Soil and water changes after sewage irrigation practice in semi-arid region of Northeast Brazil

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Abstract Due to scarcity and uneven water distribution in many regions of the world, irrigation practices are carried using water with poor chemical and microbiological quality favouring salt accumulation in soil, groundwater contamination and health risks. These impacts can be easily evaluated with small soil columns, considered an equivalent experimental plots, given sufficient information for reuse practice such as plant water needs, water losses by evaporation and percolation, groundwater quality, culture productivity and microbiological contamination of soil and culture. This work describes chemical and microbiological changes in two soils of Paraíba State – Northeast Brazil, before and after irrigation with clean water and polluted superficial water. Also investigated are the changes in water quality before and after percolating these soil columns and lettuce (Lactuca sativa, L.) contamination. The analysed parameters in water were: pH, electrical conductivity, ions (calcium, magnesium, potassium, chloride and sodium), ammonia, total phosphorus, soluble orthophosphate, BOD, fecal coliforms (FC) and fecal streptococci (FS). The pH values for both irrigation waters were slightly neutral to alkaline. Electrical conductivity values were high in irrigation and percolating waters (up to 1,753 and 2,367 µmho/cm) due to waters and soil features, not affecting plant growth. The concentrations of calcium, magnesium, potassium were considered adequate for irrigation water but not for chloride and sodium, although indirect effects on lettuce growth were observed. The BOD₅ of polluted water ranged from 8 to 15 mgO₂/L and was reduced to 85% after the percolating soil columns. FCs in polluted water were well above the recommended WHO values of 1,000 CFU/100 mL with soils reducing these values in 99.8% for FC (2 × 10⁶ – 4 × 10³ CFU/100 mL) and 98% for FS (2.5 × 10⁴ – 4 × 10² CFU/100 mL). Soils were highly contaminated with both FC (2.2 × 10⁴ MPN/100 g) and E. coli (8.3 × 10² MPN/100 g) and when polluted water was used these numbers either increased or did not change. There was an increase of soil nitrogen and organic matter percentages after polluted water was added to the soils. Lettuces were also contaminated when both waters were used (with polluted water FC up to 2.0 × 10⁵ MPN/100 g) and associated with aerosol formation during manual irrigation. Although some inconveniences are shown, water reuse must be considered as an alternative for food production in semi-arid regions and will be successful when adequate and continuously technical support is given.

Keywords Saline soil; semi-arid region; sewage irrigation

Introduction
Water reuse has become a viable option for sustainable water resources planning in governmental policies all over the word particularly those areas where the uneven distribution water supply together with periodic droughts limited human activities specially those related to food production. Accordingly to WHO (1989), many are the advantages of wastewater reuse in irrigation: from effluent polishing, water recovery, cost reduction on chemical fertilizers to increase of soil fertility by humus formation due to slow mineralization of organic matter.

The increasing population in urban areas around the world, including semi-arid Northeast Brazil, together with lack of wastewater collection and adequate treatment favoured the discharge of untreated or partially treated wastewater into streams and lakes. These contaminated water bodies frequently are the only available water source used for irrigation to guarantee some agricultural production and income to human survival during the dry season (Magalhães et al., 2000).
When correctly managed irrigation has many advantages to rural workers such as higher yields, more than one harvest per year and out of normal seasons, food production guaranteed since agriculture is completely independent from the rainfall, more working places, less people movement from rural to urban areas (Daker, 1984). Irrigation using wastewater offers some level of treatment of sewage effluents and introduces inorganic nutrients for plant growth but needs technical and sanitary advice to reduce the health risk for workers and consumers (FAO, 1992; Shuval et al., 1986).

In order to be successful in the practice of wastewater reuse some attention must be given to the irrigation water salt content since its accumulation in the nearby root zone has severe consequences for plant growth (Ayres and Wescot, 1991). In arid and semi-arid regions around the world soluble salts and alkali accumulations in irrigated soils mix with the origin of irrigation. The ascending and decline of some civilizations are related to the problem and still today great land expanses in Africa, Asia and America are lost due to soil salinization due to inadequate irrigation procedures (Daker, 1984).

Reuse environmental impact on any soil and culture can be easily evaluated with small soil columns since they are equivalent to experimental plots capable of giving sufficient information on the plant water needs, losses through evaporation and percolation together with the influence of the irrigation water on groundwater quality, culture productivity microbiological contamination of soil and culture.

This work describes chemical and microbiological changes in two soils of Paraíba State – Northeast Brazil, before and after the irrigation with clean water and polluted superficial water. Also investigated are the changes in water quality before and after percolating these soil columns and lettuce (Lactuca sativa, L.) contamination, grown in these conditions.

Experiments were conducted in the Paraiba Federal University Campus (Campina Grande – Paraíba State (7°13′11″S; 35°52′31″W) Northeast Brazil) using six PVC columns (750 mm tall; 200 mm diameter). Non-polluted irrigation water came from the Campina Grande Municipality Water Supply System and superficial polluted water from a nearby urban stream crossing the University Campus. Irrigation and percolated waters were analysed for pH, electrical conductivity (EC), ions (calcium, magnesium, potassium, chloride and sodium), ammonia, total phosphorus, soluble orthophosphate, BOD5, faecal coliforms and faecal streptococci (APHA, 1995). Two types of soil were used: a lateritic-podzolic (exp I) from Lagoa Seca Municipality (temperatures of 25°C and 1,000 to 1,000 mm precipitation – annual means) and a halomorphic soil called litossoil-regosol soil (exp IIA and IIB) originated from Pocinhos Municipality (temperatures of 26°C and 382 mm precipitation – annual means). Each experiment lasted three months: Jan–Mar/98 (exp I), Apr–Jun/98 (exp IIA) and Jun–Aug/98 (exp IIB). During 1998 Campina Grande was under a severe drought and a severe program to reduce water consumption was imposed on urban and rural users. Data were evaluated through descriptive statistics and multiple correlation analysis (SPSS for Windows 8.0).

Results
Values of pH in supply water used for irrigation varied from 7.9 (exp IIA) to 8.3 (exp I) and related to the soil composition (rich in carbonate and bicarbonates (Wright, 1981)) and salt concentration caused by the negative balance when evaporation exceeds precipitation; typical phenomena in semi-arid regions (Payne, 1986). The polluted water pH was slightly basic (7.4 to 7.8) but within the recommended values of 6.8 to 8.4 (Ayres and Westcot, 1991) with a small increase (7.7 to 7.9) after percolating the two types of soils (Figure 1a).

The EC (Figure 1b) of the supply and polluted irrigation waters presented higher variation in exp IIA (1,015 and 1,753 µmho/cm) followed by exp I (1,044 and 1,701 µmho/cm) and exp IIB (1,112 and 1,698 µmho/cm). All this values were adequate for lettuce growth
since it tolerates waters with EC up to 2,080 µmho/cm (Molle and Cadier, 1992). After percolating the soil columns these values were raised up 127% in exp I (1,044–2,367 µmho/cm supply water) to a 6% decreased in exp IIB for both irrigation waters: supply (1,112–1,046 µmho/cm) and polluted (1,698–1,590 µmho/cm) showed that soil features have influence on the percolating water EC.

Calcium concentrations (Figure 1c) in percolated water always increased despite the type of soil and irrigation water used with highest value in exp I (38–106 mg/L – 179%);
supply water) and lowest in exp IIB (65–103 mg/L; polluted water). These increases were associated with calcium leached due to sand incorporated in the soils in order to improve drainage.

Mean magnesium values (Figure 1d) in irrigation waters were adequate and below 60 mg/L as recommended by Ayres and Westcot (1991) except in exp I where the polluted water presented 94 mg/L. All percolated water had less magnesium and reduction to 25% was observed (exp IIB: 39–29 mg/L; supply water) due to plant absorption for chlorophyll molecule construction and nitorgen metabolism.

The recommended potassium concentration in irrigation waters ranges from 0 to 78 mg/L (Ayres and Westcot, 1991) and was not exceeded in any of the soils tested, irrigations and percolating waters analysed (Figure 1e). After passing through the soil column mean potassium concentration showed increases in 5 out of 6 experimental columns varying from 7% (exp IIB: 25–27 mg/L; supply water) up to 442% (exp I: 7–38 mg/L; supply water) and a decrease of 39% (exp IIB: 51–31 mg/L; polluted water).

Ayres and Westcot (1991) recommend chloride concentrations from 107 to 142 mg/L for superficial or sprinkle irrigation. However Molle and Cadier (1992) call attention to toxic levels with values varying from 142 to 355 mg/L, causing severe damage to the plant when this higher concentrations is exceeded. In exp I irrigation and percolated waters did not reach toxic levels (below 237 mg/L). However in exp IIA and IIB chloride concentrations (Figure 1f) were much higher in both irrigation waters and associated with ion concentrations in the supply water due to negative water balance (evaporation higher than precipitation) in the Campina Grande Municipality water reservoir. This phenomenon increased the supply water and polluted water chloride contends around 260 and 345 mg/L respectively. After percolating halomorphic soil columns (exp II) these waters had chloride levels increased to 292 mg/L (supply water in exp IIA) and 377 mg/L (polluted water in exp IIA). In this experiment the effect of high chloride content on irrigation water was observed with some necroses at the plant edge. On the other hand deficiencies of chloride can cause problems to plant metabolism since it is responsible for others ion transport such sodium, potassium, calcium and magnesium.

During the experimental period, sodium concentration (Figure 1g) in the supply water varied from 124 mg/L (exp I) to 199 mg/L (exp IIA) and in polluted water from 237 mg/L (exp I) to 300 mg/L (exp IIA). This high sodium content in the water supply system is a result of some regional climatic features such as intense evaporation due to high insolation levels, which concentrate ion content of the surface water. In all percolated waters sodium content was higher than 189 mg/L (exp IIB – supply water) but below 309 mg/L (exp I – polluted water). Laraque (1991) points out the deleterious effects of sodium when concentrations are between 69 and 207 mg/L being problematic above these values when it causes necroses on plants leaves. A positive correlation at 5% level among sodium and chloride was observed for supply water \(r = 0.9481; \alpha = 0.05\) and polluted water \(r = 0.5467; \alpha = 0.05\).

In both experiments ammonia content (Figure 1h) in the supply water was below 0.2 mg/L in contrast to the 31.8 mg/L in polluted water (exp I). After irrigation with supply water some ammonia was incorporated from the soil to the percolated liquid water but concentrations did not exceed 1.5 mg/L (exp I). In the three experiments both soil (as a good filter) and culture (assimilation into biomass) were capable of retaining up to 98% (17.6–0.3 mg/L; exp IIB) when polluted water was used.

In all three experiments the supply water had low phosphorus content but considerable amounts of total phosphorus and soluble orthophosphate (Figures 2a and 2b) were leached to the percolated water with higher values in exp I (5.1 mg/L and 3.9 mg/L respectively). Polluted water phosphorus content was similar to that found in raw sewage both for total
phosphorus (3.1 to 4.1 mg/L) and orthophosphate (2.6 to 3.4 mg/L). After percolation these mean values increased 18% in exp I, for both total phosphorus (4.1–4.8 mg/L) and orthophosphate (3.2–3.8 mg/L respectively) because soil had high concentrations of assimilable phosphate due to previous utilization of cow manure as organic fertilizer. The soil used in exp IIA and IIB removed only 15 to 23% of total phosphorus (4.0–3.4 mg/L; 3.1–2.4 mg/L) and 52 to 23% of soluble orthophosphate (3.4–1.6 mg/L; 2.6–2.0 mg/L) respectively.

When polluted water was applied to the columns both soils acted as efficient filters removing $\text{BOD}_5$ (Figure 2c) from 64% (11–4 mg/L; exp IIA) to 75% (12–3 mg/L; exp I) although some organic matter not exceeding 4 mg/L was incorporated to the percolating liquid when both waters were used.

Microbiological indicators (Figures 2d and 2e) were absent in the water supply samples and increased to $7.9 \times 10^2$ CFU/100 mL in percolated water (exp IIA) showing natural soil contamination. When polluted water was used removals of faecal indicators ranged from 99% for fecal coliforms (exp IIB) to 98% for streptococci (exp IIA and IIB) suggesting soil with good retaining capacity of fecal indicators.

Soils were naturally contaminated both with faecal coliforms and $E. \text{coli}$ (Table 1) and higher values were found in exp II (2.2 $\times 10^4$ and 8.3 $\times 10^2$ MPN/100 g respectively). When polluted water was applied the number of faecal indicators in soil either increased (exp I and IIB) or was maintained the same (exp IIA), and for supply water these numbers either decreased (exp IIA) or were maintained the same (exp IIB). These results showed that contamination levels of polluted water (FC of $10^4$ to $10^5$ CFU/100 mL) were transferred to soil (1.3 $\times 10^5$ MPN/100 g) increasing FC numbers to a level similar to the irrigation water in a period of 6 months of exp IIB (Apr–Aug/98).

Lettuce contamination also occurred (Table 1) when both waters were used and associated with aerosol formation during manual irrigation (König et al., 1998). Higher values were found when polluted water was used (up to $1.5 \times 10^5$ MPN/100 g; exp IIB) since water was drained over the lettuces leaves. Even so these contamination levels were considered below those found in similar experiments (Barros et al., 1999) and associated with the good bactericide effects of solar radiation when combining the high intensity and long hours of insolation, typical in tropical regions.

In both experiments the irrigation with polluted water increased soil concentration of nitrogen (0.04 to 0.07% – exp I and 0.03 to 0.05% – exp IIA and IIB) and the percentage of organic matter (0.74 to 1.2% exp I and 0.52 to 1% – exp IIA and IIB). Soluble phosphorus was high in exp I (57.4 mg/100 mg soil; due to previous fertilizations with animal manure) when compared to exp II (6.73 mg/100 mg). Soil electrical conductivity ranged from 200 $\mu$mho/cm (exp I) to 160 $\mu$mho/cm (exp II) not showing significant alteration at the end of the experiments, indicating small risks of salinization.

Despite all the inconvenience, particularly those related to human health and soil changes, water reuse must be encouraged in semi arid regions where water scarcity is a

Table 1  Bacteriological analysis of soil and lettuce (MPN/100 g), Paraiba State – Brazil

<table>
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<tr>
<th>Soil</th>
<th>lateritic-podzolic</th>
<th>halomorphic soil – litossoil – regosol</th>
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<tr>
<td></td>
<td>Experiment I</td>
<td>Experiment IIA</td>
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<td></td>
<td>Irrigation</td>
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<td></td>
<td>Type of water</td>
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<td>Soil</td>
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<td>$9 \times 10^2$</td>
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<td></td>
<td>$E. \text{coli}$</td>
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reality and will succeed with adequate technical support in a multidiciplinarity approach aiming at sustainability in those areas.

Conclusions
The use of soil columns have shown to be an efficient and simple way to estimate the effects of different irrigation water quality on any soil giving also an important additional information: the quality of the groundwater produced. In this work the irrigation with polluted water on saline soil increased the percolated water chloride contend but not necessarily increase on the other parameters when compared to a non saline soil. The fecal indicators were removed up to 99% when polluted water was used suggesting the good retaining capacity of soils. In both experiments the use of polluted water increased nitrogen and organic matter content of soil. Lettuces were contaminated when irrigated with both clean and polluted water suggesting the transport of fecal indicators via aerosols.

References


