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Seasonal and depth variation of soil chemical and biological properties in alfalfa crops irrigated with treated wastewater and saline groundwater

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ABSTRACT

In areas with limited water resources, treated wastewater can be used for irrigation. This is the case in many places on the Mediterranean coast where groundwater is affected by seawater intrusion. A study was conducted under real agricultural conditions and during irrigation and non-irrigation seasons in order to evaluate changes in soil chemical and biological properties in crops of alfalfa (*Medicago sativa* L.) irrigated with secondary-treated municipal wastewater and saline groundwater for >20 years. Depth distribution and the effect of soil type were also investigated. The soil parameters studied were: salinity, content of N-NO_3^-, N-NH_4^+ and water-extractable organic carbon (WEOC), microbial biomass C (MB) and the enzymatic activities of dehydrogenase (DH), β-glucosidase (GL), alkaline phosphatase (AP), arylsulphatase (AS), BAA-protease (PR) and urease (UR). The results demonstrate the positive effect of treated wastewater on soil GL, AS and UR activities during the irrigation season in comparison to irrigation with saline groundwater. Salinity and N-NO_3 also increased during the irrigation season although these parameters decreased considerably after the rains in soils irrigated with both types of water. Soil salinity, WEOC and extracellular enzymatic activities differed significantly between soil types; these were higher in the soils of finer texture and higher soil organic carbon content. Traditional non-tillage crop management (between 5 and 7 years without ploughing) produced a clear depth distribution of most soil chemical and biological parameters in five-year-old alfalfa crops. The results indicate that treated wastewater is a suitable alternative to saline groundwater and allows the maintenance of traditional irrigation of alfalfa crops.

1. Introduction

The use of treated wastewater for agricultural irrigation allows the maintenance of irrigated agriculture in areas where water resources have been depleted or directed to other uses. Moreover, treated wastewater irrigation supplies nutrients and low molecular weight organic compounds that can be utilized by plants and soil microorganisms (Kiziloglu et al., 2008; Pereira et al., 2010). In fact, several researchers have observed an increase in soil biological activity in soils irrigated with treated wastewater compared to those irrigated with water from other sources (Brzezinska et al., 2006; Chen et al., 2008), although other authors have also highlighted the increased soil salinity associated with irrigation with treated wastewater (Klay et al., 2010; Qian and Mecham, 2005).

Alfalfa (*Medicago sativa* L.) is a crop that can tolerate a moderately low-quality water supply (Helalia et al., 1996). Moreover, it is mainly used as a dehydrated cattle fodder, which reduces the risk of pathogen infection through the treated wastewater (UNEP, 2005). For these reasons, it constitutes the main crop in areas irrigated with treated wastewater in Majorca (Adrover et al., 2012) and in other Mediterranean areas (Belaid et al., 2012; Shomar et al., 2010). This crop is considered a high consumer of water during the growing season (Lloveras et al., 2001), when it is mainly irrigated by flooding (Gallego et al., 2011). As a pluriannual crop, alfalfa is usually cultivated for 5–7 years and the soil is therefore untilled over this period of time with crop residues remaining on the soil surface.

Several authors have studied the depth distribution of different soil parameters in tillage and no-tillage systems, observing a decrease in soil organic carbon content and biological activity along soil profiles, particularly in non-tilled compared to tilled soils (Franzluebbers, 2002; López-Fando and Pardo, 2011; Roldán et al., 2005). It is widely recognized that continuous no-tillage farming leads to depth distribution of the soil organic matter, with the highest accumulation in the surface layer (Sá and Lal, 2009; Franzluebbers, 2002). The increase of organic carbon is a natural process governed by continuous input of carbon by litter at the soil surface. The organic matter enrichment in the surface layer maintains soil quality by favouring aggregation and biological activity. The common soil depth sampling intervals in these types of studies are usually 0–5 cm, 5–10 cm and 10–20 cm (Alvear et al., 2005; Madejón et al., 2007; Roldán et al., 2005) or every 10 cm (Niemi et al., 2005; Zaman et al., 2002), although a pronounced differentiation within

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the top 2 cm has also been reported (Heinze et al., 2014). All these authors agree that the highest biological activity is found in the soil surface layer.

Soil biological properties are also affected by seasonal variations (Geisseler and Horwath, 2009), increasing in months with higher temperature and moisture (Ge et al., 2010; Shi et al., 2013). Other factors, such as plant development and substrate availability, may also play a role in the temporal variation of enzymatic activities (Piotrowska and Dlugosz, 2012). The effect of irrigation season on soil biological properties has been less well studied. Meli et al. (2002) observed an increase in microbial biomass and a reduction of alkaline phosphatase during the irrigation season in soils irrigated with lagooned urban wastewater. Elifantz et al. (2011) also observed an increase of Fluorescein diacetate hydrolytic activity during the irrigation season relative to the rainy season. This effect was higher in soils irrigated with treated wastewater than in those irrigated with fresh water.

The purpose of this study is to evaluate the changes on chemical and biological properties of soils irrigated with treated wastewater and saline groundwater, in terms of seasonal variation and depth distribution in two soil types cultivated with alfalfa.

2. Material and methods

2.1. Study area

This study was conducted in the area of Pla de Sant Jordi (UTM ETRS89 31S 477700E, 4380100N), which is an alluvial plain located near Palma Bay, on the island of Majorca (Balearic Islands, Spain). The typical soil is a Petric Calcisol (Chromic) developed on ancient alluvial parent materials (IUSS Working Group WRB, 2014) although there is also a Calcaric Gleyic Phaeozem developed on marls (IUSS Working Group WRB, 2014), corresponding to a wetland that was drained in the beginning of the XIX century for health and agriculture purposes (Rosselló, 1959). The physical and chemical properties of both soil types are shown in Table 1.

The area was traditionally irrigated with groundwater until this source became affected by seawater intrusion as a result of over-extraction at the end of the sixties (Mateos et al., 2001). In the early seventies, secondary-treated municipal wastewater from the two activated sludge wastewater treatment plants of the city of Palma substituted groundwater as the main water source (Mateos Ruiz and López García, 2003). The wastewater is treated to meet the quality level 2.3 issued by the Spanish government for its use in irrigation of industrial non-food crops, nurseries, silo fodder, cereals and oilseeds (Real Decreto 1620/2007).

During the whole time of the study (August 2003–September 2004), irrigation with treated wastewater was generalized and only one plot in the Calcisol area remained with saline groundwater irrigation. As a result, it was not possible to find a plot in the Phaeozem that was irrigated with saline groundwater. Water properties are shown in Table 2.

Table 1
Physical and chemical properties of the plough layer (0–20 cm) of the two soil types of the study area.

	Petric Calcisol (Chromic)	Calcaric Gleyic Phaeozem
Sand (g kg^{-1})	246	100
Silt (g kg^{-1})	428	439
Clay (g kg^{-1})	327	461
WAS (%)	75.3	91.2
CCE (g kg^{-1})	350	384
AL (g kg^{-1})	102	135
pH H_2O (1:2,5)	8.3	8.5
TOC (g kg^{-1})	21.4	25.9
N (g kg^{-1})	2.05	2.67
C/N	10.5	9.7
Total P (mg kg^{-1})	838	818
Olsen P (mg kg^{-1})	49.4	57.3
CEC (cmol (+) kg^{-1})	16.4	21.4

WAS: water aggregate stability; CCE: calcium carbonate equivalent; AL: active limestone; TOC: total organic carbon; CEC: cation exchange capacity.

Table 2
Chemical composition of irrigation water.

	Treated wastewater	Saline groundwater
EC 25 °C (dS m^{-1})	2.30	7.61
SS (mg L^{-1})	71.3	–
N-NO_3^- (mg L^{-1})	4.4	49.1
N-NH_4^+ (mg L^{-1})	31.5	–
P total (mg L^{-1})	0.83	–
Total salt (g L^{-1})	1.28	5.81
Cl^- (mg L^{-1})	501	2569
Na^+ (mg L^{-1})	341	718
Ca^{2+} (mg L^{-1})	98	716
Mg^{2+} (mg L^{-1})	37	390
K^+ (mg L^{-1})	25	32

–: not detected.
EC: electrical conductivity; SS: suspended solids.

The zone is characterized by a typical Mediterranean climate, with average rainfall of 464 mm and average temperature ranging between 10 °C in winter and 25 °C in summer. The heaviest rainfall occurs during the autumn and there is a dry period from May to September. The total rainfall during the period of study (August 2003–September 2004), was 498 mm. Mean minimum and maximum temperatures ranged from 3.9 °C in January 2004 to 34.5 °C in August 2003 (Fig. 1). August 2003 was exceptionally hot while the spring of 2004 was relatively wet and the irrigation period began later than usual as a consequence (Meteorological data collected from the Palma Airport Station (<2 km from the study area), data source: Agencia Estatal de Meteorología).

2.2. Soil sampling

Two plots in Phaeozem irrigated with treated wastewater (P-TWW), two plots in Calcisol irrigated with treated wastewater (C-TWW) and one plot in Calcisol irrigated with saline groundwater (C-SGW) were selected. Irrigation with treated wastewater in the studied plots started in the early eighties (20 years before the sampling). The heavy metal content in the selected plots was low and below the legal limits (Adrover and Vadell, 2007). All plots were cultivated with a local variety of alfalfa (*Medicago sativa* L.) conventionally farmed according to local practice. Soils are usually tilled with a mouldboard plough to a depth of 20–25 cm when intended for annual crops; however, once alfalfa is established, the soil is not tilled again since alfalfa is a multi-year

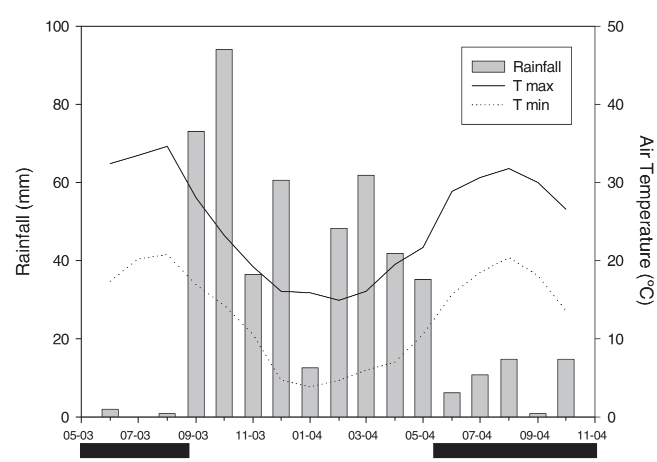

Fig. 1. Monthly rainfall and maximum and minimum monthly temperature during the study period (August 2003–September 2004). The broken horizontal bar below the x-axis indicates the period of irrigation. Meteorological data collected from the Palma Airport Station (<2 km from the study area), data source: Agencia Estatal de Meteorología.