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Olive orchard irrigation with reclaimed wastewater: Agronomic and environmental considerations

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ABSTRACT

The olive (*Olea europaea*) oil industry is experiencing a transition from traditional rain-fed to intensively managed irrigated orchards. Moreover, since fresh water resources in typical olive cultivation regions are often scarce, alternative water sources, often marginal in quality, are increasingly used for the irrigation of olives. Utilization of reclaimed wastewater (RWW) increases the susceptibility of olive trees to osmotic stress and augments the potential of groundwater contamination by nutrients and salts. The objective of this study was to evaluate tree growth and productivity and to quantify nitrate and chloride (Cl) losses in an olive orchard irrigated with RWW. A four year field study compared two olive tree varieties, 'Barnea' and 'Leccino', and three treatments: (i) fresh water application with commercial fertilizer at recommended rates (*Fr*), (ii) RWW application with commercial fertilizer at recommended rates (*Re*) and (iii) RWW application with commercial fertilizer reduced according to the amounts of the nutritional constituents in the wastewater itself (*Re−*). No significant difference was found in nutrient and mineral accumulation in diagnostic leaves and no differences in trunk growth, fruit production or oil yields were observed between treatments. In spite of this, lower measured Cl concentration in diagnostic leaves of 'Barnea' and higher Cl concentrations in its root zone relative to 'Leccino' suggested that 'Barnea' trees better controlled Cl uptake. While similar amounts of water were applied, the *Re* and *Re−* treatments loaded the soil profile with 1.75 times more Cl then the *Fr* treatment. Additionally, significantly more nitrates were transported out of the root zone in the *Re* treatment compared to *Fr* and *Re−* for both cultivars. We conclude that RWW used for irrigating olive oil orchards had no effect on vegetative growth and productivity but increased salt loads into and beyond the root zone. The nutritional constituents in the RWW used to irrigate olives should be accounted for in order to increase fertilizer application efficiency and minimize the transport of nutrients into groundwater.

1. Introduction

Fresh water scarcity in semi-arid environments and lack of options for disposal of domestic liquid waste have inspired a global agricultural move towards utilization of treated domestic wastewater (reclaimed wastewater – RWW) for the irrigation of crops (Pedrero et al., 2010). In Israel, for instance, 32.7% of the irrigation water in 2007 originated from RWW (Statistical abstract of Israel, 2009). Similar trends of RWW replacing fresh water for irrigation are occurring in the USA and other countries (Hamilton et al., 2007). The olive oil industry is particularly relevant and important regarding RWW utilization for a number of reasons: (i) it has concurrently experienced a transition from traditional rain-fed to modernized intensive cultivation practices, where water and fertilizer application have become inherent to olive oil production (Connor and Fereres, 2005); (ii) the olive tree is considered relatively tolerant to salinity (Chartzoulakis, 2005) and (iii) olive fruits are not eaten fresh but only consumed after processing, thus decreasing the risk from direct exposure to pathogenic microorganisms presented in RWW (Palese et al., 2009). Additionally, fresh water scarcity in the Mediterranean region, where olive oil production is concentrated (Vossen, 2007), has promoted the utilization of RWW to irrigate olive orchards (Bedbabis et al., 2009; Charfi et al., 1999; Al-Abasi et al., 2009).

Reclaimed wastewaters are domestic liquid wastes typically treated by screening, oxidation, sedimentation and biological digestion at designated plants. The composition of RWW includes soluble minerals and organic matter which depend quantitatively and qualitatively on the original source of the water and the types and levels of treatment (Pescod, 1992; Pedrero et al., 2010). Typically, RWW is defined as brackish water (Na and Cl as major ions) containing major plant nutritional constituents such as nitrogen

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(N), phosphorous (P) and potassium (K). On one hand, RWW application can positively affect plant growth conditions by increasing plant water availability and soil fertility (Da Fonseca et al., 2007). On the other hand, excess amounts of these minerals as well as other dissolved salts can adversely affect plant development as a result of salt accumulation in the root zone (Biggs and Jiang, 2009) and can also increase the potential for groundwater contamination by salts and nutrients due to leaching below the root zone (Kass et al., 2005).

Although the olive tree is defined as a crop "moderately tolerant" to salinity (Maas and Hoffman, 1977; Aragues et al., 2004), high soil salinity has a negative effect on its photosynthetic activity, vegetative growth, and fruit and oil production (Chartzoulakis, 2005). In principle, the effects of irrigation water salinity can be minimized by maintaining a leached root zone by frequent water applications and by applying quantities in excess of plant consumption. Practically, such water management is not always feasible or desired for reasons of controlling tree growth and oil quality.

The mineral nutrition of olive trees has mainly been studied on rain fed orchards. Recommended N application amounts for traditional orchards range between 0.45 and 2 kg tree^{-1} year^{-1} (Freeman et al., 2005; López-Villalta, 1996; Jasrotia et al., 1999). Similar amounts, 0.5–1 kg tree^{-1} year^{-1} were recommended for application of K by Hussein (2008) and Morales-Sillero et al. (2007, 2009). Due to its extensive root system and the symbiosis with mycorrhizal fungi, the olive tree takes up P very efficiently (López-Villalta, 1996; Therois, 2009; Freeman et al., 2005). Therefore, P deficiency in olives is rare and P fertilization is often not recommended or practiced (López-Villalta, 1996; Fernández-Escobar et al., 1999; Freeman et al., 2005; Therois, 2009). As olive cultivation moves to more arid environments and nutrient poor soils, and as intensive management leads to significantly increased yields, P fertilization is becoming more necessary and common. Erel et al. (2008) showed that fruit yield can be severely limited by P availability as flowering intensity and fruit set of 'Barnea' olives increased as a function of P in irrigation water. On the other hand, the intensive management might result in over application of N, which was found to have a negative effect on olive oil quality indices, including polyphenol and free fatty acid contents (Fernández-Escobar et al., 2006; Dag et al., 2009).

The agronomic importance of considering the nutritional constituents of RWW in fertilizer management has been studied on several crops including bermudagrass (Adeli et al., 2003), grapevines (Paranychianakis et al., 2006) and cotton (Mandal et al., 2008). Regarding olives, Al-Abasi et al. (2009) found no statistical differences in leaf mineral concentrations between trees irrigated with RWW and fresh water. However, the N concentration of the two water sources in those studies was alike and much lower than recommended application amounts (20% for RWW and 14% for fresh water). In spite of findings that indicate nutrients in RWW are available for crop mineral nutrition in most forms, it is still common practice for growers of crops including olives to follow the standard fertilizing recommendations, without considering the nutrients arriving with the RWW.

Application of RWW has potential substantial environmental implications as the water and its constituents are transported out of the root zone into ground and surface waters. Such transport can lead to the salinization of groundwater (Kass et al., 2005), contamination of drinking water with nitrates (Duan et al., 2010) or pathogens (Bradford and Segal, 2009), and loading of surface waters with nutrients (Bond, 1998).

We hypothesized that when irrigating olive orchards with RWW, subtracting the content of the major nutritional constituents in the RWW from the recommended nutrient application rates would not affect tree growth and yield. Moreover, reduction in applied fertilizers would minimize the potential contamination

Table 1
Soil physical and chemical properties prior to experimental treatments. Values represent average and standard deviation.

Depth (cm)	Physical properties							Chemical properties								
	Sand (%)	Silt	Clay	SP[a]	θ_{fc}[b] (cm^3 cm^{-3})	θ_{wp}[c] (cm^3 cm^{-3})	A.W.[d] (mm)	EC_e[e] (dS m^{-1})	pH	Na (meq L^{-1})	K (meq L^{-1})	SAR[f] (meq L^{-1})$^{1/2}$	$CaCO_3$ (%)	O.M.[g] (%)	Total N (%)	P[h] (mg kg^{-1})
0–40	24.3 (2.9)	25.0 (2.0)	50.7 (2.5)	69.4 (4.5)	0.33	0.18	58.7	1.6 (0.8)	7.8 (0.2)	7.6 (4.1)	0.36 (0.23)	3.9 (1.5)	13.3 (2.8)	0.48 (0.01)	0.051 (0.008)	13.9 (3.7)
40–80	21.7 (8.1)	24.0 (2.0)	54.3 (6.4)	69.2 (8.5)	0.34	0.20	58.8	1.4 (0.1)	8.0 (0.1)	8.6 (0.9)	0.16 (0.04)	5.5 (1.3)	14.1 (2.6)	0.32 (0.05)	0.044 (0.009)	4.5 (1.8)
80–120	22.3 (2.4)	22.0 (1.7)	55.7 (3.1)	75.3 (1.8)	0.34	0.19	58.1	1.4 (0.1)	8.2 (0.1)	9.6 (0.8)	0.16 (0.02)	7.7 (1.5)	13.6 (1.1)	0.20 (0.04)	0.049 (0.002)	1.7 (0.3)

[a] SP is saturation percentage.
[b] θ_{fc} is the soil water content under field capacity conditions.
[c] θ_{wp} is the soil water content under wilting point conditions.
[d] A.W. is the available water.
[e] EC_e is the electrical conductivity of the extracted soil saturated paste.
[f] SAR is sodium absorption ratio.
[g] O.M. is the soil organic matter content.
[h] Olsen bicarbonate extractable P.