The Journal of Animal & Plant Sciences, 29(4): 2019, Page: 1037-1045
ISSN: 1018-7081

EFFECT OF IRRIGATION FREQUENCY ON THE YIELD AND VEGETATIVE GROWTH OF TWO OLIVE CULTIVARS (CVS. KORONEIKI AND PICHOLINE) IN ARID LANDS

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ABSTRACT

A field experiment was carried out to investigate the effect of tree irrigation frequency on the vegetative growth and yield of two introduced olive cultivars (*Olea europaea* L. cvs. Koroneiki and Picholine). The trials took place in 2014. There were four different irrigation treatments, which were irrigating every other day (T0), every 4 days (T1), every 8 days (T2) and scheduling irrigation according to farmer experience (FM). Vegetative tree responses, such as shoot growth, basal diameter and number of leaves, were evaluated. Olive fruit morphological characteristics (olive length, olive diameter and weight) and yields were also determined. The vegetative growth of both cultivars was directly associated with water availability throughout the experiment. The Picholine cultivar had better growth-related parameters than Koroneiki. However, Picholine did not have an autumnal growth period. Furthermore, it only produced a significant yield under well irrigated conditions. Koroneiki tree yields were higher than Picholine yields for all irrigation frequencies. Irrigation treatment T2 had the most water depressive effect on the Koroneiki cultivar because a 50% reduction in the water supply reduced the yield by 43%. The olive characteristics of both cultivars were not affected by watering frequency.

Key words: Shoot growth, fruit characteristics, heat stress, water stress.

INTRODUCTION

In Tunisia, more than 30% of the cultivated land is dedicated to olive growing (1.68 million ha), and over 66 million olive trees produce 129 300 tons of olives per year on average (Larbi and Chymes, 2010). Olive orchards are scattered across the country from the north, where rainfall can reach 900 mm a year, to the south, where precipitation does not exceed 150 mm. Over 97% of these orchards rely on a rain-fed water supply system and are located in semiarid and arid regions (central and southern Tunisia), which are characterized by low rainfall, water scarcity and limited underground water resources (Taamalli *et al*., 2012). Despite the fact that olive traees are highly adapted to these conditions, there is still a reduction in photosynthetic activity, which leads to significant declines in vegetative growth, low yields, fluctuations in production and pronounced alternate bearing behaviour.

The recognized health benefits and the high nutritional value of olive oil have led to significantly increased consumption (Boussadia *et al*., 2017; Roselli *et al*. 2017). Therefore, there has been an increase in demand, which has pushed production to new limits. This has led to grove intensification and an increasing tendency to grow olives in regions where precipitation is insufficient to support economic yields (Fernández *et al*., 2018; Souilem *et al*., 2017).Water resources are very scarce in south of the country. The potential water resources are estimated to be 4.8 Mm^3/year, of which 4.6 Mm^3/year (80%) can be mobilized for agriculture (Masmoudi *et al*., 2009). Furthermore, these rare resources are abused and used inefficiently, especially in fruit tree plantations (Hassine *et al*., 2017), and climate change projections suggest that there will be a dramatic increase in temperature and a decrease in precipitation in the future (IPCC, 2015; Field *et al*., 2014; Sonwa *et al*., 2017). These challenges have led to improvements in production, notably by intensifying production, introducing more productive cultivars and shifting from rain-fed to irrigated conditions (Mezghani *et al*., 2014). New orchards are planted at higher densities and with newly introduced cultivars, which achieve greater yields with reduced fluctuation. This increases the pressure on the already scarce water resource. However, previous research has shown that olive trees respond favourably to the low water volumes during the dry season (Ahmed *et al*., 2007; Chehab *et al*., 2009; Masmoudi *et al*., 2010). Deficit irrigation is one of the techniques that has been shown to considerably improve water productivity in olive plantations without having any major effects on yield (Gertsis *et al*., 2017; Iniesta *et al*., 2009). However, the effect of watering frequency on the introduced cultivars in a particularly hot and dry climate still needs further investigation.

In this context, the aim of our study was to evaluate the effect of tree irrigation frequencies on the vegetative growth and yields of two introduced olive cultivars (*Olea europaea* L. cvs. Koroneiki and Picholine).

MATERIALS AND METHODS

Experimental site: The experiments were conducted during 2014 in a commercial olive orchard (*Olea europaea* L. cvs. Koroneiki and Picholine) at Bir-Mgurin, Medenine, Tunisia (20 km west of Medenine City, latitude: 33°19'12.7"N, longitude: 10°22'59.0"E, altitude: 130.7 m). The bio-climate is arid with hot and dry summers and mild winters. The reference evapotranspiration is generally about 938 mm, as estimated by the FAO–Penman–Monteith equation (Nagaz *et al*., 2012). The rainfall is irregularly distributed throughout the year and ranges from 100–200 mm. The soil is a sandy loam.

The olive orchard used in this study consisted of 1100 trees (*Olea europaea*, 750 cv. Picholine and 350 cv. Koroneiki) that had been planted in 2005 on 4.2 ha of land. Tree spacing was 6m × 6m and standard cultural practices used in the region were applied.

Experimental design: The experimental layout followed a split-plot design. The main plot units had a $4^{*}2$ factorial design with four irrigation frequencies and two olive cultivars. Irrigation frequency was the main factor and the split-plot units within each main plot consisted of 28 olive trees.

Irrigation was designed to deliver 100% of the available water content (AWC). The irrigation treatments consisted of irrigating every other day (T0), irrigating every 4 days (T1), every 8 days (T2) and scheduling irrigation according to farmer experience (FM) i.e. the farmer stopped irrigating after rain events and irrigated more when irrigation was critical. The irrigation water salinity level was 2.6 g/L.

Measurement methods:

Soil moisture: Time domain reflectometry (TDR), equipped with a TRIME T3-50IPH tube access probe (IMKO, Ettlingen, Germany), was used to monitor the volumetric water content of the soil (θv). Four trees per treatment and cultivar were selected for soil water content measurement via access tubes. The tubes were able to measure volumetric water content from the surface down to 0.8 m at intervals of 20 cm.

Shoot growth: Shoot length, basal diameter and number of leaves were the three parameters used to evaluate shoot growth. Measurements were carried out on four trees selected from each treatment and variety. At the beginning of the growing season, four shoots produced during the current year were selected on the east side of the canopy of each tree. Shoot measurements were made at weekly intervals during the growing season. The final shoot lengths and basal diameters of the different varieties were measured in December.

Yield and oil chemical determination: The fruits of both varieties, i.e. Picholine and Koroneiki, were manually harvested in October 2014 and the average olive yield per plant was determined. Representative samples of 800 olive fruits per plot (100 olives per tree) were used to determine the fruit characteristics i.e. olive length and diameter. Fruit weight was determined as the weight of 100 fruits.

Statistical analysis: A two-way analysis of variance (ANOVA) was used to examine the effect of cultivar and irrigation treatment on the measured parameters. The differences between irrigation treatments were compared using Tukey's test at $p < 0.05$. These analyses were performed using SPSS 16.0 statistical software for Windows (SPSS, Chicago, IL, USA).

RESULTS

Soil water content: As expected, soil water content decreased along with irrigation frequency. Both cultivars showed similar results after the T0, T1 and T2 treatments. However, after irrigation treatment FM, the soil water contents at 0.6 and 0.8 m soil depths were significantly higher for Picholine (Figure 1).

Shoot length: The shoot growth parameter results recorded during the experimental year for each cultivar and irrigation treatment are shown in Figure 2. The results showed that water treatment had a significant effect on the vegetative growth of the two cultivars. Annual shoot length for the Picholine cultivar varied between 16.2 cm and 26.7 cm for the T2 and T0 treatments, respectively, and between 7.4cm and 21 cm for the T2 and T0, respectively for Koroneiki cultivar.
Longer shoot lengths were recorded for the Picholine cultivar regardless of the irrigation frequency applied. The Picholine shoot lengths were 11.6% to 20.6% longer than the Koroneiki lengths. However, Figure 2 shows that the Koroneiki cultivar performed better under irrigation treatment FM than Picholine.

For both cultivars, primary growth began in early March, immediately after bud burst, which had occurred by the end of February. However, its evolution was different for the two cultivars (Figure2). During the experimental year, the Koroneiki length dynamic was characterized by a double-sigmoid pattern, with a first spring flush observed from early March to late May and a second growth flush recorded from mid-August to November. However, Picholine had a simple-sigmoid pattern and growth had practically stopped by mid-May.

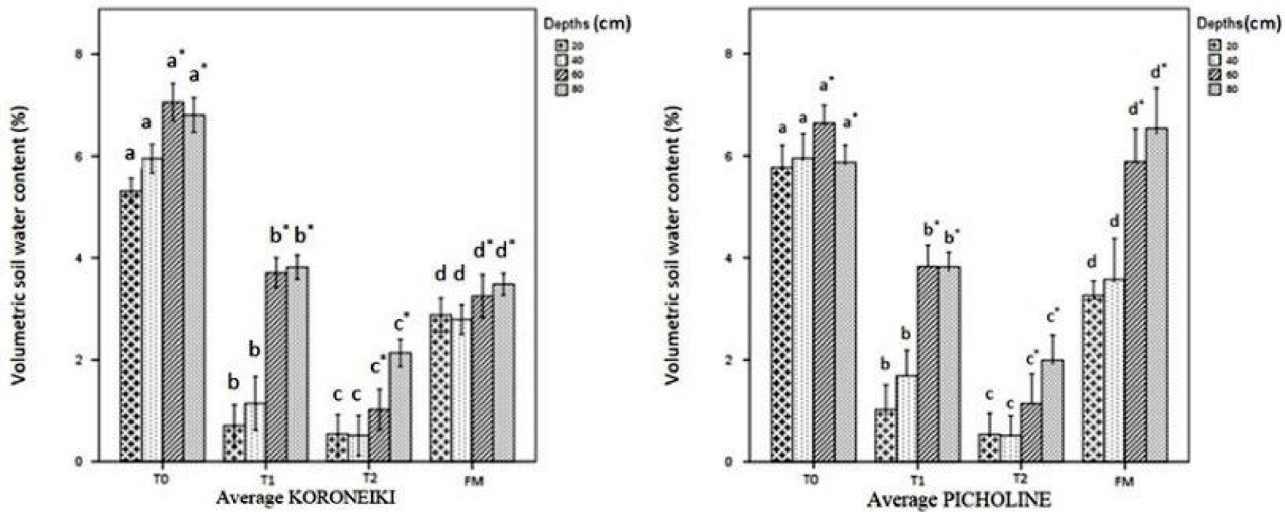

Figure1. Mean soil water contents at 0.2m, 0.4m, 0.6m and 0.8m depth for Picholine and Koroneiki under the different irrigation treatments (T0, T1, T2 and FM). Means with different letters or an asterisk are significantly different at $p < 0.05$.

Basal diameter: Irrigation level also had an important influence on basal diameter. The most frequent water irrigation treatment (T0) produced a significant increase in olive tree basal diameter (Figure 3). The increase varied from 2.3 mm (T2) to 3.07 mm (T0) for Picholine and between 2.03mm (T2) and 3.06 mm (T0) for Koroneiki. Therefore, water availability increased the Picholine and Koroneiki basal diameters by 26.73% and 36.29%, respectively.

The well irrigated trees (T0) and moderately stressed trees (T1) had similar final basal diameters for both cultivars. However, the severely stressed Koroneiki trees (T2) showed lower decreases in basal diameters (2.03 mm) than the Picholine cultivar (2.31 mm). In a similar manner to shoot length, the Picholine cultivar produced better results after the farmer irrigation method (FM) than after the T0 treatment.

Secondary growth was analogous to shoot elongation. There was a spring growth burst for both cultivars and autumnal growth for Koroneiki. However, this second burst was nearly absent in the water stressed trees (T1 and T2).

Number of leaves per shoot: The results for the number of leaves had a similar trend to shoot length and basal diameter. They showed the clear effect of water availability. In summer, the number of leaves on Picholine trees slightly decreased for all irrigation treatments. However, there was a slight recovery in leaf numbers on the trees that received the most frequent water application (T0). The autumnal growth results for the Koroneiki cultivar showed, that there was a minor increase in leaf number during autumn.

Yield and fruit characteristics: Table 1 shows the yield parameter results for the Koroneiki and Picholine cultivars. It shows the means for olive fruit length, diameter and mass. The Koroneiki fruits had relatively large olive oil production yields at all irrigation frequencies. However, the Picholine trees only produced olive oil under irrigation treatments T0 and FM. The irrigation treatments did not have a significant effect on olive fruit dimensions. Similarly, olive fruit mass was not significantly affected by irrigation frequency.

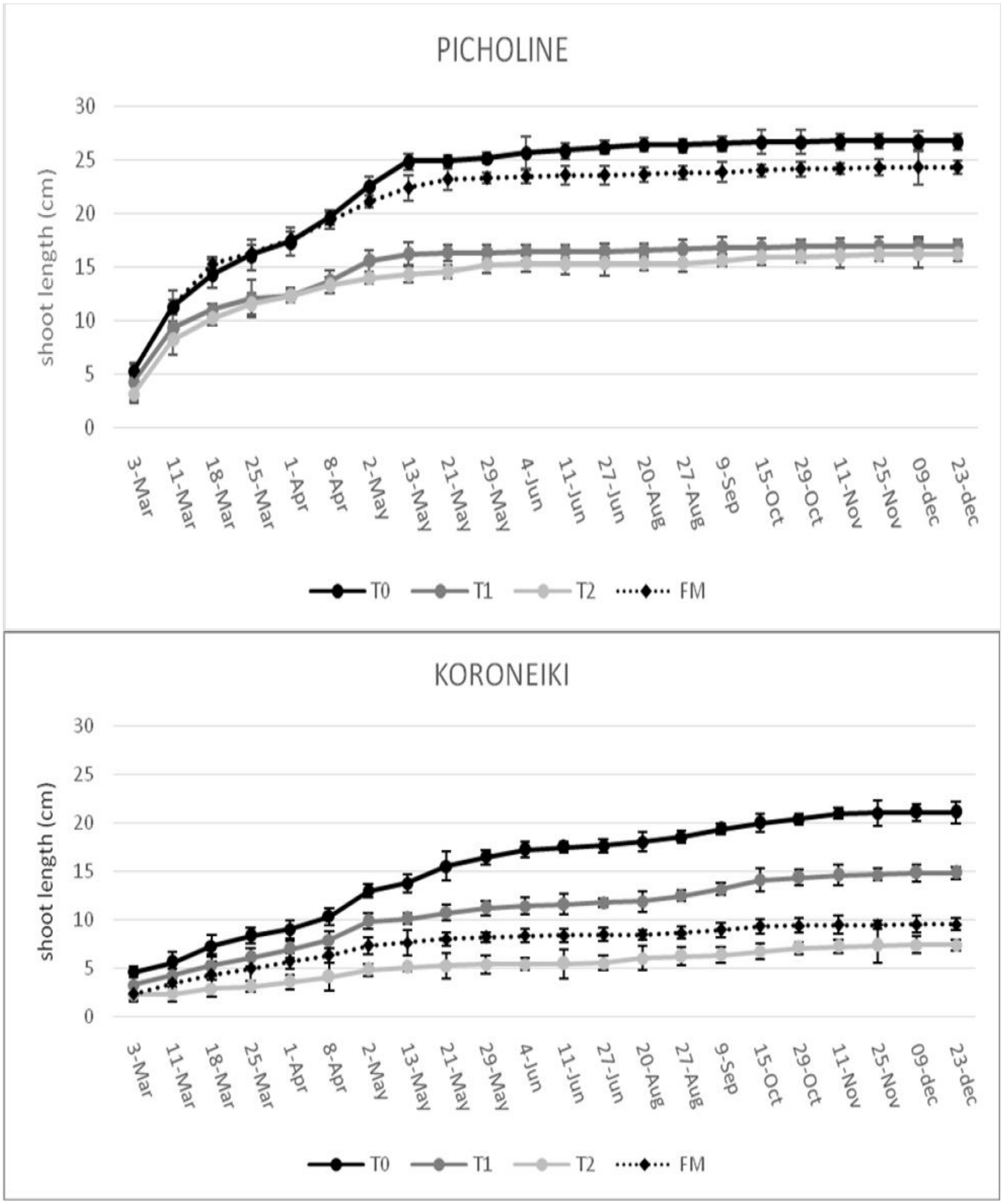

Figure 2. Evolution of shoot length (cm) during the growing season (2013–2014) for the Picholine and Koroneiki cultivars under irrigation treatments T0, T1, T2 and FM.

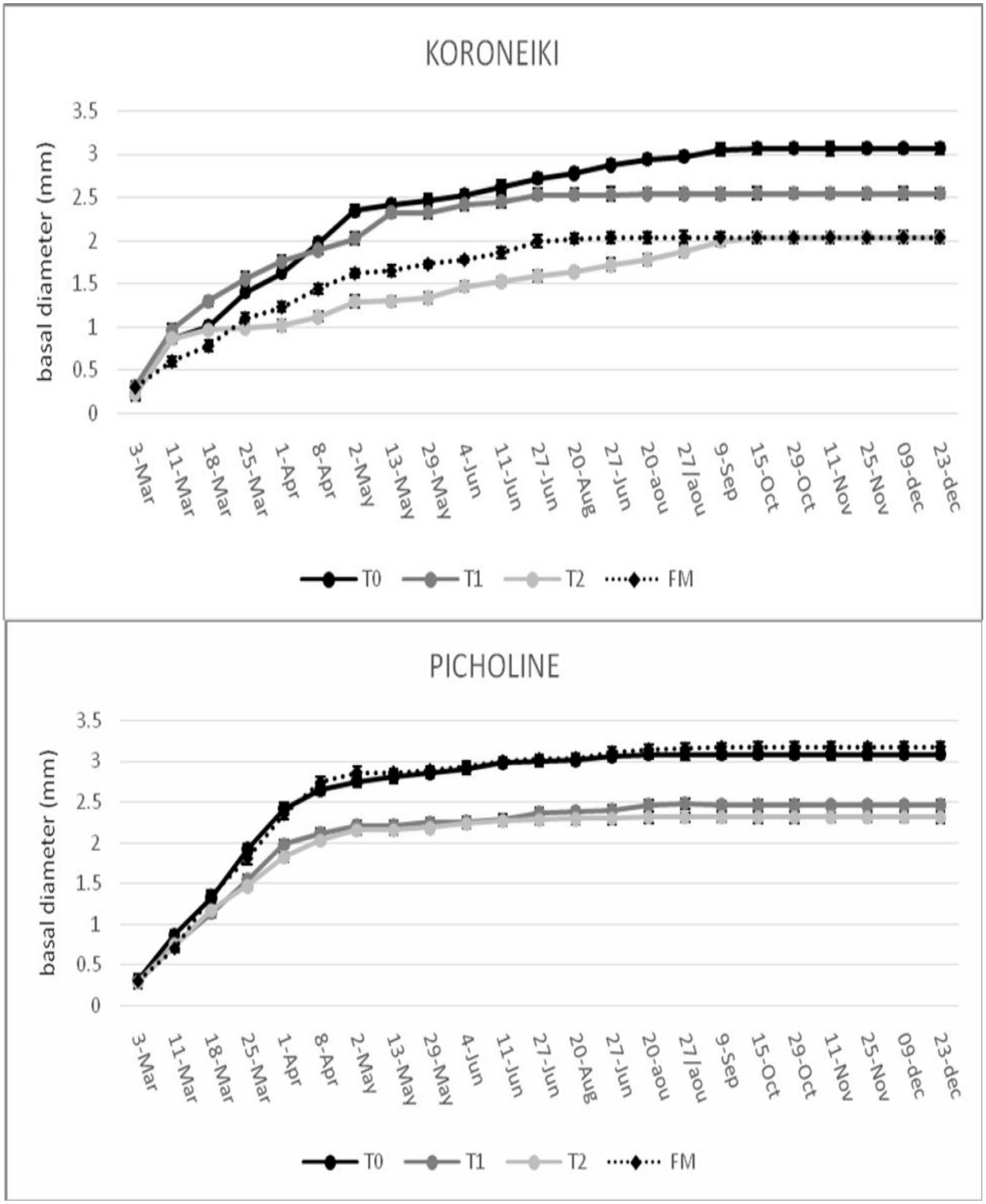

Figure 3. Evolution of basal diameter (mm) during the growing season (2013–2014) for the Picholine and Koroneiki cultivars under irrigation treatments T0, T1, T2 and FM.

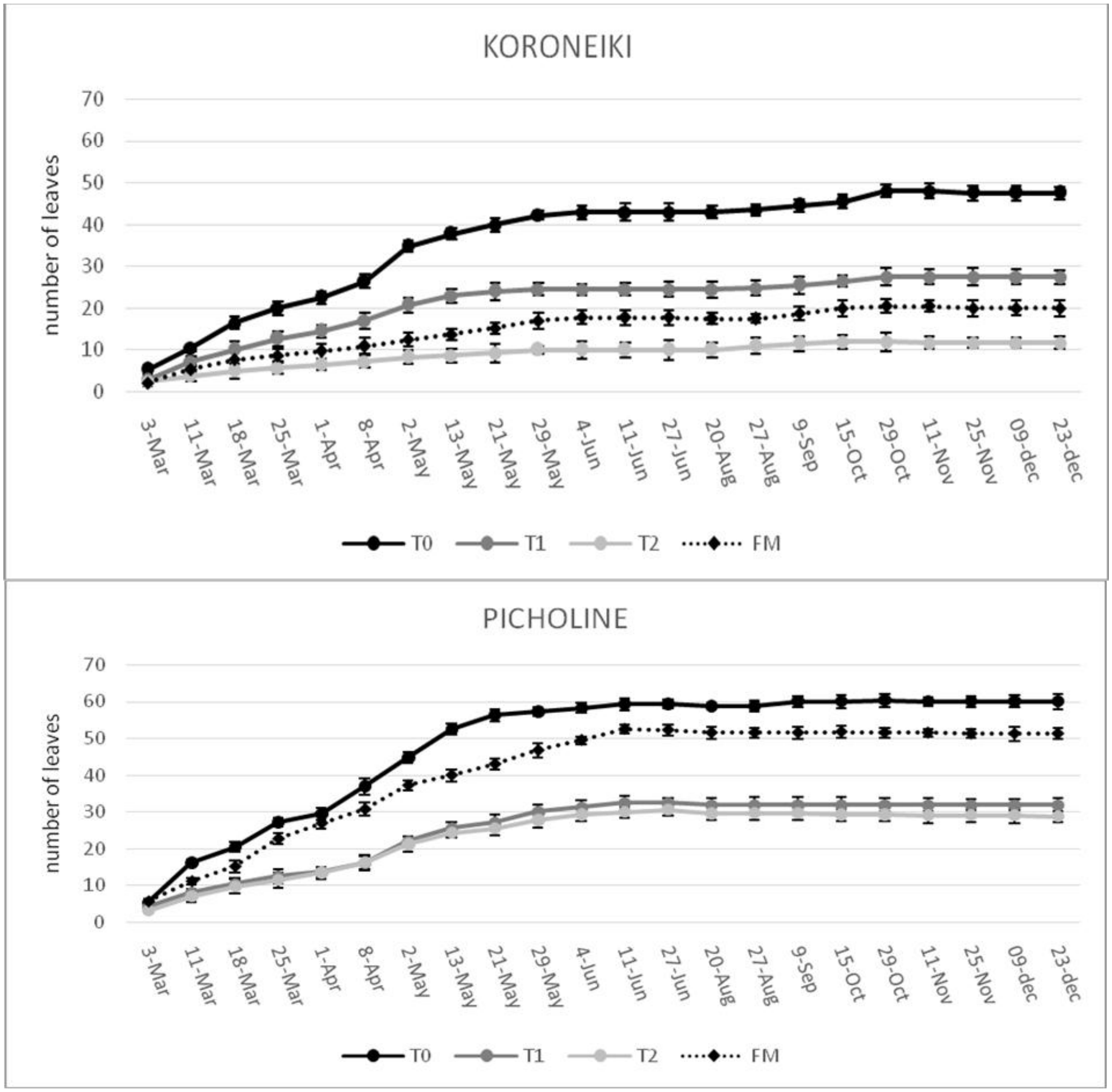

Figure 4. Evolution in the number of leaves per shoot during the growing season (2013–2014) for the Picholine and Koroneiki cultivars under irrigation treatments T0, T1, T2 and FM.

Table1. Yield and fruit characteristics for the Picholine and Koroneiki cultivars under irrigation treatments T0, T1, T2 and FM.

		Olive production (kg)	Olive length (cm)	Olive diameter (cm)	Olive fruit mass (g)
Picholine	**T0**	15.8 ± 10.7	2.2 ± 0.07	1.49 ± 0.16	3.32 ± 0.1
	T1	0	2.1 ± 0.09	1.52 ± 0.1	3.16 ± 0.2
	T2	0	1.93 ± 0.09	1.49 ± 0.13	3.13 ± 0.09
	FM	2.6 ± 4.2	2.21 ± 0.08	1.63 ± 0.09	3.15 ± 0.13
Koroneiki	**T0**	26.3 ± 15.3	1.5 ± 0.09	0.92 ± 0.1	2.00 ± 0.08
	T1	14.1 ± 5.2	1.5 ± 0.1	0.98 ± 0.08	1.88 ± 0.11
	T2	15.7 ± 3.2	1.7 ± 0.08	1.07 ± 0.11	1.88 ± 0.08
	FM	23.5 ± 7.6	1.7 ± 0.2	1.1 ± 0.08	1.96 ± 0.08

DISCUSSION

The primary growth (shoot length), secondary growth (basal diameter) and leaf numbers for both cultivars were significantly affected ($p < 0.05$) by water availability. Furthermore, an analysis of the relationship between vegetative growth and irrigation treatment showed that shoot growth was significantly affected by water application frequency. Therefore, vegetative growth was directly associated with water availability throughout the experiment. These results agree with the findings reported by previous studies (Correa-Tedesco *et al*., 2010; Grattan *et al*., 2006; Iniesta *et al*., 2009; Mezghani *et al*., 2012; Palese *et al*., 2010) which indicated that irrigation is the most important factor controlling vegetative growth. These previous studies also suggested that vegetative growth is a good indicator of water stress because even mild stress early on in the growing season could be identified.

In general, both cultivars showed a higher shoot growth rate than the rates recorded by Mezghani *et al*. (2014) and Iniesta *et al*. (2009). This difference may be due to the shoot type chosen for measurements. Mezghani *et al*. (2014) and Iniesta *et al*. (2009) measured short shoots, whereas we measured long shoots. Cultivar type tends to have a weak effect on the development of long shoots. In contrast, environmental factors have a considerable impact on long shoot development (Ben Sadok *et al*., 2013), which means that long shoots can be used to indicate potential environmental impacts on cultivar growth.

The Picholine cultivar produced better growth-related parameter results than Koroneiki. This can be explained by the differences between the two cultivars. For example, Picholine is known to have a large canopy where as Koroneiki has an intermediate growth pattern (Masmoudi-Charfi & Mechlia, 2007). Further examination shows that deficit irrigation has an important impact on the growth of Picholine. This may be because this cultivar has a smaller root system, which makes it more vulnerable to water shortage (Chehab *et al*., 2009). Furthermore, the absence of autumnal growth in Picholine for all irrigation treatments shows that the heat stress during the summer period had a considerable impact on this cultivar.

The Koroneiki yield was higher than the Picholine yield at all irrigation frequencies. This can be attributed to the alternate bearing behaviour, which has a strong influence on both yield and vegetative growth during the current year and the next year (Castillo-Llanque *et al*., 2004; Martín-Vertedor *et al*., 2011; Proietti & Tombesi, 1996). This behaviour is characterised by a high yield year with minimal vegetative growth followed by a low yield year with intense vegetative growth. During the ON year, fruits become the main sinks after fruit set (Fernández & Moreno, 2000). This creates competition for assimilates between new shoots and the growing fruits, which leads to a reduction in vegetation during the ON year. However, under T0 irrigation, Picholine trees produced 15.8 kg/tree, which indicates that alternation behaviour cannot totally explain the difference in production because alternate bearing behaviour affected yielding even under optimal cultivation conditions (Castillo-Llanque *et al*., 2004). Furthermore, farmers use modern pruning techniques that can attenuate the alternate bearing behaviour. Therefore, its effect is less pronounced from year to year and production is more or less stable. The high standard deviation values for yield at all irrigation frequencies and for both cultivars suggests that alternate bearing is concealed every year (Sant Lavee, 1977).

Table 1 shows that irrigation frequency did not influence fruit weight and only had a marginal effect on fruit size. Furthermore, Gómez-Rico *et al*. (2007) and Shimon, Lavee, & Wodner (2004) showed that fruit size and weight declined when olive tree production increased. It has also been previously reported that under deficit irrigation, individual weights and fruit dimensions were correlated with low olive yields (Antari 2002).

The above results show that irrigation treatment T2 had the greatest effect on Koroneiki because a 50% reduction in water supply reduced yields by 43%. This result agrees with the results reported by Salmani *et al*. (2016) and Zeleke *et al*. (2012).

The summer of 2014 was exceptionally hot. The mean maximum temperatures were 8.9°C and 4.9°C above the average maximums for June and July, respectively. This had a considerable impact on Picholine, which is known to be vulnerable to heat stress (Houlali *et al*., 2014). The high summer temperatures led to no autumnal growth and no production yields after theT1 and T2 treatments. Therefore, this cultivar should not be planted in areas where the climate is arid and summer temperatures are high, especially if future climate projections about increases in temperature are correct.

Conclusion: The results of this study indicated that, for the Koroneiki cultivar, spacing irrigation over longer periods of time improves water productivity and produces reasonable yields. Furthermore, the trees are able to recover from both water and heat stress. The results also showed that this cultivar can quickly recover from summer heat and resume vegetative growth and fruit production. However, the Picholine cultivar is considerably affected by high temperature in the summer, which leads to reduced or no olive production by water stressed trees (T2 treatment) and to severe yield decline in the other water treatments.

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