GROWTH, YIELD RESPONSES AND WATER RELATIONS OF DIFFERENT VARIETIES (OLEA EUROPAEA L.) CULTIVATED UNDER TWO WATER CONDITIONS IN SEMI-ARID CONDITIONS OF TUNISIA

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Abstract

Water is the most important environmental constrain determining plant growth and fruit yield of olive tree plantations in arid region of Tunisia. A field experiment was carried out with the aim to study the behavior of local and foreigner varieties under climatic conditions of central Tunisia. Plants were planted in 2002 with a density of 204 tree ha^{-1}. Trials were carried out over a 2-year period where two different irrigation treatments were applied (little water supply 10% ETc which was closed to rain-fed condition and full irrigated 100% ETc).Vegetative tree responses, as shoot growth and basal diameter, were evaluated. Morphological characteristics of leaves (leaf area, stomata density, number and diameter of the trichomes) and leaf water potential leaf were noted. Yield, fruit characteristics and oil quality indices were determined. The olive tree which received the total quantity of their water requirement, developed more important leaves, a higher stomata density and longer stomata pore. Seasonal dynamics of midday leaf water potential showed large variations over the season than those produced by the irrigation treatments. Then as the season progress, Ψ_{md}

decreased significantly during summer season, from June to September. Ψ_{md} recovered quickly on the end of dry season when autumn rainfall arrived. Shoot elongation seems to be either affected by water status plant or its bearing conditions. Comparing the vegetative growth between 2008 (On year) and 2009 (Off year), it appeared that shoot growth was more important for non-bearing trees. Maximum productions recorded through the growing season (an On year followed by Off year) were given by *Picholine*, *Coratina* and *Koroneiki* irrigated with only 10% Etc which noted a biannual yield varying between 29 kg tree^{-1} (5919 kg ha^{-1}) and 34 kg tree^{-1} (6936 kg ha^{-1}). *Chetoui* showed the lowest biannual yield which not exceeds 8 kg tree^{-1}(1600 kg ha^{-1}) even for trees which received 100% ETc. It showed poor adaptability in the south of Tunisia even under optimal conditions. Irrigation caused an increase of fruit weight and the pulp:stone ratio. From our results, it seems that water availability did not affect olive oil composition and oil fatty acid ratio.

Keywords: Shoot growth, leaf properties, leaf water potential, biannual yield, oil quality indices, fatty composition

Introduction

The Tunisian olive growing counts about 66 millions trees covering one-third of the useful agricultural area. The olive growing is characterized by a wide distribution across the country from the north to the extreme south. The major part of orchard is conducted under rain-fed conditions (97% of the area) in semiarid and arid regions (centre and south) where the average of rainfall oscillates between 100 and 350 mm/year (Jardak, 2006; DGPA, 2006). Under these conditions, despite the resistance of olive tree to drought and to severe conditions, they usually showed a decrease in photosynthesis resulting in a reduction of the vegetative growth and a significant decline of the productive performance, low yield and alternate bearing behaviour (Bongi and Palliotti, 1994; Ben Ahmed et al., 2007). In Tunisia, there have been efforts in production intensification, notably by increasing tree density and by shifting from rain-fed to irrigated conditions. New orchards are planted at higher densities (200 and 300 trees ha^{-1}) which achieve greater yields with reduced alternate bearing behaviour. The increase of plant density determines an intensification of the tree by tree competition for water and nutrients. Olive trees can, in opposite, respond favourably and quickly to low volumes of water received during the dry season, improving consistently their production (Ben Ahmed et al., 2007; Chehab et al., 2009; Masmoudi-Charfi et al., 2010; Aïachi et al., 2012).

Several studies have been carried out to assess the vegetative, productive and physiological, responses of olive trees (olive table and oil varieties) grown under full irrigations conditions or subjected to deficit irrigation (Melgar et al., 2008; Iniesta et al., 2009; Masmoudi et al., 2010; Pérez-Lopez et al., 2007; Palese et al., 2010; Martin-Vertedor et al., 2011 a et b).

Irrigating olive orchards improved significantly shoot and branch length, and increased trunk diameter and canopy size (Grattan et al., 2006; Iniesta et al., 2009; Palese et al., 2010), as well as fruit set percentage, fruit size at harvest (olive and oil productions). Supplying trees with suitable amounts, given at precise stages of the tree and the fruit development leaded to more regular yields through a better control of nutrients' and carbohydrates' distribution (Fernandez and Moreno, 1999; D'Andria et al., 2008; Iniesta et al., 2009; Palese et al., 2010). Aïachi et al (2012) noted in a previous work that the olive tree cultivated in Central Tunisia, produced properly with an irrigation amount ranging between 80 and 200 mm. This irrigation volume can be adjusted according to the fruit crop load. The olive tree is a well-known alternate-bearing species (Lavee, 1997), this is why the high yield year is generally followed by a low yield year even under optimal conditions of cultivation. The smallest irrigation amount (80 mm) was recommended for the low fruit load years, like suggested by Aïachi et al. (2012). In Spain, Martin-Vertedor et al. (2011b) reported also that the sustained season-long irrigation deficit, which reduces the yield in On years, could be advisable during Off years, when a lower water consumption was observed, thus the optimal irrigation amount will depend on the crop load level of each year.

On the other hand, irrigation affected significantly of the most physiological parameters, like the leaf water potential and the leaf stomatal resistance (Masmoudi et al., 2010). In fact, Fernandez et al. (1997) and Moriana et al. (2003) noticed that under conditions of high temperatures, olive plants can reduce an excessive water loss by closing their stomata. Also, the olive tree tolerated lower water potential than other fruit species (Larsen et al., 1989; Abd-El-Rahman et al., 1966), found mean annual values of about -4.8 MPa for olive, -2,4 MPa for almond, -1,5 MPa for Fig and -1.3 for grape. However, the tree water relations were affected not only by the level of water but also by the presence of fruits (Martin-Vertedor et al., 2011a). Under medium and high crop load, the stomatal conductance increased by an average of 17% over trees that don't have fruits. Lower water potentials were noted in trees that had a medium or a heavy crop load compared to trees that had no fruits.

The aim of this study is (1) to evaluate and compare the vegetative and productive responses of 2-year varieties experiment, (2) to assess the physiological responses of the different varieties and (3) to analyze characteristics of olive fruits and oils obtained under two different water availability regimes (with and without water supply) with the specific objective to assess the influence of the water supply on the most important varieties cultivated in the intensive conditions of central Tunisia.

Materials and methods

Experimental orchard and climatic conditions

The trial was carried out in 2008 and in 2009 in an olive grove located at the *Research Station of Taoues*, about 40 km from Sfax, central Tunisia (34°N, 21°E). Trees were planted in 2002, at 204 trees ha^{-1}, using seven varieties grouped in an oil olive cultivar like *Chemlali, Chetoui, Koroneiki* and *Coratina* or in a table olive cultivar like *Picholine and Meski.*

The area's climate is considered as semi-arid, with yearly averages of 155 and 288 mm, in 2008 and 2009 respectively (Table 1). Daily ET_o values were determined, following the Penman-Monteith equation (FAO, 1998). The data used for ET_0 calculation were recorded on the same site during the period 2000-2007, and giving an annual average value of 1400 mm.

Soil is silty (76% Sand, 14% Silt and 10% Clay), calcareous, poor in organic matter (0.32%) with a pH of 8.7, an actual density of 1.7 g cm^{-3} and a porosity of 34%. Trees were clean-cultivated and trained using the monocone system.

Table 1 Reference evapotranspiration (ET_o), rainfall (mm) and the different irrigation amounts (mm) (20% ET_c, 50% ET_c, 100% ET_c) applied from April to September for the two experimental years (2008-2009)

	2008	2009
10% ETc	41	41
100% ETc	411	411
ET_0	1400	1400
Rainfall	155	288

Water use and Experimental design

The applied water ET_c was estimated according to the FAO method (Allen *et al.*, 1998) and was calculated as follows, $ET_c = ET_o \times K_c \times K_r$ [1], where monthly K_c is the monthly crop coefficient ranging between 0.45 and 0.6 like mentioned by Pastor and Orgaz (1994) in Table 1 and K_r the coefficient relative to the tree ground cover equal to 0.7 for an average coverage of about 20 %. The olive trees were irrigated twice a week, from April to end of September, by a localized system with four emitters per tree and different hourly discharges (8 and 80 litres per tree) depending on two irrigation regimes 10% and 100% ET_c.

The experiment was designed as a randomized block. Tagged trees were arranged in 7 plots (7 varieties) of 8 trees each. For each variety (row), two randomized treatments were involved: 10%ET_c, and 100%ET_c with four replications for each variety. All experimental trees were surrounded by guard trees in order to minimize the effect of irrigation.

Measurements

Leaf properties

Twenty leaves per treatment were taken for each cultivar, on the mid-point of the current-season shoots. Leaf area has been measured. Then, the trichomes were removed from the lower surface of the leaves using an adhesive tape before the measurement of the stomatal density. That is because the lower leaf surface is densely covered by stellate hairs. Thus, it would be impossible to get impressions unless the hair was removed. The stomatal opening and the number of stomata were counted on the same leaves. Observations were conducted using the *Windias software* and a microscope type Leitz DIALUX 22 EB with the enlargement 250 times.

Plant water status

Leaf water potential ($\Psi_{,}$ MPa) was periodically measured on three leaves per variety and treatment. These measurements were realized at midday every month from March to October. Fully expanded leaves were detached from the mid-canopy wrapped in plastic envelops and rapidly enclosed in the pressure chamber (PMS Instrument Co). On the 15^{th} may, the leaf water potential was monitored every two hours from 4: 30 am (predawn) to 20:00 pm (late afternoon). Three sunny leaves for each variety and irrigation treatment were collected every 2 hours. In addition, the leaf water potential at midday was measured on three 1-year old leaves and 3 leaves from the current year detached from the trees. All measures were realized in the same pressure chamber.

Shoot Growth

Measurements were carried out on four trees, for each treatment and variety. At the beginning of the two growing season of 2008 and 2009, ten shoots aged one-year, with lengths ranging between 150 and 200 mm, were selected around the canopy of each tree. The final Shoot lengths and basal diameters of the different varieties were measured on December for the two growing seasons.

Yield and oil chemical determination

Fruits were harvested, on October 2008 and 2009 October for the table varieties, *i.e. Picholine*, *Meski and Manzanilla*, and later, on 25 December 2008 and 12 November 2009 for *Chetoui*, *Coratina*, *Koroneiki* and *Chemlali* cultivars. The olives harvest was made by hand, and the average olive yield per plant and per hectare was determined for all varieties and for the two water treatments. Biennial yield were calculated to reduce the tree to tree variations due to the alternate bearing behaviour of olives.

Representative samples of 3kg per plot, were taken to determine fruit characteristics. Fruit weight was determined as 100 fruit. The pulp:stone ratio was calculated after pitting a fruit sample of approximately 100 fruits. The oil content was determined by using a soxhlet apparatus and then determined by nuclear magnetic resonance (NMR).

The oil used for the qualitative analysis was obtained using a bench hammer mill: the crushed fruits were mixed for 30 mn at 25°C, and then the oil was separated by centrifugation. Oil characteristics (oil acidity, UV absorption at 232 and 270 nm (K232, K270), Free fatty acid FFA) were determined according to EU official methods (Commission Regulation-EEC 2568/91). Total phenols and Chlorophyll content (ppm) were determined.

Statistical analysis

Statistical analyses were performed using the SPSS statistical computer program (Version 13.0 for Windows). The leaf properties, the final shoot growth (length and diameter), and the yield components were subjected to multivariate analysis using the General Linear Model (GLM) procedure, including three fixed factors (variety, treatment and year), in order to check the effect of each factor and their interaction. Means comparisons for physico-chemical characteristics and fatty acid composition of the oil varieties, were separated using Duncan's multiple range test at different levels ($p < 0.05$ and $p < 0.01$).

Results

Leaf properties

The morphological leaves showed important variability among varieties and for the two different water status of the trees (Table 2). Leaf area was more important for trees which received a higher quantity of water. This result was verified for all varieties. The variety, the irrigation treatment and their interaction showed significant effect ($P<0.001$). The stomata olive-tree was only present on the abaxial surface of the leaves. Varieties like *Picholine, Chemlali and Koroneiki* which received 100 % ETc, showed the highest density. However, *Meski* and *Chetoui* noted the highest density at 10% Etc, equal to 998.5 and 1101.2 stomata mm^{-2} respectively. The stomata density varied between 568.5 stomata mm^{-2} (*Koroneiki*) and 1452 stomata mm^{-2} (*Coratina*) for leaves issued from trees which received 100% Etc. The effects of the variety and the irrigation treatment were significant on this parameter ($P<0.001$). The stomata length varied from 12.4 to 19.1 µm.

Table 2 Leaves morphological characteristics of the different varieties under the two irrigation treatments.

Parameters	Treatment	Pich	Cor	Koro	Mes	Chet	Chem
Leaf area (cm^2)	10%ETc	3.4	4.2	3.8	4.1	3.1	3.9
	100%ETc	3.6	4.6	3.8	5.3	3.7	4.1
Length of stomatal pore (µm)	10%ETc	14.6	15.9	13.4	19.1	15.5	15.1
	100%ETc	12.3	14.7	14.2	15.4	17.5	13.4
Stomatal density (Stomata. mm^{-2})	10%ETc	623.5	1206.2	551.4	998.5	1101.2	761.4
	100%ETc	643.5	1452.5	568.5	900.7	1033.7	894.2
Trichomes diameter (µm)	10%ETc	0.11	0.14	0.15	0.14	0.14	0.13
	100%ETc	0.14	0.13	0.15	0.14	0.13	0.13
Trichomes number (Trichomes. mm^{-2})	10%ETc	222.8	323.7	132.1	227.1	320.1	196.4
	100%ETc	245.0	246.2	152.1	243.5	220.0	190.0

Pich: Picholine; Cor: Coratina; Koro: Koroneiki; Mes: Meski; Chet: Chetoui; Chem: Chemlali.

Results showed significant interactions between the variety and the irrigation treatment (*$P<0.001$*). The number of trichomes, which are more present on the inner face of the olive tree leaves, oscillated between 132.1 and 323 per mm^{-2} of leaf area. Their diameter varied from 0.11 to 0.15 µm. However, there was no significant effect of the irrigation on the number of trichoma and their diameter, while the variety has a significant effect on these two parameters (Table 3).

Results showed that the olive tree which received the total quantity of their water requirement developed more important leaves. These results corroborate Acevedo et al. (1971), which noted a reduction of the leaf area issued from stressed trees. The full-irrigated trees noted a higher stomata density and longer stomata pore. The available literature on the influence of irrigation regime on these parameters is somewhat contrasting. Bongi et al. (1987) reported lower stomata density in a cultivar coming from a warm area, while Bosabalidis and Kofidis (2002) found an increase in the stomatal number under water stress. Variety has significant effect on these parameters. According to Bartolini et al. (1979), the stomatal density has been reported to range about 250 mm^{-2} to more 700 mm^{-2} depending on the cultivar and the nutrient status. Although, Guerfel et al. (2007a) noted differences between varieties and the extreme values corresponding to *Meski* (312 stomata mm^{-2}) and to *Tounsi* varieties (470 stomata mm^{-2}). A higher number of stomata were considered as a good criterion since it allows cooling leaves (Guerfel et al., 2007b). The reduction of water did not seem to have a strong effect on the trichomes number and their diameter. It seems that the trichomes are a barrier to the diffusion of CO_2 and H_2O lowering the boundary layer conductance in the air surrounding the stomata. According to Guerfel at al. (2007b), a high number of these structures are being effective in limiting water loss.

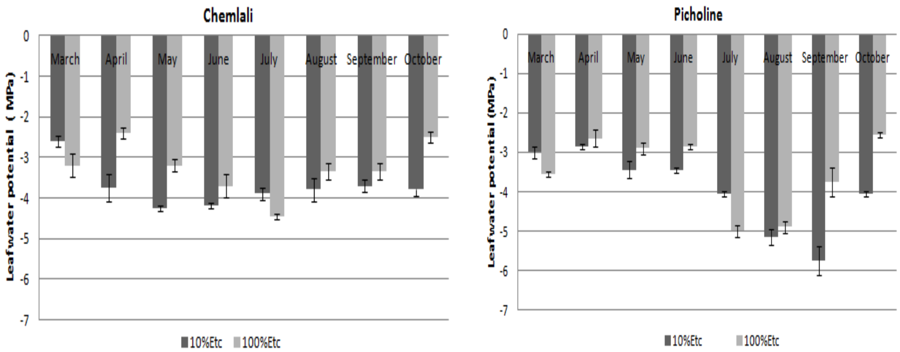
Table 3 Statistical analysis of the variety, the irrigation treatment and their interaction effects on leaf properties

	Leaf area	Length of stomatal pore	Stomatal density	Trichomes diameter	Trichomes number
Treatment	61.9**	11.7**	15.7**	0.1NS	2.8NS
Variety	46.1**	8.8**	158.9**	2.24*	52.8**
Treatment*Variety	8.5**	3.8**	9.3**	1.1NS	8.48**

* Significant at $P<0.05$,** Significant at $P<0.01$, NS: non significant

Plant water status

Monthly measurements of the leaf water potential were recorded on all varieties under the two water trees status (Fig. 1). At the beginning of the experiment, slight differences between varieties and treatments were recorded. In March, the soil water content was still enough to prevent important variations in leaves. The Ψ_{md} ranged between -2.6 (*Chemlali*) and -3.9 MPa (*Koroneiki*) for trees which were cultivated in rain-fed conditions and received only 10% Etc and between -3.1 (*Koroneiki*) and -4.3 MPa (*Chetoui*) for trees which received 100% Etc. Then as the season progress, the Ψ_{md} decreased significantly during summer season, from June to September for both the two water status trees. The water status of trees which received 100% Etc, was always higher than the status of those which received only 10% Etc, especially in Summer.



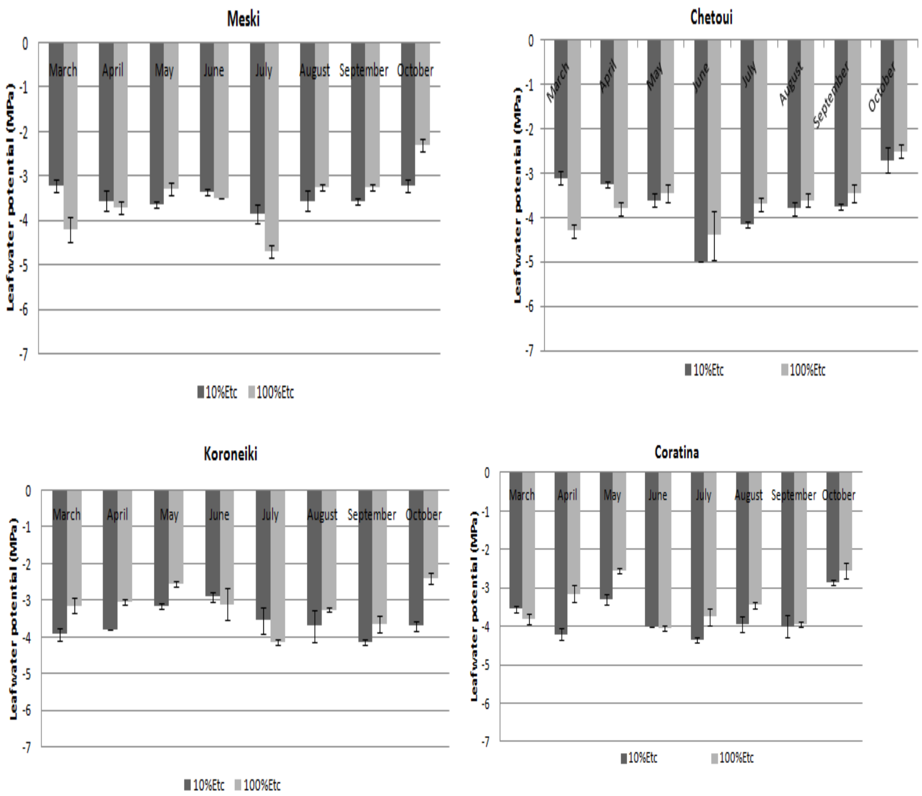


Figure 1 Seasonal changes in olive leaf water potential (MPa) measured during the season growing 2009 on the different varieties under the two different irrigation regimes (10% Etc, 100%Etc). Each value is the average of 3 observations per irrigation treatment. Vertical bars = ± SE.

The minimum values of Ψ_{leaf} were noted on *Chemlali* (-4.2 MPa), on *Chetoui* (-5 MPa), on *Picholine* (-5.1 MPa), on *Coratina* (-4.3 MPa), on *Koroneiki* (-4.1 MPa) and on *Meski* (-3.8 MPa) wheretrees were cultivated under rain-fed conditions and water supply not exceeding 10% Etc. The minimum values were recorded on *Picholine* in September (-5.75 MPa) and on *Chetoui* in June (-5 MPa) for the trees which received only 10% Etc.The Ψ_{leaf} recovered quickly by the end of the dry season when autum's rainfall arrived.

Our results are in accordance with those reported by Wahbi et al., 2005; Tognetti et al., 2006; Correa-Tedesco et al., 2010; Masmoudi et al., 2010 and Martin-Vertefor et al., 2011 which indicated that the Ψ_{md} decreased throughout the summer in stressed and irrigated plants and recovered in early fall. Rousseaux et al. (2008) reported that after fifteen days without irrigation, both the soil volumetric water content and the leaf water potential were substantially lower in the unirrigated treatment. Tognetti et al. (2006)

noted the lowest values of Ψ_{md} in rainfed plants issued of *Frontoio* and *Leccino* in early fall that won't recover yet to spring values. For our experiment, the Ψ_{md} was higher on autumn (October) than the one measured on March because the water plant status was better after the autumnal rain noted in arid zone. The water potential was strongly affected by the water supplies at tree level and varied depending on the cultivar. Measurements of Ψ_{md} showed lower values on *Picholine* and *Chetoui* which received only 10% of Etc. The values were below the minimum value observed by Moriana et al. (2003) which reached value of -8 MPa.

The daily curves of Ψ_{leaf} observed on the measured day of May 15, are shown in Fig . 2. This day was clear and the sky was blue. At the beginning of the day at predawn, slight differences of the Ψ_{leaf} between treatments and varieties were recorded. The measurement realized before dawn, was considered the base leaf water potential. At this time, soil water status was apparently high enough to prevent significant decreases of the Ψ_{leaf}. At 4:00 am, the Ψ_{leaf} varied between -1 and -1.8. MPa and between -1.05 and -1.7 MPa for 10% and 100% Etc, respectively. This agrees with Ameglio et al.(1999), Fernandez et Moreno (1999) and Tognetti et al. (2005, 2006) findings which indicated that the measurement of Ψ_{leaf} at predawn provided a good estimation of the soil water content, though may into equilibrium with the wettest portion of the soil in the plant's root zone.

Then, as the day progressed, the Ψ_{leaf} decreased. The lowest value was recorded at midday between 13:00 to 15:00 h GMT. For the varieties *Chemlali, Chetoui, Coratina* and *Picholine*, trees which received only 10% Etc showed the lowest potential during all the day. For these varieties, the Ψ_{leaf} showed minimum values which varied between -3.2 MPa and -3.3 MPa at 15:00PM. However, there was no difference between the two water status of trees (10% ETc and 100% Etc) for *Koroneiki* and *Meski*. After 15:00pm, the Ψ_{leaf} showed a tendency to increase. Such evolution was observed by Fernandez et al. (1997) and Fernandez and Moreno (1999) for *Manzanilla* showing a rapid decrease of the Ψ_{leaf} in the morning reaching a minimum values between 14:00 -16:00 GMT. It remained approximately constant throughout the day until late in the afternoon, when a sharp increase was observed.

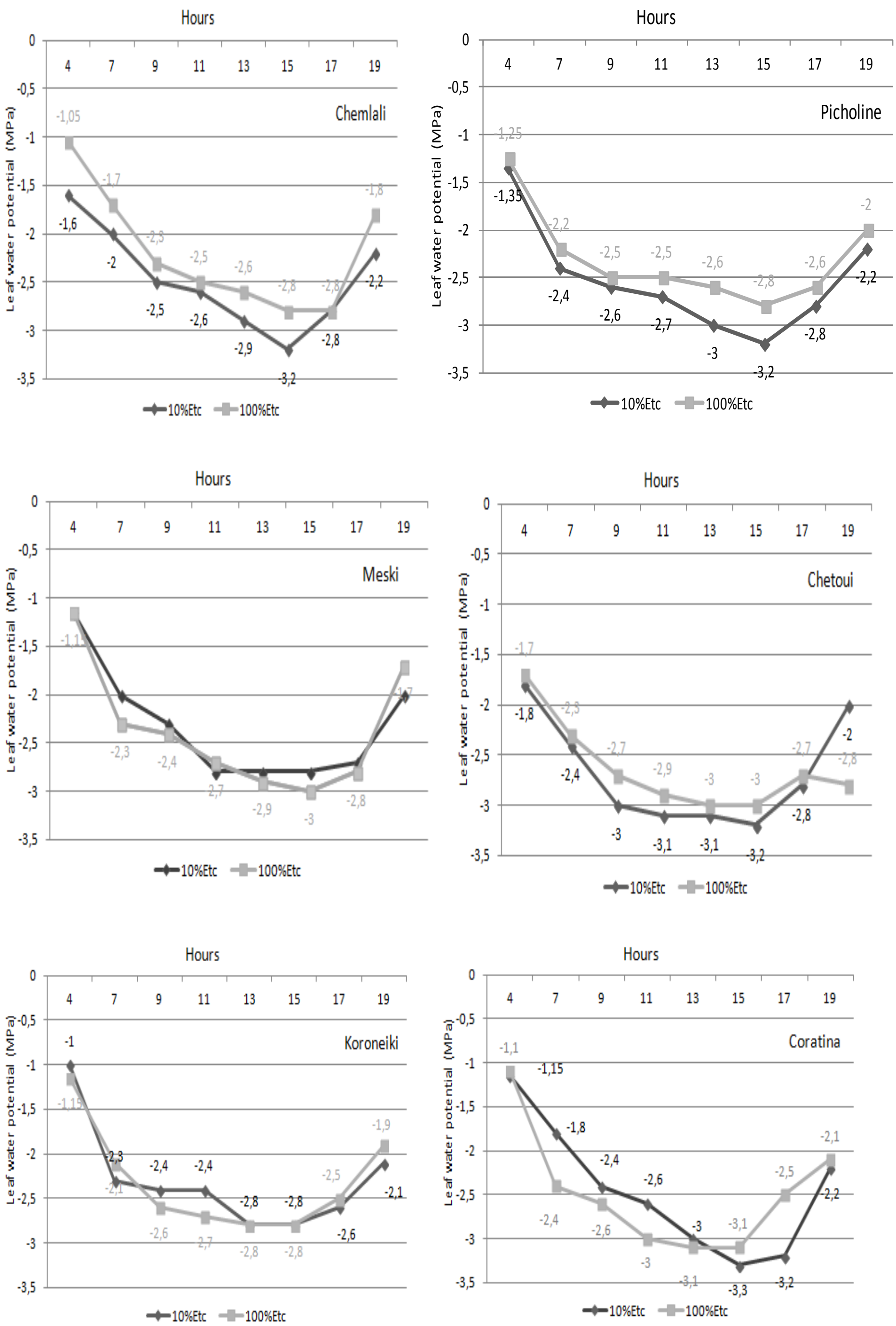


Figure 2 Diurnal time course of leaf water potential (MPa) measured on 15 May on the different varieties under the two different irrigation regimes (10% Etc, 100%Etc). Each value is the average of 3 observations per irrigation treatment.

Measurements of the Ψ_{leaf} showed marked differences between 1-year-old leaves (old leaves) and leaves of the current year (young leaves) for two water status trees of different varieties. These measurements were also realized on May 15.The leaf water potential of young leaves is lower than the one of older leaves for all varieties. This effect is more pronounced in stressed trees which received only 10% ETc (Fig.3). These results are different from those presented previously in olive tree (Bongi & Pallioti, 1994; Fernandez et al., 1997; Fernandez & Moreno, 1999). Most researchers reported that there are various changes in the leaf affecting the water use by the tree. Average values of the leaf potential were -1.11 MPa for young leaves and -1.35 MPa for old leaves (Fernandez et al., 1997). These authors also found that during a water status period, the stomata remained more open in 1-year-old leaves than in the current year leaves. Also, Reich and Borchert (1988) noted that older leaves of *Tabebuia rosea* (tropical tree species) had higher conductance and greater water deficits than had younger leaves.

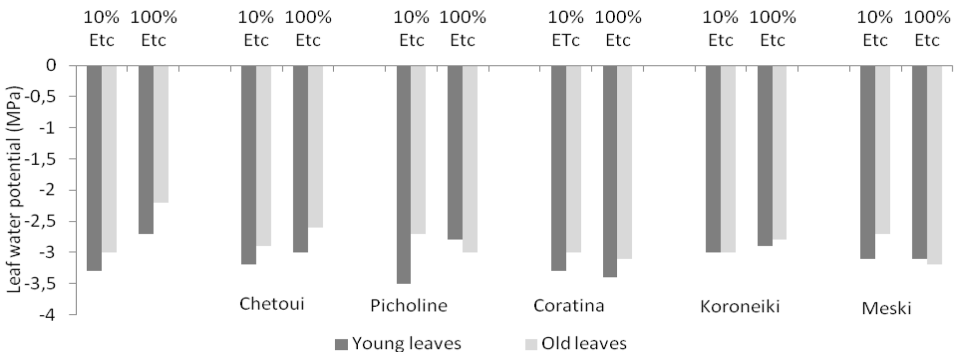


Figure 3 Midday water potential measured on 1-year old leaves and the current season leaves, taken from the six cultivars under the irrigation treatement (10% Etc and 100% Etc).

Shoot Growth
Shoot length

The shoot growth showed significant differences between the years, with higher values observed during the second year of experiment, i.e. 2009 (Table 4). The maximum shoot increment was equal to 5.10 cm in 2008 and 12.56 cm in 2009. For the same irrigation level, greater branch growth were detected in 2009 which were inherent to the fruit load. In fact, year 2008 was a fruiting year (On tree) while the year 2009 was a non-fruiting season (Off tree). The irrigation amount had also an influence on the shoot growth. Tress which received the highest water application (100% ET_c), noted an important increase of their shoot length. It varied from 1.22 cm (*Chemlali*) to 4.56 cm (*Meski*) in 2008 and ranged between 3.2 cm (*Chetoui*) and 12.56 cm (*Coratina*) on the following year. Strong effects of the growth increase were observed, with a maximum value of about 44% in 2008 and 73% in 2009. These two values were noted for Coratina variety. Trees which received only 10% ET_c showed the lowest shoot growth ranging between 1.04 cm (Chemlali) and 3.35 cm (Meski) in 2008 and between 2.58 cm (Chemlali) and 7.22 cm (Coratina) in 2009. It is important to mention that the different factors year, variety, irrigation treatment and their interaction have a significant effect on shoot length (Table 6).

Table 4 Final shoot length measured on all varieties in the two irrigation treatments during the two years of experiment (2008, 2009)

Variétés	2008		2009	
	10% ETc	100% ETc	10% ETc	100% ETc
Chemlali	1.04 ± 1.05	1.22 ± 1.85	4.97± 2.40	5.00 ± 3.00
Chetoui	2.10 ±1.87	2.43 ± 3.07	2.58 ± 1.95	3.20 ± 2.41
Koroneiki	2.00 ± 1.18	2.85 ± 2.59	3.50 ± 4.39	4.66 ± 0.35
Coratina	2.70 ± 2.28	3.90 ± 2.58	7.22 ± 4.36	12.56 ± 8.41
Picholine	3.18 ± 2.41	4.18 ± 2.26	6.89 ± 4.46	6.14 ± 3.15
Meski	3.35 ± 3.32	4.56 ± 5.02	4.79 ± 2.28	7.15 ± 4.46

Basal diameter

Basal diameter was lower in shoot issued from trees which received only 10% Etc for the two years of experiment (2008, 2009) (Table 5). The three factors (variety, treatment and year) have a significant effect on he diameter at $P < 0.01$. However, the interaction between the three factors was not, in this case, significant (Table 6).

Table 5 Basal diameter measured on all varieties in the two irrigation treatments during the two years of experiment (2008, 2009)

Varieties	2008		2009	
	10% ETc	100% ETc	10% ETc	100% ETc
Chemlali	1.00 ± 0.31	1.12 ± 0.25	2.15 ± 1.44	2.27 ± 0.52
Chetoui	1.02 ± 0.36	1.05 ± 0.27	1.84±0.37	1.93 ± 0.33
Koroneiki	1.35 ± 0.21	1.39 ± 0.21	2.55 ±0.77	2.60 ± 0.92
Coratina	1.52 ±0.28	1.48 ± 0.29	2.53 ± 0.56	3.09 ± 0.69
Picholine	1.24 ± 0.22	1.36 ± 0.29	2.66 ± 0.85	2.94 ± 0.71
Meski	1.38 ± 0.24	1.70 ± 0.41	2.70 ± 0.46	3.16 ± 0.77

Irrigation affected significantly ($p < 0.01$) primary growth (shoot length) and secondary growth (basal diameter). This finding is in agreement with that observed by others authors (Grattan et al., 2006. Iniesta et al., 2009; Correa –Tedesco et al., 2010; Palese et al., 2010; Aïachi et al., 2012). Shoot elongation seems to be also affected by the plant bearing conditions. Comparing the vegetative growth between 2008 (On year) and 2009 (Off year), it appeared that shoot growth was the most important for non-bearing trees (Table 2). These results are in accordance with those reported by Lavee (1997), Fernandez and Moreno (1999) and Martin - Vertedor et al. (2011a) which indicated that the fruit load is considered as the most important factor controlling the vegetative growth. Indeed, these authors indicated that the current shoot growth was always lower during high crop load years. The olive tree is a well-known alternate-bearing species (Lavee, 1997), this is why a high yield year is generally followed by a low yield year even under optimal conditions of cultivation. The vegetative growth is reduced during Off year due to competition for assimilates between new shoots and the growing fruits, which become the main sinks after the fruit set. Proietti and Tombesi (1996), Castillo-Llanque et al. (2005, 2008) and Martin-Vertedor et al. (2011a), who studied the interaction between the shoot growth and the reproductive behaviour in olives, reported that the bearing condition of the tree influences consistently both the current-year shoots' number and their growth. This behaviour is not only specific for olives.

Table 6 Statistical analysis of year, variety, irrigation treatment and their interaction on length and basal diameter of shoot.

Factors	Length	Diameter
Year	110.8**	1028.1**
Variety	12.73**	33.4**
Irrigation treatment	9.04**	31.2**
Year * Variety	11.05**	4.2**
Year * Irrigation treatment	5.5*	6.49*
Variety * Irrigation treatment	1.3 NS	2.22*
Year * Variety * Irrigation Treatm	3.4**	1.16NS

* Significant at *P*<0.05; ** Significant at *P*<0.01; NS: no significant

Yield and Oil quality

Yield fluctuated consistently as a result of the alternate bearing. The year effect on the yield was significant at P<0.01 (Table 7). In 2008 (On year), yield varied between 4.4 and 33 kg tree^{-1} and between 2.5 - 27.8 kg tree^{-1} for treatments of 10 and 100% Etc, respectively. In 2009 (Off year), it was much lower than that observed during the previous year. Yields during Off years on varieties like *Picholine*, *Coratina*, *Meski* and *Koroneiki*, can be reduced by as much as 90-100 % to those of the On year, like noted by Serrano et al. (1998). There were no differences between irrigation treatment (10 and 100% Etc) for either 2008 and 2009. Highest biennial yield (2008 and 2009) wase also observed for *Koroneiki* at 100% ET_c (46.1 kg tree^{-1}) and for *Coratina* 10% ET_c (34 kg tree^{-1}). Lowest biennial yield was noted for *Chetoui* for the two plants' water status; yield was equal to 8.7 and 7.3 kg tree-1 for 10% Etc and 10% Etc, respectively.

Table 7 Yield (kg $tree^{-1}$) and accumulated yield (2008-2009) for studied varieties under the two irrigation treatments. Each value is the average of four trees per irrigation treatment.

Varieties	Treatments	Year 2008	Year 2009	2008-2009
Picholine	10% ETc	27.5 ± 15.0	3.0 ± 3.4	30.5
	100% ETc	24.2 ± 6.9	1.0 ± 1.5	25.2
Coratina	10% ETc	33 ± 6.8	1 ± 1.1	34
	100% ETc	27.3 ± 6.8	0	27.3
Meski	10% ETc	18.2 ± 2.5	0	18.2
	100% ETc	16.7 ± 14.4	0.66 ± 1.15	17.3
Chetoui	10% ETc	4.4 ± 5.2	4.3 ± 7.5	8.7
	100% ETc	2.5 ± 5.0	4.8 ± 6.8	7.3
Chemlali	10% ETc	15.8 ± 5.7	0.2 ± 0.6	16.0
	100% ETc	23.7 ± 6.1	0	23.7
Koroneiki	10% ETc	8.5 ± 8.9	20.7 ± 18.2	29.2
	100% ETc	23.3 ± 14.9	22.8 ± 9.1	46.1
Variety effect *F*-value		12.83 **	11.59**	
Irrigation effect *F*-value		0.45 NS	0.72 NS	
Year effect *F*-value		3.32**		

NS Non significant, ** Significant at $P<0.01$.

The olive yields fluctuated between the 2 years of study. It seems that the typical alternate bearing behaviour of this species, alters the producing pattern of the plant over the years making the effect of irrigation on productive level less evident, like reported by Magliulo et al. (2003), Palese et al. (2010), Martin-Vertedor et al. (2011b) and Aïachi et al. (2012). It was clear that the response of varieties to water deficit may be different. Our results confirm again this statement (Table 5). It seems, under the experimental conditions of this study, that *Chetoui* showed the lowest biannual yield which not exceeds 8 kg $tree^{-1}$(1600 kg ha^{-1}) even for trees which received 100% ETc. *Picholine, Coratina* and *Koroneiki* showed an economical satisfactory yield. The biannual yield varied between 29 kg $tree^{-1}$ (5919 kg ha^{-1}) and 34 kg $tree^{-1}$ (6936 kg ha^{-1}) in the treatment which received a supply of water equal to 10% Etc. From our observations, it appeared that it was difficult to clearly quantify the effect of water stress on the yield. This can be due to the initial variability of the canopy volume and the fruit load among trees and the accumulation of some stress effects over the years; but the main difficulty resides in the alternate bearing behaviour, requiring that all analyses should be done over biennial averages, like noted by Iniesta et al. (2009). The reduction in the yield in 2009 is associated to the reduction in the vegetative growth of 2008; fewer leaf pairs mean fewer flowering points. However, the reduced vegetative growth induced a higher number of fruits per unit leaf area (Iniesta et al., 2009). Aïachi et al. (2012) noted that the irrigation volume can be adjusted following the expected fruit crop load. A smaller water amount (20% ETc) can be recommended for the non-bearing years. This amount will be adequate to limit the excessive growth for maintaining more compact canopies. Indeed, the excessive development of the leaf area limits the competition for light within and between the tree canopies and reduces tree size. Higher irrigation amounts could be advisable during On year.

Irrigation (100% Etc) caused an increase of the fruit weight and the pulp:stone ratio for all varieties (Table 8). There were statistical differences in the fresh fruit weight between rain-fed conditions and full-irrigated trees. Irrigation did not cause significant difference in the concentration of the olive oil extracted from the dry mass or from the fresh mass. From our results, it seems that the water supply did not cause any variation in the oil accumulation of the fruit. This result is in accordance with those of Patumi et al. (2002), D'Andria et al. (2008) and Martin-Vertedor et al. (2011b) that did not find any difference in the oil content between the irrigated and the non-irrigated. The effects of irrigation on oil content are quite controversial. Authors like Inglese et al. (1999), Grattan et al. (2006), Melgar et al. (2008), Iniesta et al. (2009) and Palese et al. (2010) found that higher oil content in fruits come from non-irrigated olive trees with respect to the irrigated ones. These authors reported that the higher oil yield in rain-fed olive trees was coupled with lower water contents in fruits.

Table 8 Weight fruit, pulp:stone ratio and oil yields for studied varieties under the two irrigation treatments.

Varieties	Treatment	Weight fruit (g)	Pulp:stone	Oil concentration (% Dry mass)	Oil concentration (% Fresh mass)
Picholine	10%ETc	3.38 ± 0.05	6.39 ±1.97	*	*
	100%ETc	3.64 ± 0.09	6.84 ± 1.40	*	*
Meski	10%ETc	5.89 ± 0.12	5.25 ± 2.56	*	*
	100%ETc	7.28 ± 0.44	6.10 ± 1.0	*	*
Koroneiki	10%ETc	1.35 ± 0.07	5.81 ± 0.90	52.98 ± 1.74	29.12 ± 1.80
	100%ETc	1.21 ± 0.10	5.66 ± 1.26	52.64 ±2.08	28.28 ± 1.41
Coratina	10%ETc	2.70 ± 0.20	7.03 ± 2.20	49.71 ± 1.29	30.64 ± 1.43
	100%ETc	2.60 ± 0.30	5.07 ± 1.12	50.12 ± 1.53	30.34 ± 0.32
Chetoui	10%ETc	2.22 ± 0.05	6.30 ± 1.48	52.93 ± 1.53	29.23 ± 0.85
	100%ETc	2.70 ± 0.30	8.42 ± 0.52	53.46 ± 3.32	30.92 ± 3.78
Chemlali	10%ETc	0.84 ± 0.05	5.36 ± 0.36	48.40 ± 1.25	26.13 ± 0.77
	100%ETc	0.94 ± 0.03	5.35 ± 0.18	50.52 ± 1.57	25.65 ± 0.98
Variety effect *F*-value		14.20**	3.53**	6.66**	3.68**
Irrigation effect *F*-value		6.71**	0.02 NS	0.82 NS	0.001NS

As far as the quality of the oil, the analytical data, indicate that all the oil could be classified as ''extra virgin'' at least for the accounted parameters (Table 9), their values being well below the set legal limits (COI, 2013). Acidity was inferior to 0.8% for all variety and irrigation treatments. K232 and K270 absorbance were lower for irrigated trees issued of Chemlali.

There were no differences for chlorophyll and total phenols between the treatments. The irrigation regime barely affected the oil fatty acid ratio. Differences were observed between varieties and not between irrigation treatments. *Koroneiki* and C*oratina* showed the highest percentage of oleic acid which was equal to 68-71% for *Koroneiki. Chemlali* noted the lowest percentage for this acid (57-60%) and the highest percentage for palmitic acid (17-19%).

The available literature on the influence of the irrigation regime on the quality parameters is somewhat contrasting. Berenguer et al. (2006), in a study comparing seven different levels of irrigation, found slight differences in the free acidity and the peroxide number only when comparing the extreme treatments, the least and the most irrigated ones. Controversially, others authors did not find significant differences (Patumi et al., 2002; Magliulo et al;, 2003; Tognetti et al., 2006; Palese et al., 2010). From the results of the present study, it seems that water availability did not affect the examined oil chemical parameters, which was in agreement with results of Patumi et al. (2002) and Palese et al. (2012).

Table 9 Physico- Chemical characteristics and fatty acid composition of the oil varieties for the two irrigation treatments. Statistical analysis of the data was performed between treatements (10 and 100% Etc). Different capital and small letters represent statistical differences at p <0.01 and p <0.05, respectively.

	Treatment	Chlorophyll (ppm)	Total Phenol (ppm)s	K232	K270	Acidity (%)	Palmitic Acid (%)	Oleic Acid (%)	Linoleic Acid (%)
Koroneiki	10%ETc	1.07 a	186.91 a	1.99 a	0.116 a	0.65 A	13.92 a	68.92 a	12.98 a
	100%ETc	2.27 a	257.86 a	2.24 a	0.129 a	0.25 B	13.80 a	69.36 a	12.39 a
Coratina	10%ETc	0.17 a	443.08 a	2.28 a	0.077 a	0.19 a	14.81 a	70.23 a	10.80 a
	100%ETc	0.65 a	468.60 a	2.19 a	0.083 a	0.20a	14.05 a	71.05 a	10.68 a
Chetoui	10%ETc	1.89 a	483.88 a	2.37 a	0.162 a	0.22 a	10.93 a	65.15 a	19.74 a
	100%ETc	0.39 a	565.38 a	2.21 a	0.178 a	0.38 b	11.62 a	60.75 a	23.93 a
Chemlali	10%ETc	1.28 a	265.22 A	2.44 A	0.123 a	0.24 a	16.52 a	60.45 a	17.95 a
	100%ETc	0.80 a	129.14 B	1.82 B	0.069 b	0.35 a	17.83 a	57.04 b	19.52 b

Conclusion

The scarcity of available water for irrigation is one of the most serious problems for agriculture in arid and semi arid regions. The Olive tree is considered as a heady species giving a satisfactory yield in a variety of areas. They show not only several sclerophyllous characteristics, but also an active mechanism controlling water loss. In spite of its ability to support a water shortage, olive trees can, in opposite respond favourably and quickly to low volumes of water, improving consistently their production. Nowadays, new olive orchards are planted at higher densities and irrigated during the dry season, thus achieving greater yields. New varieties were introduced in these areas while local varieties were also used with higher densities with little information about the orchard management (training system, adapted pruning, quantity of irrigation...) and cultivar characteristics (ecophysiological behaviour, growth, fruiting responses, architectural properties............).

Under our experimental conditions, the olive trees both irrigated and non-irrigated which received a little quantity of water, showed a strong plasticity of the different varieties, according the physiological responses of the different varieties to the two irrigation treatments, their vegetative growth (primary and secondary growth), and the yield component (olive production, oil yield and fatty composition) adjusting them according to the cultivar adaptability, the water status of the tree and the crop load. From the results of the present study, it seems that the full-irrigated trees noted a higher stomata density and longer stomata pore. The reduction of water did not seem to have a strong effect on the trichomes number and their diameter. Many differences were found between the seven studied varieties.

The tree water status reflects the balance between the plant water supply and the evaporative demand. The seasonal dynamics of midday leaf water potential show large variations all over the season than those produced by the irrigation treatments and a great sensitivity to the microclimatic conditions. Diurnal measurements of the leaf water potential noted synchronous variations along a spring day for the two water status of irrigation treatments applied on the different varieties. These changes responded to the fluctuation of the water status, the soil moisture conditions and the atmospheric evaporative demand. The leaf water potential of young leaves is lower than that of older leaves for all varieties. This effect is more pronounced in stressed trees which can be explained by the various changes in the leaf age affecting the water use by the tree.

The irrigation affected significantly the shoot length and the basal diameter. Shoot growth showed significant differences between the years, with higher values observed during the second year of experiment, i.e. 2009 year OFF. Fruit load seems to be an important factor that controls this elongation.

Under our experimental conditions, the olive trees, both irrigated and non-irrigated, showed a strong plasticity of the yield components (olive production, yield and oil yield) adjusting them according to the soil water availability, the crop load and its extent over the years. From the results of the present study, it seems that the water availability did not affect the examined oil chemical parameter. The irrigation regime barely affected the oil fatty acid ratio.

Many significant differences were found between the seven studied varieties which seem to be related to their genetic background. Chetoui doesn't seem to be adapted to central and south Tunisia even in irrigated conditions. *Chetoui* showed the lowest biannual yield which didn'tt exceeds 1600 kg ha^{-1} even for trees which received 100% ETc. *Picholine, Coratina* and *Koroneiki* showed an economical satisfactory yield. The biannual yield reached 6000 kg ha^{-1}even in trees which received a supply of water equal to 10% Etc. *Koroneiki* and *Coratina* can get a very interesting production potential and interesting oil characteristics which showed a lower percentage of palmitic acid equal to 14 and a rate of oleic acid above 70%.

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