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Evaluation of the use of treated municipal waste water on the yield, oil quality, free fatty acids' profile and nutrient levels in olive trees cv Koroneiki, in Greece

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ABSTRACT

Tertiary reclaimed municipal wastewater was used in order to assess its effectiveness in irrigating olive trees cv Koroneiki against fresh water (FW), for two consecutive cultivating periods. A total of 140 olive trees were used and olive production, oil quality, oil free fatty acid profile and olive nutrition were assessed. The treated municipal wastewater (TMW) used was characterized by relatively low electrical conductivity values, still higher than the FW and higher NH_4, Cl, K, Na, Fe, B, Al and Mn concentration than FW. The application of TMW slightly increased fruit production during the year of high tree yield (15.92 kg fruit per tree versus 12.73 kg per tree under FW irrigation) as well as the oil content, during the year of low yield (18.21% versus 16.43% under FW irrigation). It did not have any significant effect on the oil quality characteristics, such as free acidity, K270, K232, peroxide value and Delta K index. The irrigation treatment did not have any significant effect on the free fatty acid profile of the oil. Oleic acid was the dominant free fatty acid in the oil (ranging from 77.7 to 78.6%), followed by palmitic (10.6–11.1%), linoleic (5.5–5.8%) and stearic acid (2.5–2.8%), with their concentration falling within the range of the values for characterizing it as "Extra virgin" olive oil. The levels of K, Ca, Mg, Mn, Fe and Zn in the leaves increased with the application of TMW compared to FW, while the continuous use of TMW for two years led to a significant increase of P, Mg, Fe, Mn and Zn levels. The use of TMW under the experimental conditions described in the present study could be a valuable and profitable alternative to the use of FW in short term, by improving tree nutritional condition and enhancing oil production of superior quality.

1. Introduction

Irrigation has long been recognized as the most important factor for increasing crop productivity. In arid and semi-arid areas though, water is preserved mainly for drinking purposes, leaving water of lower quality, if any, for agriculture use (Gharsallaoui et al., 2011; Mohammad and Mazahreh, 2003). In Mediterranean basin the increasing demand for high quality water for the cities along with the natural shortage of water due to low rainfall range, has accelerated the search for alternative water sources during the last decades (Oron et al., 1999). Among them, the use of treated municipal wastewater (TMW) for agricultural purposes seems quite appealing, since its use simultaneously solves water shortage and wastewater disposal problems (Hargreaves et al., 2008; Kalavrouziotis et al., 2008). Apart from being a low cost water source, TMW combines various other advantages. It is characterized as an environmentally friendly disposal practice, which minimizes the pollution of rivers and open land by direct disposal (Mohammad and Mazahreh, 2003). Furthermore, it is a valuable source of nutrients and organic matter, enhancing soil fertility through the improvement of its physical and chemical properties (Hargreaves et al., 2008; Mohammad and Mazahreh, 2003 Xu et al., 2010). Treated wastewater usually contains essential plant nutrients such as N, P, K and micronutrients. The use of TMW in

Abbreviations: FW, fresh water; TMW, treated municipal wastewater.

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agriculture increases thus considerably the available agricultural water resources. However, apart from the above benefits of TMW, its continuous use could be responsible for the pollution of soils by trace metals and toxic organic contaminants (Keser and Buyuk, 2012 Xu et al., 2010). Therefore, TMW should be used with extreme care and precautions, in order to avoid surface water eutrophication along with excessive nutrient and heavy metal accumulation in the soil, which could be somehow transferred to the food chain (Kalavrouziotis et al., 2008).

Olive tree (*Olea europaea* L.) is the most important evergreen tree in the Medditeranean basin. It is characterized as a drought tolerant species which reacts positively to irrigation by increasing its yield and improving oil quality. Olive oil has been recognized for its great benefits for human health and its implementation in various healthy diets continually increases. The chemical and organoleptic characteristics of olive oil depend on a variety of internal and external factors, such as the cultivar—genotype, climate, soil, cultivation management and technological practices (Bedbabis et al., 2009). Among all these, irrigation plays a significant role, influencing oil quantity and quality (Bedbabis et al., 2009). Trees that face water stress produce oil of lower quality while water application has been shown to increase oil yield (Bedbabis et al., 2009). Since water shortage is a common situation among Mediterranean countries and countries where olive cultivation is dispersing, the TMW use presents a valuable alternative (Gharsallaoui et al., 2011). Till today, only a few studies have focused on the effect of TMW on olive oil quality, most of them assessing Tunisian olive oil characteristics (Bedbabis et al., 2010a, b, 2009; Batarseh et al., 2011; Gharsallaoui et al., 2011; Khabou et al., 2009). The aim of the present study was to evaluate the effects of fertigating olive trees with TMW on the yield, on oil quality characteristics and leaf nutrient levels of Koroneiki olive cultivar, a Greek cultivar of international value and interest.

2. Materials and methods

2.1. Experimental field

The experimental field (37°22′43.33″ B, 22°26′47.10″ E) consisted of 132 olive trees (cv. Koroneiki) 15 years old, planted at 6 × 6 m distances. The experimental site is located about 4 km south of the city of Sparta. Trees have not been fertilized for at least five years and not irrigated until the initiation of this experiment. Two treatments were imposed, one consisted of irrigating olive trees with fresh water and the other one with treated municipal waste water. There were 6 replicates per treatment. Out of the six replicates, five consisted of 12 olive trees and one of 6 olive trees (Fig. 1). The trial lasted two years, i.e. 2011–2012, during which a total of 7 and 12 irrigation events per summer period took place, according to local agricultural practice, respectively. Local irrigation practice was followed due to the time restrictions in the availability of FW, as it was provided from a Land Reclamation Organization conveyed by a public open channeled network for 1.5–2 h every 7–10 days. Two separate pressurized irrigation pipe networks were installed in the field, one per each treatment, with two sprinklers per tree, providing 90 L/h. The duration of each irrigation event was approximately 2 h. A flow meter was installed at the head of each plot in order to monitor the uniformity of the FW and TMW implementation. Eighteen soil moisture monitoring tubes were also installed (Fig. 1) in order to measure soil volumetric water content θ(%) at 10, 20, 30, 40, 60 and 100 cm depth. This was achieved by using PR2/6 soil moisture profile probe and HH2 Moisture meter (Delta-T Devices, 2013). These measurements verified that the irrigation depths were approximately 1 m, which is the effective root depth of olive tree (maximum rooting depth for olive tree is 1.2–1.7 m and 65% of this is the effective root depth (Allen et al., 1998), as well as that these depths were equal under both treatments.

2.2. Characterization of FW and TMW

The TMW was obtained from Sparta's treatment plant (37°04′15.41″ B, 22°26′50.80″ E) generated from domestic sources. It was reclaimed at the tertiary stage using activated sludge, nitrogen and phosphorus removal and chlorination. The TMW was transferred to the field and stored in open sealed pond just before every irrigation event, while FW was brought to site through open channels and stored to a different nearby opened sealed pond. Analyses took place in both FW and TMW before each irrigation event as described by Bourazanis and Kerkides (2015).

2.3. Olive yield and oil extraction

Olive fruits were harvested electromechanically at industrial optimum ripening stage per each plot and the yield (kg) per plot and per treatment was measured. From each replicate, 7 samples of 100 fruits were withdrawn to assess their mean weight and other production attributes.

A bulk sample was composed from all olive fruits per treatment and oil was extracted using an industrial olive mill in order to estimate oil production. Fruits were crushed with a hammer mill and milled at 28 °C for 30 min. The oil was then separated by a vertical centrifuge, collected and left to decant. Oil samples were then filtered and stored at 4 °C in amber vials in darkness till analysis.

2.4. Olive Oil characterization

Free acidity (FA) content, given as percent of oleic acid, was determined by titration of a solution of oil dissolved in ethanol–ether (1:1) with ethanolic potassium hydroxide. The K232 and K270 extinction coefficients, were measured with a spectrophotometer at the wavelengths of 232 and 270 nm. Peroxide value was determined by titration with sodium thiosulfate and Delta K index was calculated according to the European Union regulation 2568/91.

Due to the fact that TMW contained high amounts of Al, B and Fe compared to the FW, B was determined using the azomethine method, while Fe and Al by atomic absorption spectrophotometry (Varian SpectrAA300)

Fatty acids were converted to fatty acid methyl esters (FAMEs) according to 969.33 AOAC method (AOAC, 1995). The FAMEs were extracted from the oil solution with hexane and analyzed by gas chromatography using an HP 5890 Series II (Hewlett Packard, USA) gas chromatographer equipped with a flame ionization detector (FID) and a capillary column (DB-23, J & W Scientific, UK, 60 m length × 0.25 mm wide × 0.25 μm film thickness). Helium was used as carrier gas with a split rate of 50:1. The temperature of the injector was 270 °C and 280 °C for the detector, while the oven temperature was kept at 190 °C for 30 min, then increased to 230 °C with a 10 °C min^{-1} rate and then remained at 230 °C for 5 min. FAMEs standard were purchased from Supelco and used for the qualitative and quantitative analysis of fatty acids. Results were expressed as a relative percentage of the total area

The nutritional value of the oil was estimated based on fatty acid analysis.

2.5. Soil and leaf analyses

Before the onset of the trial, representative soil samples were collected at 0–30 cm, 30–60 cm and 60–90 cm depths from four points of each plot according to a sampling procedure ("W" pattern) adapted to the size of the plots by the use of a 5 cm diameter