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Research Paper

Changes in soil soluble salts and plant growth in a sandy soil irrigated with treated water from oil extraction

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ABSTRACT

The adverse effects of the use of wastewater can vary, and depend on several factors, possibly causing an accumulation of toxic minerals in the soil, making it necessary to evaluate its effect when used in the irrigation of crops. The aim of this study was to evaluate changes that take place in the soluble salts and organic matter fractions of the soil, and in the growth of plants of the BRS 321 cultivar of the sunflower (*Helianthus annuus* L.) cultivated in soil of a sandy texture and irrigated with wastewater obtained from oil extraction and treated by filtration and reverse osmosis. Soil samples were collected from the same area after each of the three periods of cultivation, and measurements taken of pH, electrical conductivity (EC), Na, Cl, Mg, Ca, K, HCO_3^-, Cl^-, metals (Ag, As, B, Ba, Cd, Co, Cr^{3+}, Hg, Ni and Pb) and organic fractions. The plants were evaluated for growth, the accumulation of root and shoot biomass, and achene production. It was found that salt concentrations and EC increased when the soil was irrigated with water treated by filtration, as did the pH, irrespective of the type of water used. Only the C of the fulvic acid fraction in the surface layer was affected by the type of water, resulting in a smaller content in the soil irrigated with FPW. Changes in the carbon content of the humic substances can be attributed in part to mobilisation of the organic fractions in the soil. The increase in salinity and alkalinity of the soil reduced plant growth and the accumulation of plant biomass. Depending on the treatment, the re-use of wastewater from oil wells may be a good option, particularly in regions with severe and extensive drought. Treatment with reverse osmosis improved the quality of the wastewater from oil wells, but for such wastewater to be used, the cumulative effects must be assessed, as alkalisation was seen to have occurred even in a sandy soil.

1. Introduction

The production of food and fibre in amounts sufficient to meet human needs depends on technology, such as irrigation, particularly in arid and semi-arid regions. Consequently, the high agricultural demand for available water, and the need to prevent its deterioration, make it necessary to consider reusing low quality water in agricultural production (Al-Rashed and Sherif, 2000). Treated wastewater can meet crop requirements for water and nutrients. However, the use of this water may cause problems from the accumulation of minerals in the soil to toxic levels, making it necessary to evaluate these effects when such water is used for irrigation (Xu et al., 2010).

The use of wastewater may result in higher levels of nutrients such as N, P, K, Ca and Mg in the soil, compared with the water usually used for irrigation (Heidarpour et al., 2007; Rusan et al., 2007; Pereira et al., 2011). Furthermore, its use contributes significantly to the accumulation of organic matter in the soil (Rusan et al., 2007; Xu et al., 2010) and affects plant development (Rusan et al., 2007). However, the continued use of wastewater may negatively affect the soil properties, causing the accumulation of heavy metals in the soil and in plant tissue, changes in soil pH, and the accumulation of salts in the soil to toxic levels (Heidarpour et al., 2007;

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Morugán-Coronado et al., 2011; Pereira et al., 2011; Rusan et al., 2007; Sou/Dakouré et al., 2013; Toze, 2006).

A high level of sodicity can mobilise soil organic matter (Churchman et al., 1993) and contribute to the leaching of organic fractions (Naidu and Rengasamy, 1993), producing a reduction in the C content. Increases in toxic elements also adversely affect the size, diversity and activity of the microbial community in the soil (Mavi et al., 2012; Marschner, 2013; Yuan et al., 2007), with a consequent decrease in the rate of decomposition of the soil organic matter (Bowles et al., 2014; Mavi et al., 2012; Rietz and Haynes, 2003; Yuan et al., 2007).

Furthermore, chemical changes in the soil occasioned by the use of wastewater are reflected in the chemical characteristics of plants, as well as affecting their development (Rusan et al., 2007; Shi and Sheng, 2005). Wastewater therefore may promote plant growth when contributing to a greater accumulation of nutrients in the plants, as seen by Pereira et al. (2011) and Rusan et al. (2007); wastewater however, can increase the level of salts in the plant tissue (Rodda et al., 2011; Rusan et al., 2007) and reduce the accumulation of nutrients essential for plant growth (Pereira et al., 2011).

Nevertheless, these adverse effects are variable and depend on several factors, such as the type of irrigation, the amount of water employed, the drainage capacity of the soil, the local rainfall, and the quality, origin and treatment of the wastewater (Heidarpour et al., 2007; Morugán-Coronado et al., 2011; Pereira et al., 2011; Sou/Dakouré et al., 2013; Xu et al., 2010). These factors should be considered in studies which aim to evaluate the effect of wastewater on the soil-plant system, in order to collect the information necessary for the proper management of these water resources.

The information available in the literature is from studies using wastewater which derive from domestic or industrial sewage (Heidarpour et al., 2007; Morugán-Coronado et al., 2011; Pereira et al., 2011; Rusan et al., 2007, Sou/Dakouré et al., 2013; Toze, 2006; Xu et al., 2010). However, there are other types of wastewater that can be used in agriculture, such as water obtained during oil extraction.

The wastewater generated during oil extraction may contain high levels of salts and heavy metals (Al-Haleem et al., 2010), and cannot be discarded directly into the environment. In Brazil, current environmental legislation determines that wastewater from oil extraction should be re-injected, which represents a loss to the oil industry, as the proportion of water in relation to the extracted oil increases with time and reduces the yield of the wells. In the Potiguar oilfield, located in the Brazilian semi-arid region, the average proportion of water for 2012, 2013 and 2014 was 95%, while for oil it was 5%, generating a mean volume of 4,139,864.466 m^3 of wastewater per year (ANP, 2016).

The reuse of this water in agriculture is an interesting alternative for farmers in the Northeast of Brazil, as this is a region with a pronounced shortage of water which limits agricultural production. The use of wastewater from oil wells treated for agricultural production is therefore a promising possibility, which is of interest to farmers in the region and to the oil industry. However, there is no information available on the use of this type of water in agricultural production, which makes it necessary to investigate its effects on the chemical quality of the soil, the decomposition of soil organic matter and the development of crops; factors which are related directly to the quality of the environment and agricultural production.

The aim of this study was to evaluate changes in the soluble salts and organic matter fractions of the soil and in the growth of plants of the sunflower (*Helianthus annuus* L.) cv. BRS 321, cultivated in soil of a sandy texture and irrigated with wastewater obtained from oil extraction and treated by filtration and reverse osmosis.

Table 1
Chemical attributes of ground water (UGW) and water from oil extraction treated by the processes of reverse osmosis (OPW) and filtering (FPW).

Chemical attribute	UGW	OPW	FPW
Class of salinity[1]	C2S3	C2S2	C4S4
EC^{ac*} (dS m^{-1})	0.69	0.53	2.67
pH^{ac*}	8.11	7.56	8.46
SAR^{ad*}	24.98	17.41	43.95
Na^{ac*} (mg dm^{-3})	237.24	104.40	424.95
K^{ac*} (mg dm^{-3})	6.81	15.76	27.21
Ca^{af*} (mg dm^{-3})	4.39	2.08	3.11
Mg^{af*} (mg dm^{-3})	1.47	3.53	12.46
Cl^{-ag*} (mg dm^{-3})	116.70	85.88	628.35
$HCO_3{}^{ag*}$ (mg dm^{-3})	170.44	85.88	214.22
Ag^{bh**} (μg dm^{-3})	<0.70	<0.70	<0.70
As^{bh**} (μg dm^{-3})	0.98	<0.40	2.08
Hg^{bh**} (μg dm^{-3})	0.45	0.75	0.40
B^{bh**} (μg dm^{-3})	160.92	284.47	385.56
Ba^{bh**} (μg dm^{-3})	110.30	25.19	155.42
Cd^{bh**} (μg dm^{-3})	<0.80	<0.80	<0.80
Co^{bh**} (μg dm^{-3})	<1.20	<1.20	<1.20
Cr^{bh**} (μg dm^{-3})	<2.50	<2.50	<2.50
Ni^{bh**} (μg dm^{-3})	2.51	2.50	1.66
Pb^{bh**} (μg dm^{-3})	6.52	8.00	11.41
Zn^{bh**} (μg dm^{-3})	2.95	31.31	8.41

[*] Average of 17 samples;
[**] Average of 5 samples; [1] Richards (1954); EC: electrical conductivity; SAR: Sodium Adsorption Ratio;
[c] Potentiometry;
[d] SAR calculated from the values of Na, Ca e Mg (Tedesco et al., 1995);
[e] Flame photometry (Tedesco et al., 1995);
[f] Atomic absorption spectrometry (Tedesco et al., 1995);
[g] Volumetrics (Tedesco et al., 1995).
[h] inductively coupled plasma atomic absorption spectrometry (ICP-OES,) (USEPA, 2012).

2. Material and methods

The study was carried out at the experimental area of Petrobras, located on the Fazenda Belém Farm, in the municipality of Aracati, in the State of Ceará (4°43′6″ S, 37°32′48″ W). The area is in the northeast of Brazil and has a hot semi-arid climate as per the Köppen classification. The temperature varies between 26 °C and 28 °C and the average annual rainfall is 935.9 mm, with the rainfall concentrated between January and April (IPEEC, 2015). The dominant class of soil in the experimental area is an Arenosol (FAO, 2006), equivalent to a quartz-sand Neosol (Quartzipsamment) in the Brazilian System of Soil Classification.

The wastewater used in the experiment was obtained from the oil field in the municipalities of Aracati and Icapuí, in Ceará and was submitted to two treatmentscommonly used during oil extraction. In the first treatment, after separation from the oil, the wastewater was passed through sand filters and then through cation-resin filters to remove residues of the sodium hydroxide used in the oil-water separation process (FPW). In the second treatment, the filtered water was subjected to a process of reverse osmosis, with preliminary chemical treatment with sulphuric or hydrochloric acid for pH correction, aluminium sulphate for the flocculation of possible solutes, and an anticrusting agent and biocides for the elimination of microorganisms which are prejudicial to oil extraction (OPW). Groundwater (UGW) was used as a control treatment. The UGW was extracted from the Açu aquifer, which is at a depth of 240-250 m. The chemical characteristics of the different types of water used are shown in Table 1.

Plants of the sunflower (*H. annuus* L.) cv. BRS 321 were grown for three successive periods in plots of 400 m^2 (20 × 20 m) irrigated with OPW, FPW and UGW. In the first period (P1), the crop cycle was from July to October 2012; in the second (P2), the cycle was from March to June 2013; and in the third (P3), from August to November 2013. The average maximum and minimum temperatures of the