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Treated domestic sewage irrigation effects on soil hydraulic properties in arid and semiarid zones: A review

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ABSTRACT

In arid and semiarid regions, the use of treated domestic sewage (effluent) for irrigation is becoming a common practice, because of the shortage of freshwater resources. However, the use of effluent for irrigation could have an impact on the chemical and hydraulic properties of soils. This paper reviews the effects of irrigation with effluents that have undergone various treatments on hydraulic properties of semiarid and arid soils. Irrigation of semiarid clay and sandy soils with secondary effluent increased the salinity at depths down to ~1.5 m, and the sodicity down to ~1.5 and >4 m, respectively. The increase of the organic matter load in the effluents resulted in inconsistent effects on the organic matter content of the topsoil, but it could lead to its decrease in the subsoil because of a "priming effect" of the effluent. Percolation of effluent through the soil profile can reduce its saturated hydraulic conductivity (K_s) to an extent that depends on the effluent quality, soil chemical properties, and the pore size distribution in the soil. Leaching a loamy and a clay soil with secondary effluent decreased the K_s because of plugging of the pores with suspended solids, whereas the K_s of a sandy soil was not affected because of its large average pore size. Irrigation of high sodicity, arid soils with effluent that had undergone reverse osmosis treatment decreased K_s because of the low electrolyte concentration of the effluent, which enhanced soil swelling and clay dispersion. An increase of soil sodicity, caused by effluent irrigation, decreased the K_s of a clay soil leached with water of low electrolyte concentration, as a result of enhanced clay swelling and dispersion. In a non-calcareous, sandy soil, the higher sodicity in the effluent-irrigated soil led, under rainfall conditions, to enhanced seal formation, reduced infiltration, and increased runoff, as a result of enhanced clay dispersion. In contrast, for calcareous soil under similar conditions, no effect of effluent irrigation on runoff and soil loss was observed. This was, probably, because of the release of Ca during the dissolution of $CaCO_3$; this Ca replaced exchangeable Na, thereby reducing the soil sodicity to its natural levels. Because of the interaction between effluent irrigation and soil properties, it is necessary to identify sensitive regions and soils prior to irrigation with effluents, to prevent possible deleterious effects on soil structure and hydraulic properties.

1. Introduction

Arid and semiarid regions are characterized by evapotranspiration that exceeds precipitation during most of the year. Therefore, agriculture in these regions relies on supplementary irrigation to enable productive crop growth. At the same time, one of the main environmental problems in these regions is a shortage of freshwater, which is expected to become more severe in the future because of the growing pressure on water resources, as well as climate change. Therefore, in these regions, one of the challenges facing agriculture, which commonly uses large amounts of water, is to find new sources of water for irrigation. One of the alternatives that have become more common in recent years is the reuse of treated domestic sewage (effluent) for irrigation.

Currently, the effluent used for irrigation is mainly obtained after secondary (biological) treatment. However, this effluent differs from freshwater in its salinity, sodicity, pH, and concentrations of microelements, nutrients, dissolved organic matter (DOM), and total suspended solids (TSS), all of which are significantly higher than in freshwater (Feigin et al., 1991; Halliwell et al., 2001; Ben-Hur, 2004). With regard to soil hydraulic properties, these differences in the quality of the effluent can affect water movement through the soil, either because of differences in the compositions of the percolating solutions, or as a result of changes in the chemical and physicochemical properties of the effluent-irrigated soil; changes that could affect soil structure.

Because of the growing interest in the use of effluents for irrigation, and in light of their possible impacts on soils, water

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Table 1
Average values of pH, electrical conductivity (EC), Cl^- concentration, sodium adsorption ratio (SAR), biological oxygen demand (BOD), total suspended solids (TSS), and dissolved organic matter (DOM) of raw sewage and treated effluents from different treatment plants and of freshwater in Israel. Numbers following ± are standard deviation values (after Ben-Hur, 2004).

Location and effluent treatment types of different treatment plants	pH	EC (dS m^{-1})	Cl^- (meq L^{-1})	SAR, (meq $L^{-1})^{0.5}$	BOD (mg L^{-1})	TSS (mg L^{-1})	DOM (mg L^{-1})
Raw sewage							
Haifa	7.5 ± 0.8	2.4 ± 0.2	8.9 ± 1.5	8.5 ± 1.8	650 ± 132	605 ± 398	191 ± 44
Tel Aviv	7.8 ± 0.5	2.0 ± 0.0	8.8 ± 1.3	4.9 ± 0.6	547 ± 135	330 ± 175	194 ± 45
Netania	8.0 ± 0.2	1.6 ± 0.1	5.2 ± 0.3	3.8 ± 0.5	500 ± 175	330 ± 106	144 ± 20
Migdal Haemek	7.7 ± 0.7	1.8 ± 0.1	9.4 ± 0.7	5.5 ± 0.4	662 ± 69	298 ± 55	185 ± 27
Treated effluent							
Haifa—activated sludge	7.9 ± 0.4	2.3 ± 0.1	10.4 ± 1.1	7.2 ± 0.3	38 ± 12	47 ± 20	50.0 ± 1.9
Tel Aviv—activated sludge	8.0 ± 0.4	2.0 ± 0.4	10.2 ± 1.7	5.6 ± 1.1	6.7 ± 11	4.4 ± 1.7	31 ± 2.7
Tel Aviv—oxidation ponds	8.0 ± 0.2	1.7 ± 0.1	8.4 ± 1.0	5.1 ± 0.5	77.5 ± 32	110 ± 67	58 ± 2.6
Netania—activated sludge	7.6 ± 0.3	1.5 ± 0.4	5.5 ± 1.2	3.5 ± 1.3	8.0 ± 7.8	6.0 ± 2.6	26 ± 2.2
Migdal Haemek—oxidation ponds	8.1 ± 0.3	2.1 ± 0.1	9.9 ± 0.9	5.9 ± 0.5	59 ± 16	16 ± 9	40 ± 2
Freshwater	7.2 ± 0.2	0.9	9	2.5	~0	~0	4.3 ± 1.7

resources, and agricultural production, several authors have studied the effects of effluent irrigation on the soil chemical and physical properties (Levy et al., 1986; Balks et al., 1998; Halliwell et al., 2001; Ben-Hur, 2004; Dawes and Goonetilleke, 2006; Heidarpour et al., 2007), including soil hydraulic properties (Rice, 1974; Vinten et al., 1983; Cook et al., 1994; Levy et al., 1999; Tarchitzky et al., 1999; Magesan et al., 1999, 2000; Mamedov et al., 2000, 2001; Ben-Hur and Assouline, 2002; Agassi et al., 2003; Lado et al., 2005; Gloaguen et al., 2006; Gharaibeh et al., 2007; Bhardwaj et al., 2007, 2008; Mandal et al., 2008). Several mechanisms have been hypothesized to cause changes in soil hydraulic properties when effluent is used for irrigation. The suspended solids in the effluent can block the water-conducting pores in the soil and, in addition, effluent irrigation can change soil chemical and biological properties, as exchangeable sodium percentage (ESP), salinity, organic matter content and quality, and micro-organism activity, all of which can affect the soil-structure stability and soil-pores architecture. Organic constituents applied with the effluent can also increase soil water repellency. These effects of effluent irrigation on soil hydraulic properties can be classified into two main types: (i) direct effects—changes in soil hydraulic properties that occur during the movement of the effluent through the soil profile; and (ii) indirect effects—changes in soil hydraulic properties that occur after irrigation with effluents, when the soils are leached with rainfall or irrigation water other than effluent. The present paper reviews the present knowledge about the direct and indirect effects of effluent irrigation on hydraulic properties of soils from arid and semiarid regions.

2. Effluent qualities

Domestic sewage comprises 99.9% water and 0.1% organic and inorganic, possibly toxic, compounds in suspended and soluble forms (Feigin et al., 1991). In addition, this water contains microorganisms that may be pathogenic (bacteria, viruses, and parasitic protozoa) and parasitic worms. Therefore, in order to protect the public both from consumption of contaminated crops and from direct exposure to sewage water, and to prevent the development of nuisance conditions, of operational problems in the irrigation system, and of adverse effects on soil, crops and water resources, the sewage water intended for irrigation should be treated before its application to the soil.

The most common treatment of the sewage water used for irrigation in many countries is a secondary (biological) treatment. In Israel, for example, the two most common secondary treatment systems use oxidation ponds and activated sludge. The average quality of secondary effluents from some sewage treatment plants in various locations and of freshwater in Israel are presented in Table 1, which shows the main parameters that can affect soil hydraulic properties. The values of electrical conductivity (EC) and sodium adsorption ratio (SAR) of the effluents, which reflect the salinity and the sodicity of the water, respectively, are relatively high; they differ among the treatment plants, mainly because of differences in the quality of the raw sewage waters (Table 1), since secondary treatment does not remove salts from the water (Ben-Hur, 2004). However, the secondary treatment decreased the concentrations of total suspended solids and organic matter in the effluents, although they still remained relatively high (Table 1). Because of the concentrations of these salts, organic matter and total suspended solids in the effluents (Table 1), irrigation with these waters could change the salinity, sodicity and organic matter content of the irrigated soils, and consequently could affect their structural stability.

Recently, new sewage treatment technologies have been developed to produce effluents suitable for unrestricted irrigation and recharge of aquifers, among other uses (Shannon et al., 2008). These technologies are based on the filtration of secondary effluent through various membranes, to remove suspended solids, organic molecules, pathogens, parasitic worms, and in some cases, even salts from the water. The qualities of the effluents produced from domestic sewage by consecutive treatments in oxidation ponds (OP, secondary treatment), polishing ponds (PP, secondary treatment), ultrafiltration (UF, membrane treatment), and reverse osmosis (RO, membrane treatment) in Arad, Israel are presented in Table 2, which contains average data from 24 water samples that were taken from each effluent during 2002–2004. As in Table 1, only the main parameters that could affect soil hydraulic properties are presented in Table 2. The UF treatment removed most of the suspended solids and part of the DOM, but did not significantly change the EC and SAR of the effluents, whereas the RO treatment significantly reduced all the quality parameters of the water, including the salinity and sodicity (Table 2).

3. Effect of effluent irrigation on soil chemical properties

Irrigation with effluents can change the chemical properties of the irrigated soils. Three of the main soil chemical properties that can be changed by effluent irrigation and that could affect soil structure and hydraulic properties are: (i) soil salinity; (ii) soil sodicity; and (iii) organic matter content.

The EC and SAR values in saturated soil pastes of sandy and clay soils that were sampled from experimental orchard plots located in the Coastal Plain and the Yizre'el Valley, both in the semiarid region in Israel, are presented in Fig. 1 as functions of soil depth. These experimental plots had been irrigated with secondary effluent or freshwater for >10 years. The soil samples were taken