Monitoring of soil in Mediterranean olive groves irrigated with reclaimed water

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Abstract Nowadays, many countries face significant problems of water scarcity. In this context, the reuse of treated wastewater represents a valid option, in some cases urged by the absence of viable alternatives. This study evaluates long-term effects of reclaimed water irrigation on soil of olive groves in a typical semi-arid region in Crete, Greece. Sampling was conducted in olive groves irrigated for more than 10 years with secondary treated wastewater. A 4-year monitoring period was conducted. Results shown that irrigation with reclaimed water had no significant impact on soil properties. Organic matter, nitrogen and phosphorus concentration was 2.5%, 625 mg/kg and 40 mg/kg, respectively. Soil salinity was also stable ranged from 1.0 mS/cm to 1.3 mS/cm. No accumulation of heavy metals in soils was observed during the experimental period.

Keywords: irrigation, water quality, carnations, domestic wastewater

1. Introduction

Nowadays, water scarcity is one of the main problems faced by many countries in the world, particularly in semi-arid and arid regions. Agriculture is the sector affected more than any other by water scarcity, as it accounts for 70% of global freshwater withdrawals and more than 90% of consumption (FAO, 2012). Several alternative solutions could be implemented in order to close the gap between demand and supply, such as the control and reuse of runoff water (Al-Seekh, 2009), desalination of saline/sea water (Avni *et al*., 2013), cloud seeding (Guo *et al*., 2006) and wastewater reuse (Van Lier and Huibers, 2005). Among them, wastewater reclamation for agriculture has several advantages as reduces a) the demand for fresh water, b) the discharge of pollutants into surface waters, c) wastewater treatment cost, and d) fertilizer application.

For these reasons, wastewater reuse in arid and semi-arid areas, and especially in areas with major tourist development such as Crete, is considered an important solution to the long-term sustainable use of generally limited freshwater resources. This is particularly evident in agriculture, which currently consumes almost 87% of the fresh water of the island. Hersonissos, one of the largest tourist resorts in the Mediterranean, is located on the north coast of Crete, about 25 km from Herakleion, the capital and largest city of Crete. Rainfall in the area occurs mainly from November to March, with almost none during the rest of the year (May to October). The local population does not exceed 10,000 during the winter period, while over 500,000 tourists visit the area during the summer (April to October), dramatically increasing water requirements. The Hersonissos wastewater treatment plant (WTP) has been operational since 2001, receiving domestic wastewater from the Hersonissos Municipality and septage from the wider area. The tertiary treated wastewater is distributed into the nearby fields. Nearly one million cubic meters of effluent are used each year, mainly for the irrigation of olive trees.

Up to date, there are a significant number of previous studies regarding the effect of wastewater use on olive groves. (Palese *et al*., 2009; Bedbabis *et al*., 2010; Segal *et al*., 2011; Batarseh *et al*, 2011). The main conclusions from these studies were that a) treated wastewater can be used as an additional water resource for olive irrigation in water-scarce Mediterranean environments b) the application of wastewater increase concentration of elements in olive leaves and c) Varieties of olive trees respond differently to wastewater irrigation. It is clear that more efforts needed in order to examine the application of treated wastewater for the irrigation of different varieties of olive trees. Furthermore, these studies were conducted mostly on experimental/controlled olive orchards or/and were examined short-term impact. The present work was aimed at investigating the long-term effect of reclaimed water use on soil physical and chemical properties under field conditions.

2. Materials & Methods

2.1 Experimental field

The open field study was conducted at the area of Hersonissos, Crete, Greece (Fig.1). Eighteen (18) commercial olive groves were randomly selected and monitored for a period of four (4) years. The highest monthly mean temperature was 28.4 ^oC (July 2012) and the lowest 10.5 (January 2012). Average annual precipitation was 442 mm, 457 mm, 563 mm and 461mm for 2010, 2011, 2012 and 2013 respectively, falling mainly between October-April. Average annual humidity ranged from 53% to 73%. Climate could be characterized as typical "Mediterranean" as the examined olive groves had relatively mild winters and very warm summers receiving almost all of their precipitation during their winter seasons while the summers are dry.

2.2 Sampling and analysis

Soil samples were collected near the drip emitters from a depth of 0-40 cm. The air-dried soil samples were sieved to pass from 2mm screen before analyses. The values of pH and EC were determined for saturated paste solution using pH-meter (Crison, GLP 21, Barcelona, Spain) and EC-meter (Crison, 525, Barcelona, Spain), respectively. The organic matter in soil was determined according to the Walkley-Blank acid dichromate digestion method (Walkley, 1946) and total Kjeldahl N using the Kjeldahl digestion method. The sand, silt, and clay content of the soil samples were determined using the Bouyoucos method (Bouyoucos, 1962). Available P was extracted with sodium carbonate and was measured spectrophotometrically (Olsen *et al*. 1954). For the determination of K and Na soil samples were extracted with ammonium acetate and the extracts were analysed by flame photometer (Model 410, Sherwood Scientific, Cambridge, UK). The extraction of macro-elements (Mg, Ca) and heavy metals (B, Cu, Zn, Cr, Ni) prior to ICP-MS was performed by acid digestion using a microwave digestor (Multiwave 3000 by Anton Paar, Graz, Austria) according to the standard operating procedure EPA 3051a (USEPA, 1995).

2.5 Data Analysis

The data were analysed through one-way analysis of variance (ANOVA) to compare the effect of each irrigation type on plant growth characteristics. Differences between means were tested for significance ($p<0.05$) by Tukey's test.

3. Results

3.1 Irrigation water

The chemical composition of irrigation water is presented in Table 1. It is mentioned that treated wastewaters had a mean EC value of 2.1 mS/cm. Copper and Zinc

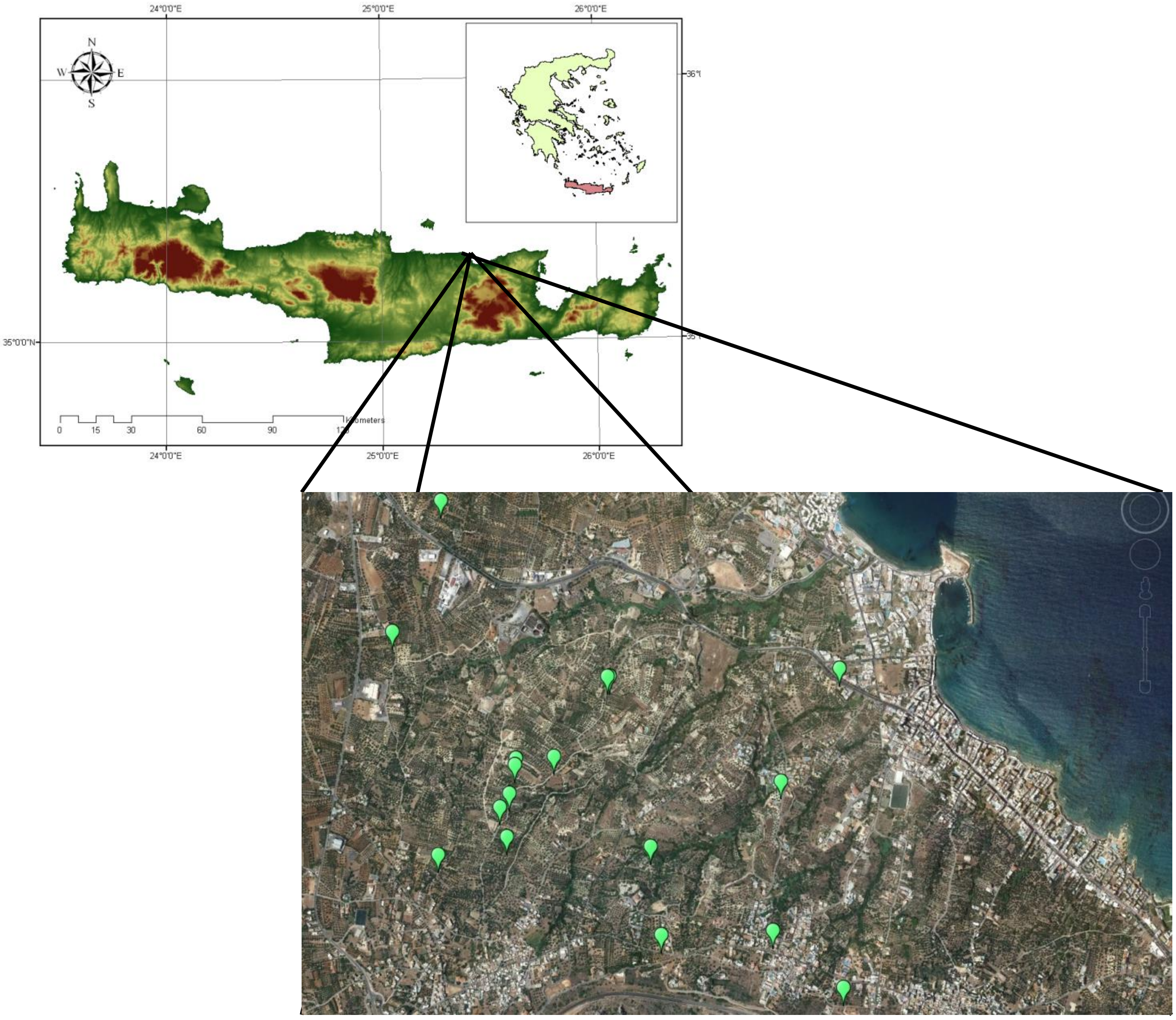

Figure 1. Layout of the sampling points

concentrations were not detected in the examined wastewaters. In Greece and especially in Crete industrial activities are limited. This is reflected in the total amount of heavy metals found in wastewater. Treated wastewaters contain significant quantities of nutrients as well as essential elements compared to tap water. Boron an important mineral for olive tree production (Saadati *et al*., 2013) was found in treated wastewaters at a concentration of about 0.3 mg/l.

Results were roughly in line with what we would expect from a properly performing wastewater treatment plant. Treated wastewaters contain soluble minerals and organic matter which depend quantitatively and qualitatively on the original source of the water and the type of treatment. Chemical characteristics in soil are reported in Table 2. No significant differences in concentrations of all these compounds were observed. In particular, Organic matter, nitrogen and phosphorus concentration was 2.5%, 625 mg/kg and 40 mg/kg, respectively. Soil salinity was also stable ranged from 1.0 mS/cm to 1.3 mS/cm.

Heavy metals and minerals in soil during four years study are presented in Table 2. Irrigation with treated wastewaters had no effect on soil concentrations. As already mentioned treated wastewaters do not contained significant quantities of any heavy metal.

No significant differences for Ca and Mg concentration in olive orchard's soils irrigated with well water and treated wastewater for a period of 4 years were also reported in a previous study in Tunisia (Bedbabis *et al*., 2014). In the same study Ca accumulation over the years was also observed in irrigated soils, indicating that the absorption of this element on the exchangeable complex was higher than plant roots uptake.

Table 1. Quality of reclaimed water

Parameter	Mean	Min-max
pH	7.7 ± 0.2	7.2-8.1
EC (mS/cm)	2.1 ± 0.4	1.4-3.0
COD (mg/L)	6 ± 3	1-18
BOD (mg/L)	24 ± 8	2-56
TSS (mg/l)	7 ± 4	0-14
TN (mg/L)	5 ± 4	0-16
TP (mg/L)	5 ± 3	0-12
K (mg/L)	37 ± 11	15-52
Mg (mg/L)	75 ± 14	41-89
Ca (mg/L)	135 ± 23	112-162
B (μg/L)	0.3 ± 0.1	0.1-0.6
Cu (μg/L)	n.d	n.d
Zn (μg/L)	n.d	n.d

Table 2. Effect of irrigation on soil properties

Parameter	2010		2011		2012		2013	
	Mean	Min-max	Mean	Min-max	Mean	Min-max	Mean	Min-max
pH	7.8	7.0-8.1	7.7	7.0-7.9	7.6	7.1-7.8	7.6	7.1-7.8
EC (mS/cm)	1.3	0.5-3.3	1.0	0.7-2.2	1.1	0.9-3.0	1.0	0.7-1.9
Organic matter (%)	2.5	1.5-3.7	2.5	1.0-3.3	2.6	0.8-4.1	2.4	0.8-3.4
N (mg/kg)	632	127-1050	681	145-1231	617	151-980	645	136-1120
P (mg/kg)	47	32-74	36	21-55	40	21-65	45	25-102
K (mg/kg)	174	7-630	157	25-447	169	28-518	182	18-446
Mg (g/kg)	9.5	7.3-12.1	9.3	7.0-9.8	9.6	7.4-11.8	9.4	7.1-10.3
Cu (mg/kg)	25	4-37	21	7-42	25	8-39	23	6-31
Zn (mg/kg)	18	5-26	19	8-31	18	5-29	16	4-23

4. Conclusions

This study examined long-term effects of reclaimed water irrigation on soil of olive groves in a typical semi-arid region in Crete, Greece Results show that reclaimed wastewater could be used without any significant problem as an alternative water source for the production of olive in arid and semi-arid regions. The high salinity and boron concentrations levels in treated wastewater had no adverse effect on soil. Furthermore, treated wastewater contained significant amount of nutrients (nitrogen, phosphorus, potassium) and minerals (calcium, magnesium) which could reduce fertilizer requirements.

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