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Water reuse for irrigated agriculture in Jordan: challenges of soil sustainability and the role of management strategies

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Reclaimed water provides an important contribution to the water balance in water-scarce Jordan, but the quality of this water presents both benefits and challenges. Careful management of reclaimed water is required to maximize the nutrient benefits while minimizing the salinity risks. This work uses a multi-disciplinary research approach to show that soil response to irrigation with reclaimed water is a function of the management strategies adopted on the farm by the water user. The adoption of management methods to maintain soil productivity can be seen to be a result of farmers' awareness to potentially plant-toxic ions in the irrigation water (70% of Jordan Valley farmers identified salinization as a hazard from irrigation with reclaimed water). However, the work also suggests that farmers' management capacity is affected by the institutional management of water. About a third (35%) of farmers in the Jordan Valley claimed that their ability to manage salinization was limited by water shortages. Organizational interviews revealed that institutional awareness of soil management challenges was quite high (34% of interviewees described salinization as a risk from water reuse), but strategies to address this challenge at the institutional level require greater development.

Keywords: perceptions; reclaimed water; soil management; salinity; wastewater

1. Introduction

Jordan is a country with very limited water resources, and treated domestic wastewater offers a valuable contribution to the country's water balance. Water reuse is particularly well suited to irrigated agriculture, for which water is in constant demand. Approximately 51 per cent of all domestic wastewater originating from households in urban areas was collected and treated in 2002, and almost all of the treated effluent (reclaimed water) is used for irrigated agriculture (Ministry of Water and Irrigation 2004). The quantity of wastewater being collected, treated and made available for irrigation is also rising owing

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to increasing urbanization (Potter *et al.* 2008; Darmame & Potter 2009, 2010; Potter & Darmame 2010), resulting in a greater percentage of the country's population being connected to the sewerage network.

The use of reclaimed water for irrigation presents a number of benefits and challenges owing to the nature of the water quality. Reclaimed water in arid countries is typically slightly saline and can also have a relatively high concentration of boron (Feign *et al.* 1991). These ions are potentially plant-toxic, and crop productivity and the long-term sustainability of the soil can be jeopardized if suitable management of the soil and water is not employed. Despite this challenge, reclaimed water can also contain significant quantities of plant-beneficial ions (nutrients) such as nitrogen, phosphorus and potassium. Careful management of the water is therefore required to prevent detrimental effects on soil and crops while benefiting from the 'free' nutrients in the water, which can enhance yields without the additional costs of chemical fertilizers (Lazarova *et al.* 2005; Qadir *et al.* 2010).

Our research into water reuse in Jordan aimed to explore how irrigation with reclaimed water affects soil sustainability, with particular consideration for the role of water management decisions taken both on and off the farm. Several research aims were identified:

- How does water reuse affect soil sustainability?
- How do farmers using reclaimed water perceive the resource and how do they recognize and manage the benefits and limitations?
- How do the institutions involved in managing reclaimed water view the resource and how do they recognize their role in maintaining soil sustainability?

A multi-disciplinary research approach involving both the natural and social sciences was therefore taken in order to explore how aspects of soil sustainability were affected by irrigation with reclaimed water and how the management of the water on the farm and away from the farm affected the soil. This approach was selected with the intention of gaining a wide and holistic view of the numerous processes taking place that result in soil changes due to irrigation with reclaimed water. It was expected that soil response would be a function not just of water quality, but also of water management at multiple scales (from the farmer's field to the government's catchment management plan). As such, simultaneous investigation of soil and water management at the farm and institutional level was deemed to be essential in this research.

2. Research methods

A range of research methods was therefore used, which included reclaimed water sampling and standard chemical analysis (including pH measurement, electrical conductivity measurement and the concentrations of major cations and anions determined with inductively coupled plasma optical emission spectroscopy and ion chromatography, respectively). Soils that had been irrigated with reclaimed water for known periods of time were sampled and analysed to determine the chemical character of the soil saturation extract, which is commonly used to

represent the soil solution (Bressler *et al.* 1982). The standard method given by Rowell (1994) was followed. Water and soils were sampled from the irrigated area surrounding Khirbet As Samra wastewater treatment plant (located in the arid eastern desert of Jordan), Ramtha wastewater treatment plant (located in the semi-arid northern highlands of Jordan) and Deir Alla (located in the central Jordan Valley, where a mixture of fresh water and reclaimed water from the King Talal Reservoir is used for irrigation); see Carr (2009) for further details.

Following well-established methodological approaches (Kitchin & Tate 2000; Desai & Potter 2006), semi-structured interviews were conducted with a total of 39 farmers irrigating with reclaimed water to document and investigate their experiences and perceptions and the strategies they employ in seeking to manage soil risks from reclaimed water on the farm. These were mainly conducted with the assistance of a translator with advanced knowledge of agricultural systems in Jordan. The role of international agencies, governmental, non-governmental, private and research organizations in water reuse was also considered through semi-structured interviews with a total of 29 organizational representatives. These interviews paid particular attention to the effects of water resource decision making on water quality and water quantity provision to the farm, and the effect of these actions for the soil management strategies adopted by the farmer. Interviews were either recorded or notes were taken and these were typed up or transcripts prepared immediately after the interviews. Following the guidelines of Kitchin & Tate (2000), each 'data bit' (piece of information) within the transcripts was then coded following a coding framework developed for each of the interview groups (farmers and organizations). Through examining each similarly coded group of data bits, similarities and differences became clear and narratives could be developed around specific themes.

3. Results and discussion

Water sampling and analysis, combined with data available in the literature, revealed that the reclaimed water from the selected study sites in Jordan contained significant quantities of both plant-beneficial ions and potentially plant-toxic ions (table 1). The phosphate in the reclaimed water is of particular benefit as it has the potential to meet a substantial proportion of crop requirements at Khirbet As Samra and in the Jordan Valley, depending on the crops grown and the intensity of cropping. At Ramtha, the concentration of phosphate is lower owing to the removal of this nutrient during wastewater treatment. The removal of phosphate during treatment is perhaps questionable owing to the use of the water for irrigation directly around the wastewater treatment plant and the value of the phosphate for crop productivity (Carr 2010).

The chloride, sodium and boron in the irrigation water have the potential to reach concentrations in the soil beyond which a reduction in crop productivity can be experienced based on guidance by the Food and Agriculture Organization (Ayers & Westcott 1985). The effect of solute accumulation is highly dependent on the sensitivity of the crop to these ions (Maas 1987). Additionally, a high proportion of sodium relative to other positively charged ions in the soil can cause soil structural problems (Oster & Jayawardane 1998). The sodium adsorption ratio (SAR) is an indicator of the sodium risk, and the data suggest that the

Table 1. Selected water quality parameters for reclaimed water from Khirbet As Samra, Ramtha and the King Talal Reservoir based on samples collected in the field and available published data (GTZ 2005; Al-Zu'bi 2007; Ammary 2007; Bashabsheh 2007).

location	potentially plant-beneficial ions in the irrigation water (mg l^{-1})					potentially plant-toxic ions in the irrigation water (mg l^{-1})					additional parameters		
	sulphate (SO_4)	calcium (Ca)	potassium (K)	magnesium (Mg)	phosphate (PO_4)	chloride (Cl)	sodium (Na)	boron (B)	electrical conductivity (dS m^{-1})	pH	sodium adsorption ratio (SAR)		
Khirbet As Samra	65.09	44.55	31.32	27.22	35.63	364.61	261.14	0.91	2.14	7.86	7.67		
Ramtha	104.66	49.71	32.97	34.19	6.80	398.76	232.46	0.73	1.71	8.21	6.30		
King Talal Reservoir	90.78	50.09	15.74	31.39	21.74	276.66	125.67	0.54	1.91	7.85	1.92		
tap water (Amman)	52.90	56.47	5.36	20.61	4.13	153.38	65.41	<0.0016	0.79	6.90	1.89		

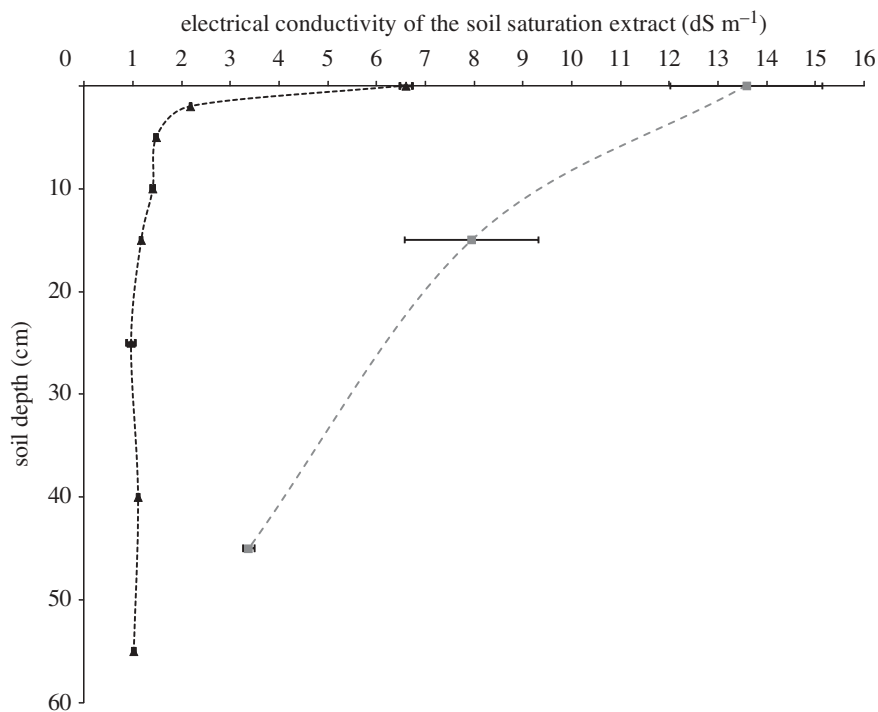


Figure 1. Soil salinity (measured by the electrical conductivity of the soil saturation extract) in soils irrigated with reclaimed water for extensive periods of time (error bars show standard error from the mean): dashed black line with filled triangles, Jordan Valley (28 years of irrigation); dashed grey line with filled squares, Khirbet As Samra (18 years of irrigation).

water at Khirbet As Samra may present a soil sodicity risk, but this would be dependent on the physical properties of the soil and its response to elevated sodium (Rowell 1994).

Analysis of soils irrigated with reclaimed water for extended periods of time showed that the management methods employed by the farmers altered the accumulation of potentially plant-toxic ions in the soil. Figure 1 shows how soil in the Jordan Valley that has been irrigated with reclaimed water for 28 years has a low solute concentration (electrical conductivity in the soil saturation extract) in the crop root zone. This reflects the regular application of leaching water by the farmer in order to transfer solutes through the soil profile. In comparison, the electrical conductivity of the soil irrigated for 18 years at Khirbet As Samra, also shown in figure 1, is much higher throughout the soil profile and reflects how leaching has not taken place on this soil. Leaching has not been conducted because the land has been used for olive cultivation, olives having a deeper rooting depth and so not being sensitive to salinity in the upper soil profile.

Interviews with farmers showed a high awareness to salinity risk in the Jordan Valley and 70 per cent of farmers identified soil salinization as a hazard due to irrigation with reclaimed water. In contrast, farmers using reclaimed water directly around the wastewater treatment plants of Ramtha and Khirbet As Samra were not so concerned about salinity (18%). This is likely to be due to the use of flood irrigation directly around the treatment plants, which results in the

regular flushing of the solutes through the soil. Flood irrigation is possible around the treatment plants owing to high water availability and the use of irrigation as a form of waste disposal. Drip irrigation is used in the Jordan Valley as a result of low availability of water, resulting from the high intensity of cropping, both seasonally and spatially (Molle *et al.* 2008).

The interviews with farmers in the Jordan Valley revealed that, although awareness of salinity risk was high, and the need for leaching was recognized, 35 per cent of the farmers interviewed described how their capacity to leach was limited owing to water shortage. Farmers acknowledged that this was a result of the environmental conditions of low rainfall and high evaporation in Jordan, but it was also noted by several farmers that institutional weaknesses affected their ability to maintain the soil in a sustainable manner. Issues identified included: the distribution of water between farmers, with some farmers describing how they received very little water while their neighbour received plenty; the seasonal distribution of water, with resources being supplied in higher quantities than required in winter and not supplied in sufficient quantities at other times of the year; inadequate management of water infrastructure, such as canals; and the enforcement of regulations to protect the quality of the irrigation water (for example, through preventing industrial waste entering the domestic wastewater system).

Interviews with organizations showed that there was high awareness among this stakeholder group with regard to the protection of the soil resource (34% of interviewees identified salinization as a risk from water reuse). However, no organizations discussed their role in protecting soil sustainability through ensuring the water provided to farmers is of a suitable quality and quantity to meet their needs. Awareness of risks from reclaimed water quality was present, but this was primarily with regard to human health protection.

4. Conclusions

This work has shown that the use of reclaimed water for irrigation in Jordan does have the capacity to affect the soil in a detrimental manner, but the effect of the water on soils can be managed through the application of suitable strategies on the farm. Farmers recognize the challenges and the benefits of using reclaimed water for irrigation, and endeavour to manage the risks to minimize the detrimental effects on the soil and to maintain productivity. However, their capacity to manage their soil is intricately connected to the management of water at the institutional level through the control of water quality and the provision of water in quantities and at the times it is required by farmers. It is stressed that the multi-disciplinary approach adopted has proved to be of immense value for this study owing to its capacity both to document physical processes taking place in the soil and to link these directly with processes of water management taking place at the farm and institutional levels.

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