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Long-terms effects of irrigation with treated municipal wastewater on soil, yield and olive oil quality

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ABSTRACT

In Tunisia, water scarcity is one of the major constraints for agricultural activities. The reuse of treated wastewater (TWW) in agriculture can be a sustainable solution to face water scarcity. The research was conducted for a period of ten years in an olive orchard planted on a sandy–silty soil and subjected to two different irrigation treatments: (a) well water (WW) and (b) treated wastewater (TWW). The main aim of the present study was to investigate the influence of irrigation with TWW on soil chemical properties, olive tree yield and on virgin olive oil (VOO) quality during an heavy crop year ("on year") in "Chemlali" olive orchard. Soil samples were collected at the beginning of the study (before irrigation), after five and ten years for each treatment. pH, electrical conductivity (EC), organic matter, major elements, salts and heavy metals contents in soil were investigated. Standard quality parameters, chlorophyll, β-carotene, total phenols (TP), induction time and total tocopherols such as α-,β-,γ-,δ-tocopherol of VOOs were also investigated. Results showed that irrigation with TWW increased soil pH, EC, OM, major elements, salts and heavy metals contents. Data obtained indicated that standard quality indices (free acidity, K_{232}, and K_{270}) of VOO and oil content were not affected significantly by water quality. Instead, chlorophyll, total phenols, induction time and δ-tocopherol values decreased significantly after ten years of irrigation with TWW. However, both fruit water content, and the concentrations of β-carotene and tocopherols (α, β and γ) in VOO increased.

1. Introduction

Olive tree is drought tolerant (Fernández and Moreno, 2000), able to survive severe water stress, and still produce a crop. However, prolonged drought stress is one of the major limiting factors in the production and yield of the fruit of the olive tree, as this directly affects crop load, oil production per tree, oil quality and alternate bearing. So, there are two main reasons for irrigating the olive orchard. On one hand, the plant has a marked response to additional water supplies, even if only small doses of water are applied. On the other hand, considering that increment in the diffusion of new orchards characterized by a high-density cropping system (Camposeo and Vivaldi, 2011; Camposeo and Godini, 2010; Godini et al., 2011), the irrigations becomes a necessity. Under Mediterranean climate, where olive tree is the most cultivated crop, the limited water resources and the increased need for good water quality for urban and industrial sector uses, led to the use of non-conventional water sources: agricultural drainage water, brackish or saline water and industrial or municipal wastewater for agricultural irrigation particularly under actual conditions of rainfall scarcity. The reuse of treated wastewater (TWW) in agriculture could be among the management practices to promote olive tree extension and cultivation at least under described experimental conditions in the south of Tunisia as reported by several studies (Bedbabis et al., 2009, 2010a; Ben Rouina et al., 2011). In Tunisia, this practice is actually more and more extended. Indeed, in 2009, wastewater treatment stations were of 106 generating approximately 238 mm^3 $year^{-1}$ of TWW among which 30% were recycled and supplied for irrigation of 9600 ha of agricultural lands (ONAS, 2010). The treated wastewater (TWW) use in agriculture has potential benefits that can be summarized as follows:

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- provides a reliable source of water supply to farmers and nutrients source for crop production (Jimenez-Cisneros, 1995);
- conserves nutrients, thereby reducing the need for chemical fertilizers (Gil and Ulloa, 1997);
- increases crop yields and returns from farming also if applied on olive orchards (Bedbabis et al., 2009, 2010a; Ben Rouina et al., 2011); is a low-cost method for sanitary disposal of municipal wastewater. However, application of TWW can have some risks either for agriculture products or soil properties (Yadav et al., 2002; Tarchouna et al., 2010 ; Vivaldi et al., 2013). The changes of the physical and chemical properties of soil, as a consequence of irrigation with TWW, can affect water movement in the soil thus also altering the soil hydraulic properties. Moreover, TWW could also increase exposure of farmers, consumers and neighboring communities to infectious and lead to groundwater contamination. However, in the Mediterranean countries and other arid and semi-arid regions which are confronting increasing water shortages, the reuse of TWW for purposes such as agricultural and landscape irrigation reduces the amount of water that needs to be extracted from natural water sources as well as reducing discharge of wastewater to the environment. Thus, treated municipal wastewater is a valuable water source for recycling and reuse. Tunisia belongs to the North Africa area, which is considered one of the driest regions in the world (World Bank, 1996). The reuse of TWW in Tunisia could satisfy the increasing water requirements for agriculture and may constitute an opportunity to preserve freshwater resources for human consumption. TWW is typically reclaimed at the secondary level by using biological processes. These processes consist of eliminating biodegradable material by transforming it into microbial residues in the case of olive mill waste water treatment Hachicha et al. (2009) and Jarboui et al. (2010).

Agriculture is the major mainstay of the Tunisian economy, and the cultivation of olive trees constitutes one of the principal economical sectors of agriculture. In fact, about 65 million olive trees are spread over 1.6 million hectares (Hannachi et al., 2007). Chemlali is the main olive cultivar grown in northern and central Tunisia, and accounts for 80% of Tunisia's oil production (Baccouri et al., 2007). The chemical and organoleptic characteristics of this oil depend, besides the fundamental genetic basis, on several factors clustered into four main groups: environmental (soil, climate), agronomic (irrigation, fertilization), cultivation (pruning, ripening, harvesting) and technological factors (fruit storage, extraction procedures) (Aparicio and Luna, 2002; Clodoveo, 2012, 2013; Clodoveo et al., 2013a,b, 2014; Camposeo et al., 2013). Among these factors, irrigation seems to plays a key role for oil quality (Gomez-Rico et al., 2007).

Several studies have focused on the effects of irrigation with treated wastewater and the application of olive mill wastewater and moderate saline water on soil chemical properties (Al-Absi et al., 2009; Mechri et al., 2011; Bedbabis et al., 2010a, 2014) and little information is known about the effects of TWW on chemical properties of a cultivated sandy–silty soil. Studies on the effect of TWW on olive's growth, productivity and oil quality in Tunisia are scarce (Bedbabis et al., 2009, 2010a; Ben Rouina et al., 2011). The aim of this study was to assess the effect of TWW in a "Chemlali" olive orchard on soil characteristics, olive yield and VOO quality.

2. Material and methods

2.1. Study area, plant material and irrigation schedules

The olive orchards were located at 'El Hajeb' experimental farm in Sfax, (34°43N, 10°41E) in Central–Eastern Tunisia. In this geographical area, the average annual rainfall and temperature averages over 52 years were 250 mm and 23 °C, respectively. The study was carried out from 2003 to 2012 in an olive orchard planted in 1987, with 'Chemlali' olive trees. Trees were spaced 24.0 × 24.0 m, trained to vase and rain-fed.

Fifteen-years 'Chemlali' olive trees cultivated at the density of 17 trees ha^{-1} were selected to be similar in canopy and potential yield. A randomized block design with three blocks and two treatments (TWW and WW irrigation) were used. Both plots contained twenty four olive trees (8 × 3 replications). The water used was either that supplied after biological treatment process (TWW), or the WW from a well situated in the area of the experimental station. The amount of water supplied to olive trees was estimated according to the Penman–Monteith–FAO equation (Doorenbos and Pruitt, 1977) as described by Ben Ahmed et al. (2007). The irrigation was delivered using a drip irrigation system, with four drip nozzles (two per side) set in a line along the rows (at 0.5 m from the trunk). Without taking rainfall into account, the daily water supply per olive tree was 4.5 m^3, for a total water supply of 5000 m^3 ha^{-1} $year^{-1}$. Since the beginning of the irrigation design, trees of both WW and TWW plots does not receive any chemical or organic fertilization. The characteristics of TWW and WW were reported in Table 1.

Table 1
Chemical analysis of irrigation waters from both sources.

Characteristics	WW	TWW	Tunisian limits
pH	7.95 ± 0.10	7.60 ± 0.11	6.50 - 8.50
EC ($dS\,m^{-1}$)	4.70 ± 0.02	6.30 ± 0.03	7.00
TDS ($g\,L^{-1}$)	1.51 ± 0.02	1.82 ± 0.01	2.00
HCO_3^- ($mg\,L^{-1}$)	288.50 ± 0.3	370.00 ± 0.20	600.00
SO_4^{2-} ($mg\,L^{-1}$)	87.50 ± 0.8	363.00 ± 1.50	1000
N_{total} ($mg\,L^{-1}$)	–	58.80 ± 1.20	30.00
N-NO_3^- ($mg\,L^{-1}$)	1.11 ± 0.01	15.90 ± 0.05	
N-NH_4^+ ($mg\,L^{-1}$)	2.24 ± 0.01	37.90 ± 0.01	
N-NO_2^- ($mg\,L^{-1}$)	0.08 ± 0.02	5.00 ± 0.01	
P_{total} ($mg\,L^{-1}$)	0.80 ± 0.11	10.30 ± 0.01	0.05
K^+ ($mg\,L^{-1}$)	30.00 ± 0.09	38.00 ± 0.02	50.00
Na^+ ($mg\,L^{-1}$)	355.00 ± 0.01	470.00 ± 0.02	300.00
Cl^- ($mg\,L^{-1}$)	1580 ± 0.04	1999.00 ± 0.04	600.00
Ca^{2+} ($mg\,L^{-1}$)	184.50 ± 0.01	95.80 ± 0.03	
Mg^{2+} ($mg\,L^{-1}$)	126.20 ± 0.01	83.80 ± 0.02	
Pb^{2+} ($mg\,L^{-1}$)	0	<0.004	0.10
Cd^{2+} ($mg\,L^{-1}$)	0	<0.004	0.005
Zn^{2+} ($mg\,L^{-1}$)	0.10 ± 0.01	0.42 ± 0.01	5.00
Mn^{2+} ($mg\,L^{-1}$)	0.19 ± 0.01	0.50 ± 0.01	
SM ($mg\,L^{-1}$)	4.30 ± 0.02	13.40 ± 0.03	
COD ($mg\,L^{-1}$)	0	73.00 ± 0.11	90.00
BOD ($mg\,L^{-1}$)	0	22.00 ± 0.04	30.00

Data represents mean values ± standard deviation.
EC: electrical conductivity; TDS: total dissolved solids; SM: suspended matter; COD: chemical oxygen demand; BOD: biological oxygen demand; WW: well water; TWW: treated wastewater.

2.2. Soil characteristics and mineral analysis

Soil samples were collected quarterly from each plot at both 0–40 cm and 40–80 cm depth twice by year (July and December). They were saved in plastic bags and stored in a portable cooler. The samples were air–dried at room temperature, ground and crushed to pass through a 2 mm sieve, and mixed thoroughly for analysis. Soil texture was performed by pipette method according to the method described by Gee and Or (2002). Soil pH was determined using a pH meter (420A, Orien) in water (pHH_2O) and in saline solution of 0.01 M $CaCl_2$ ($pHCaCl_2$). Soil/water ratio of the suspensions was 1:2.5 (w/v). The soil textural classes were determined at the beginning of the trial (2003) according to the USDA soil texture classification.

The soil salinity was assessed by determination of electrical conductivity (EC) at 25 °C on a saturated paste using a conduc-