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Soil chemical properties, leaf mineral status and crop production in a lemon tree orchard irrigated with two types of wastewater

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ABSTRACT

The effects of applying different types of treated wastewater on citrus trees were studied in Murcia, in the south-east of Spain. Two treatments with wastewater effluents of different quality were applied for three consecutive years. In the first case, the wastewater received a secondary treatment (conventional activated sludge). In the second case, the irrigation water was a mix of well water and wastewater from a tertiary treatment plant (conventional activated sludge with ultraviolet tertiary treatment). The characteristics of the tertiary treated wastewater make it better for irrigation than the secondary treated wastewater. It was considered that high salinity, Cl and B concentration could be the main restrictions associated with treated wastewater irrigation in both cases, although leaf toxicity levels were not observed. The soil nitrate concentration increased over the experimental time period in both water irrigation treatments. The production was affected by the wastewater quality and the total crop yield was lower in the plots irrigated with secondary treated wastewater. However, in these plots, the fruit-quality indexes such as external colour, weight, peel thickness, firmness, soluble solids, pH, total acidity and maturity index were significantly better than those observed in the plots irrigated with tertiary treatment. The soil microbiological analysis revealed an absence of faecal coliforms, *Escherichia coli* and helminth eggs in the experimental plots irrigated with tertiary treated wastewater, but with secondary treated wastewater the soil accumulation of faecal coliforms exceeded health standards. In both cases, there was an absence of microbiological contamination on fruits.

1. Introduction

Wastewater reuse in agriculture is an important management strategy in areas with limited freshwater resources. Such a strategy is important because of the potential economic and environmental benefits. It is therefore necessary to initiate and support wastewater reuse projects all over the world, particularly since the population and demand for food is growing steadily and the fresh water resource will not increase.

Several studies have shown the advantages and disadvantages of using wastewater for citrus crops irrigation (Zekri and Koo, 1993, 1994; Aucejo et al., 1997; Morgan et al., 2008; Reboll et al., 2000; Pedrero and Alarcón, 2009; Pedrero et al., 2010; Maurer et al., 1995; Meli et al., 2002; Pereira et al., 2011). Reuse of treated wastewater is a good management option for increasing water supplies to agriculture. One of its benefits is the plant's use of both water and nutrients thereby reducing the pollution load that wastewater contributes to the surface water supply (Zekri and Koo, 1994). However, depending upon its sources and degree of treatment, wastewater may contain high concentrations of salts, heavy metals, trace elements, viruses and bacteria. Irrigation with poor quality wastewater may create undesirable effects on soils and plants or pose a potential health threat to the consumer. Improperly treated wastewater can contain food-borne pathogens such as pathogenic bacteria, viruses, protozoa and nematodes (Steele and Odumeru, 2004; Steele et al., 2005). This situation is particularly relevant in some developing countries, where poorly treated wastewater is used for crop irrigation (Rattan et al., 2005).

Asano et al. (2007) define reclaimed water as the municipal wastewater that has gone through various treatment processes to meet specific water quality criteria with the intent of being used in a beneficial manner (e.g., irrigation). The term recycled water is used synonymously with reclaimed water. The current water quality criteria for agricultural reuse have been established by USEPA (2004), based mainly on total dissolved solids (TDS), salinity and sodicity (Ayers and Westcot, 1989), and the need for periodic microbiological analysis of the irrigation-water supplies,

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independently of the water source considered, to minimize negative public health impacts (WHO, 2006). More specific water quality parameters for the use of reclaimed water have been presented by Levine and Asano (2004) and there is considerable interest in the long-term effects of reclaimed water on crops intended for human consumption. In many areas of the world water reuse is viewed increasingly as a means to augment existing water resources against the prospect of continued droughts and water supply shortages. Reclaimed water use projects have been developed in countries facing water shortages (Angelakis et al., 1999). In the United States, for example, California reused 670 hm^3/year in 2003 (330 hm^3/year in 1987) while Florida reused 915 hm^3/year in 2006 (capacity 1900 hm^3/year) (Asano et al., 2007). The use of reclaimed water for irrigation has been progressively adopted by virtually all Mediterranean countries (Lazarova, 2000). Israel was pioneer in this field, soon followed by Tunisia, Cyprus, and Jordan. More recently, European Mediterranean countries started considering water reuse for irrigation (Marecos Do Monte et al., 1996).

In Spain, the intensive agriculture is concentrated in the south east, where fresh water is very scarce (Intrigliolo et al., 2011). The present work was conducted in Segura Basin (Murcia), a semiarid Region of Spain, where drought and water deficit are the main factor limiting agricultural production. In this Region, some investigations on precise irrigation scheduling procedures using different plant measurements (García-Orellana et al., 2007) and shading with aluminised-plastic nets (Alarcón et al., 2006), were aimed at improving water use efficiency of lemon trees. The water deficit in the Segura Basin, together with the ever-increasing demand due to the continued urban growth in the coastal zone and the major demand from intensive agricultural activity, has made it necessary to use treated wastewater for irrigation.

According to the Murcia Regional Ministry of Water and Agriculture, the annual volume necessary to cover the regional agricultural water needs exceeds 880,000 Ml (CARM, 2007). The current volume of treated wastewater in Murcia is 101,800 Ml/year (ESAMUR, 2009), which represents a sixth of renewable resources of the Segura River Basin, and, besides serving other purposes, it supplies 12.8% of the water used for irrigation. In Murcia, the 54.8% of the wastewater treatment plants receive a secondary treatment, and the 42.2% receive a tertiary treatment (ESAMUR, 2009). The major problem associated to reclaimed water use in Murcia is salinity. In this region, 93% of the treated wastewater has an electrical conductivity (EC) higher than 2 $dS\,m^{-1}$ and 37% has EC values higher than 3 $dS\,m^{-1}$ (ESAMUR, 2005), and it is known that water with EC $\geq$ 3 $dS\,m^{-1}$ requires very intensive management to control adverse salinity effects.

The effects of treated wastewater on environmental pollution, plant growth or crop production are rarely studied in field conditions and thus, these types of experimental approaches are scarce (Pedrero et al., 2010). The aim of this work was to study the effects of different reclaimed irrigation waters on citrus tree performance. In particular, the objective of this research was to compare the effects of two types of wastewater, the one obtained through a secondary treatment and the other from a tertiary treatment, and to study their effects on soil chemical properties, leaf mineral status, crop production, fruit quality of citrus and microbiological safety.

2. Materials and methods

2.1. Experimental conditions

The experiment was conducted during 2005–2007 in one experimental site planted to lemon trees in the Region of Murcia. The experimental orchard size was 12 ha of ‘Fino’ lemon grafted on ‘*Macrophyla*’ rootstock. The trees were 7 years old and were spaced 7 × 5 m. The water was supplied to trees by drip irrigation with eight compensated pressure emitters per tree, each with a flow rate of 4 $L\,h^{-1}$.

The soil was classified as a clay loam soil (32% clay, 32% loam and 36% sand). Two different irrigation wastewater qualities were applied, secondary treated wastewater (STW) was used in one case, while tertiary treated wastewater (TTW) was used in the other case. In this trial, STW was based on the process of Biological Purification of Activated Sludge, and TTW was a mix of well quality groundwater and wastewater from a tertiary treatment plant (conventional activated sludge with ultraviolet tertiary treatment).

The experimental design of each treatment was 4 standard experimental plots distributed randomly in blocks. The standard plot was made up of 12 trees, organized in 3 adjacent rows. The two central trees of the middle row were used for measurements and the other 10 trees were guard trees. The irrigation doses were scheduled from January 2005 until December 2007 on the basis of weekly crop evapotranspiration (ETc) estimated from reference evapotranspiration (ETo), calculated with the FAO56 Penman–Monteith equation (Allen et al., 1998), and a monthly crop factor (Castel et al., 1987). Meteorological data at the experimental sites were also used to calculate the water application. The data were collected from a weather station located 2 km from the experimental plots. The total irrigation amounts were measured with inline water flowmeters. The average amount of water applied was 601 mm/year. The average annual precipitation was 318 mm. During the season of the experiment the average annual ETc was 903 mm (Fig. 1). The fertilizers rates of $N–P_2O_5–K_2O$ applied through the drip irrigation system were 240–90–100 ($kg\,ha^{-1}$).

The statistical analysis was performed by weighted analysis of variance (ANOVA) using linear model for SPSS software (version 17.0, SPSS Inc., Chicago, USA).

2.2. Water analysis

Three water samples from each irrigation water source were collected monthly between 2005 and 2007 in order to characterize irrigation water quality (36 samples/year). The samples were collected in glass bottles, transported in an ice chest to the lab and stored at 5 °C.

The concentration of macronutrients (Na, K, Ca, Mg), micronutrients (Fe, B, Mn) and heavy metals (Ni, Cd, Cr, Cu, Pb, Zn) were determined by Inductively Coupled Plasma (ICP-ICAP 6500 DUO Thermo, England); anions (chloride, nitrate, phosphate and sulphate) were analysed by ion chromatography with a Chromatograph Metrohm (Switzerland); pH was measured with a pH-meter Cryson-507 (Crisom Instruments S.A., Barcelona, Spain); EC and total dissolved solids (TDS) were determined using the multi-range equipment Cryson-HI8734 (Crisom Instruments, S.A., Barcelona, Spain) and turbidity was measured with a turbidity-meter Dinko-D-110 (Dinko Instruments S.A., Barcelona, Spain).

The microbiological quality of irrigation water was assessed through the detection of total coliforms, faecal coliforms and *E. coli* by membrane filtration procedure (APHA, 1985). Samples were filtered using a vacuum system through a sterile 0.45-μm-pore-size membrane filters (Millipore, Billerica, USA). Colony formation was obtained after incubation on top of Chromocult agar plates (Merck, Darmstadt, Germany) for 24 h. Incubation temperatures were 37 °C for total coliforms and *E. coli*, and 44.5 °C for faecal coliforms. Microbial counts were expressed as log $cfu\,ml^{-1}$. The helmint eggs were measured following the Bailenger’s method (Bailenger, 1979). For *E. coli* O157:H7 detection, enrichments were prepared pouring 25 ml of water samples into sterile stomacher bags and adding 225 ml of mTSB + Novobiocin (Oxoid, Basingstoke,