substantially higher than the target ECiw of 4 and 2 dS m^{-1}, respectively. These higher than expected ECe values given the high LF imposed in the trial could be ascribed to high evaporation rates in high-frequency drip irrigation.

Vegetative growth (tree height and trunk diameter)

In terms of growth in tree height, the Duncan's test and the treatment ratios T4/T2 and T10/T2 shown in Table 3 indicated that Empeltre was somewhat more tolerant than Arbequina to soil salinity, since decreases in height growth in Empeltre were 11% (T4) and 27% (T10), as compared to 22% (T4) and 40% (T10) in Arbequina. In terms of trunk diameter growth, both cultivars were quite similar in salinity tolerance (Table 3). Comparison between traits shows that height was more tolerant than diameter to salinity, since heights were the same in T4 and T2, whereas diameters were already lower in T4 than in T2. Based on the values obtained in the control treatment (T2), the overall vegetative growth of olive (i.e., mean values for tree height and trunk diameter growths for both cultivars) decreased by 17% at ECe=6.1 dS m^{-1} and by 33% at ECe=11.2 dS m^{-1}, indicating its high salinity tolerance. Melgar et al. (2009) indicated that saline irrigation did not cause changes in any of the growth parameters measured, including shoot length, whereas Aragüés et al. (2004, 2005) found significant decreases in trunk diameter growth with increases in soil salinity.

The slopes of the linear regression equations shown in Fig. 2 were similar in both cultivars and traits (values between −3% and −5%), suggesting similar salinity tolerances of tree height and trunk diameter and similar salinity tolerances of Arbequina and Empeltre. The value of −3.1% for the slope of Arbequina trunk diameter was much higher than the values of −12– −16% obtained for the same trait and cultivar by Aragüés et al. (2004, 2005) in a saline-sodic, flood irrigated field subject to severe water-logging. The higher Arbequina sensitivity to soil salinity obtained by these authors could be ascribed to the concomitant and deleterious sodium toxicity and hypoxia effects. Based on the −3% to −5% slope values and the divisions for classifying crop tolerance to salinity (Maas 1990), olive vegetative growth was classified as tolerant.

The ECe$_{50}$ estimates were 11.6 dS m^{-1} (Arbequina) and 13.3 dS m^{-1} (Empeltre) for tree height (cultivar's average of 12.5 dS m^{-1}) and 14.7 dS m^{-1} (Arbequina) and 13.3 dS m^{-1} (Empeltre) for trunk diameter (cultivar's average of 14.0 dS m^{-1}). The average values of both traits were 13.2 dS m^{-1}

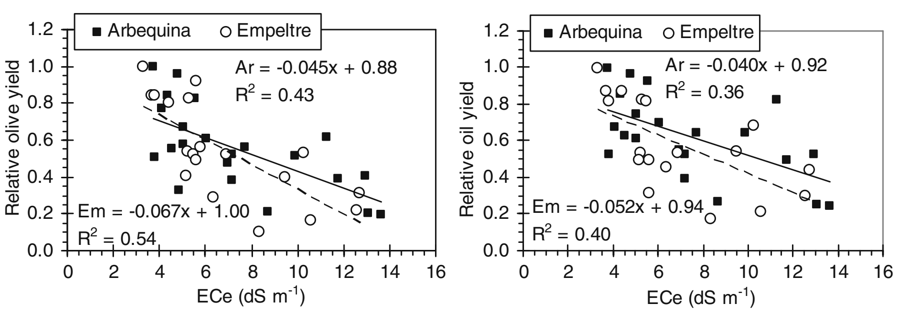

Fig. 3 Arbequina and Empeltre relationships and linear regression equations between relative olive and oil yields, and mean soil salinity (ECe) for the 2003–2007 study period

Table 5 Arbequina and Empeltre 2003–2007 mean soil ECe and weights of olive, stone, pulp, and pulp:stone ratio in saline treatments T2, T4 and T10. T4/T2 and T10/T2 are treatment ratios. For each cultivar, means followed by the same letter are not significantly different ($P>0.05$)

Treat.	ECe (dS m^{-1})		Weight of 20 fruits (g)							
			Olive		Stone		Pulp		Pulp/Stone	
	Arbe.	Empe.	Arbe.	Empe.	Arbe.	Empe.	Arbe.	Empe.	Arbe.	Empe.
T2	4.4 a	4.2 a	43.3 a	71.3 a	7.7 a	11.5 a	35.5 a	59.8 a	4.6 a	5.2 a
T4	6.3 b	5.9 b	41.1 a	65.6 a	7.9 a	11.1 a	33.2 ab	54.5 a	4.2 b	4.9 a
T10	11.6 c	10.7 c	37.7 b	55.0 b	7.2 b	10.6 a	30.5 b	44.5 b	4.2 b	4.2 b
T4/T2	1.47	1.38	0.87	0.92	1.02	0.96	0.94	0.91	0.91	0.94
T10/T2	2.70	2.49	0.95	0.77	0.93	0.92	0.86	0.91	0.91	0.81

(Arbequina) and 13.3 dS m^{-1} (Empeltre). Although there were some numerical differences between these ECe$_{50}$ estimates, they were not significantly different ($P>0.05$) suggesting, as for the slope's analysis, similar salinity tolerances of tree height and trunk diameter and similar salinity tolerances of Arbequina and Empeltre. The decrease of 50% (both traits and cultivars) at ECe=13.2 dS m^{-1} was in agreement with the previously estimated decreases at T4 and T10 (Table 3). Based on this ECe$_{50}$ value and the divisions for classifying crop tolerance to salinity (Maas 1990), olive vegetative growth will be classified as moderately tolerant. Hence, taking into account the slope and ECe$_{50}$ values, olive vegetative growth was classified as moderately tolerant to tolerant to soil salinity.

Olive and oil yields

Fruit yield in these young trees was very low and irregular (i.e., alternate bearing) as typically found in olive (Rallo and Cuevas 2008; Melgar et al. 2009). The comparison between these two traits shows that their tolerances to soil salinity were quite similar, although oil yield was slightly more tolerant than olive yield at the highest soil ECe (average decreases for both cultivars of 46% for oil yield and 55% for olive yield) (Table 4). Based on both yields, the salinity tolerances of Arbequina and Empeltre were statistically the same ($P>0.05$), but the treatment ratios indicate that decreases at T10 with respect to T2 were lower in Arbequina than in Empeltre. Thus, in practical terms Arbequina will be preferred over Empeltre in salt-affected soils because of its higher inherent yield and the higher treatment ratios. Murillo et al. (2000) reported losses in olive yield of 30% for only 2 months of irrigation with high sodium waste-waters with an EC of 4.3–6.0 dS m^{-1}. These losses were similar to those obtained at T4 (Table 4) although a proper comparison among results was not feasible because ECe or other soil salinity trait was not given in the cited publication.

Mean decreases for both cultivars and yield traits were 23% at T4 and 50% at T10, as compared with corresponding mean decreases of 17% and 33% for vegetative growth. Hence vegetative growth will be more tolerant than yield at high soil salinity values (11.2 dS m^{-1}), but tolerances will be comparable at moderate values (6.1 dS m^{-1}).

The slopes of the regression equations shown in Fig. 3 were similar in both cultivars and traits (values between −4% and −7%), suggesting similar salinity tolerances of olive and oil yield and similar salinity tolerances of Arbequina and Empeltre. Hassan et al. (2000) reported slope values between −3.4% and −5.2% for fruit yield of three olive cultivars, similar to our values of −4.5% (Arbequina) and −6.7% (Empeltre).

The ECe$_{50}$ estimates were 8.6 dS m^{-1} (Arbequina) and 7.5 dS m^{-1} (Empeltre) for olive yield (cultivar's average=8.0 dS m^{-1}) and 10.5 dS m^{-1} (Arbequina) and 8.4 dS m^{-1} (Empeltre) for oil yield (cultivar's average=9.4 dS m^{-1}). The average values of both traits were 9.6 dS m^{-1} (Arbequina) and 7.9 dS m^{-1} (Empeltre). Although there were some numerical differences between these ECe$_{50}$ estimates, they were not significantly different ($P>0.05$) suggesting, as for the slope analysis, similar salinity tolerances of olive and oil yields and similar salinity tolerances of Arbequina and Empeltre. For both traits and cultivars, the ECe$_{50}$ was 8.7 dS m^{-1}. This value is 34% lower than the ECe$_{50}$ of 13.2 dS m^{-1} previously reported for vegetative growth, indicating that yield is more sensitive to salinity than growth. It should be noticed the higher variability when describing salt tolerance based on oil yield as compared to fruit yield. Based on the divisions for classifying crop tolerance to salinity (Maas 1990), olive yield was classified as moderately sensitive to soil salinity, in contrast to the classification of vegetative growth as moderately tolerant to tolerant to soil salinity. Hassan et al. (2000) also concluded that vegetative growth was more tolerant to salinity than fruit yield production.

Fruit characteristics

Arbequina and Empeltre fruit (olive and stone) sizes were in general quite tolerant to soil salinity, with average decreases for all traits and both cultivars of 2% at ECe=6.1 dS m^{-1} and 4% at ECe=11.2 dS m^{-1}. Melgar et al. (2009) also found that fruit size was not affected by salinity of irrigation water (5 and 10 dS m^{-1}) in any of the study 1998–2004 years.

Arbequina and Empeltre olive, stone and pulp weights were more sensitive to soil salinity that fruit sizes, although they were also relatively independent of soil salinity as shown by the average decreases of all traits for both cultivars (7% at ECe=6.1 dS m^{-1} and 12% at ECe=11.2 dS m^{-1}). The pulp:stone ratio was significantly lower at T10 than at T2 in both cultivars (Table 5), although numerical decreases were low in Arbequina (9%) and somewhat higher in Empeltre (19%). These results are different to those found by Melgar et al. (2009), where irrigation water salinity (5 and 10 dS m^{-1}) did not affect pulp:stone ratios in any of the studied years (1998–2006).

Conclusions

This work showed that soil salinity may be quite variable for a given irrigation water salinity due to variations in soil characteristics, crop attributes and water management typical in field studies. It is therefore essential to analyze salinity tolerance on the basis of measured soil salinity rather than on targeted water salinity. Empeltre and Arbequina olive cultivars were similar in its response to soil salinity. Fruit size and weight were quite tolerant to soil salinity. Olive and oil yields were more sensitive to salinity than vegetative growth (tree height and trunk diameter). Thus, based on the ECe_{50} estimates, olive yield was classified as moderately sensitive whereas olive growth was classified as moderately tolerant to soil salinity.

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