Water reuse for irrigation in Jordan: plant beneficial nutrients, farmers' awareness and management strategies

G. Carr, S. Nortcliff and R. B. Potter

ABSTRACT

The reuse of treated wastewater (reclaimed water) is particularly well suited for irrigated agriculture as it often contains significant quantities of plant essential nutrients. This work has shown that reclaimed water in Jordan can have adequate concentrations of potassium, phosphate, sulphate and magnesium to meet all or part of the crop's requirements. To fully benefit from these inputs farmers must have an awareness of the water quality and reduce the application of inorganic fertilisers accordingly. Interviews with farmers have shown that 75 per cent of farmers indirectly using reclaimed water are aware of the nutrients. Farmers' decision making as to the application of inorganic fertilisers appears to be influenced by a range of factors which include the type of crops being cultivated, the provision of training on nutrient management and the availability of information on the nutrient content of the reclaimed water.

Key words | irrigation, nutrient management, phosphorus, potassium, reclaimed water, water reuse

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INTRODUCTION

The reuse of urban domestic wastewater after it has been treated offers a means of maximising available water resources and alleviating water scarcity. Treated wastewater (reclaimed water) is particularly well suited for irrigated agriculture as it often contains significant quantities of plant essential nutrients like nitrogen, phosphorus and potassium and treatment which removes potentially harmful pathogens presents little direct hazard to health. These nutrients have the potential to supplement the crop requirements for inorganic fertilisers that can substantially reduce farm costs. Crop growing experiments in Saudi Arabia found that the use of reclaimed water reduced the need for 50 per cent of the inorganic nitrogen usually required for maximum crop productivity (Hussain and Al-Saati 1999). A survey of farmers in Jordan by Abu-Madi (2004) found that farmers could reduce their fertiliser expenditure by 65 per cent when irrigating fruit trees with reclaimed water as compared to groundwater. Work in Jordan by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) has shown that the nutrients in reclaimed water can meet 75 per cent of the fertiliser requirements of a typical farm in the Jordan Valley (MWI 2004).

While nutrient additions are generally beneficial, the application of some nutrients in quantities beyond the requirement of the crop at certain times in the growing season can be detrimental to plant productivity (Feign *et al.* 1991). A high concentration of solutes in the soil solution, including beneficial solutes, can reduce water availability to the plant if the osmotic pressure in the soil solution exceeds that in the root. Excesses of some nutrients can lead to deficiency in others nutrients, for example, magnesium can replace calcium, leading to calcium deficiency in the plant. Excessive quantities of sulphates can reduce phosphorus and calcium absorption (Lopez *et al.* 1996) and there is a potential for soil structural damage from excessive potassium as this ion can lead to clay deflocculation, in a similar manner to excessive sodium (Arienzo *et al.* 2009; Smiles 2006). High availability of nitrogen during certain plant growth stages can also reduce fruiting (Rowell 1996). Careful nutrient management to reduce fertiliser costs and to prevent a reduction in crop yields due to excess nutrients is therefore essential when reclaimed water is used. This requires awareness by farmers of the nutrient content of the water and the corresponding nutrient requirement of the crop which changes through the growing season with the growth stage of the crop.

This paper attempts to quantify the nutrient additions to agricultural systems in Jordan from irrigation with reclaimed

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water and to simultaneously explore how these nutrient additions are recognised and managed by farmers. Jordan was selected for this investigation because reclaimed water makes a substantial contribution to the agricultural water supply in the country. Approximately 100 million cubic metres (MCM) of wastewater are produced every year, which constitutes about 13 per cent of Jordan's 750 MCM of renewable water annually (MWI 2009). Data from the Ministry of Water and Irrigation (MWI 2009) show that irrigation consumes approximately 293 MCM of water in the Jordan Valley (a major agricultural area of about 33,000 hectares) and reclaimed water contributes approximately 87 MCM to this water supply. These data suggest that reclaimed water contributes to the agricultural productivity of just under one third of the irrigated area. However, it is also important to consider that the consistent nature of reclaimed water means that it provides a reliable supply of water during times when seasonal irrigation supply is unavailable and therefore is likely to contribute to the productivity of a large part of the Jordan Valley (Carr 2010).

METHODS

Research methods from both the natural and social sciences were employed to investigate nutrient management under irrigation with reclaimed water. Water and soil sampling and chemical analyses were conducted to quantify and understand nutrient additions and dynamics in the soil system. Interviews were then conducted with Jordanian farmers who use reclaimed water in order to explore how farmers view and manage the water and perceive the benefits of the nutrients.

Soil and water sampling and analysis

Soil and water samples were taken from three research sites where reclaimed water is used for irrigation; Khirbet As Samra and Ramtha in the Jordan highlands and Deir Alla in the Jordan Valley. At Khirbet As Samra and Ramtha reclaimed water is being used to irrigate land directly surrounding the wastewater treatment plants while in the Jordan Valley reclaimed water is used indirectly, after it has been released from wastewater treatment plants and blended with fresh surface runoff in a natural river system.

At each research site, barley (*Hordeum vulgaris*) was being grown with reclaimed water under experimental conditions. Data were therefore available on the quality of the irrigation water and the exact quantities of water that had been applied to the crop (calculated according to the crop water demand, see Allen *et al.* 1998). Soil samples were taken with an auger to extract material from a number of set depths in the profile and were collected at the end of the cropping season (May) over two consecutive years (2006 and 2007). As well as sampling from the research sites it was also possible to take soil samples from an olive plantation that had been irrigated with reclaimed water for 18 years at Khirbet As Samra.

Soil analysis was conducted to obtain the soil saturation paste extract which gives a sample of the soil solution, following the method of Rowell (1994). The solution was then analysed to determine the concentration of soluble cations (calcium, magnesium and potassium) and anions (sulphate and phosphate) using inductively coupled plasma optical spectroscopy (ICP-OES) (Optima 3000) and ion chromatography (Dionex) respectively. Water samples taken in the field were analysed in a similar manner. The water data were then integrated with historic data collected from published literature (GTZ 2005; Al-Zu'bi 2007; Ammary 2007; Bashabsheh 2007) in order that a more complete picture of the water quality could be obtained. Additionally, the amount of plant available phosphorus in the soil was determined using the Olsen 0.5 M sodium bicarbonate method (Rowell 1994). Nitrate and ammonium in soils were not determined in either the soil or water samples due to the need for rapid analysis to obtain accurate data (Rowell 1996), which was not feasible in this study.

Interviews with farmers

Extensive semi-structured interviews were conducted with 39 farmers who were irrigating with reclaimed water. Through interviewing farmers who were using reclaimed water directly around the wastewater treatment plants of Ramtha and Khirbet As Samra and those using reclaimed water indirectly in the Jordan Valley, it was possible to compare the perceptions, awareness and management methods adopted by direct reusers with those among indirect reusers.

To ensure that an economically diverse sample of farmers were interviewed the size of the farm was used as an economic indicator. A sampling frame was devised which gave quotas of small-, medium- and large-scale farmers to be interviewed. These quotas were not rigidly enforced to the extent that they limited spontaneous interviews, but they were used to shape the sampling. The interviews were conducted in the field via a translator with advanced knowledge of Jordanian agricultural systems. Notes were taken and often a tour of the farm was provided to clarify and explain management methods and issues. Interview notes were typed up and expanded according to memory immediately after the interviews. Each data bit (piece of information) within the interview transcript was then coded and grouped according to its code. For example, all comments relating to fertiliser application were grouped together. This method meant that similarities and discrepancies between the farmers' views became clear and factors that were frequently mentioned or ignored were highlighted (Kitchin and Tate 2000).

RESULTS AND DISCUSSION

Nutrients in reclaimed water

The nutrient content of the irrigation water with respect to potassium, phosphate, sulphate and magnesium at each of the research sites is shown in Table 1. These quantities have been extrapolated to show the estimated amounts of nutrients added to the soil through the irrigation water when sufficient water is applied to meet the water requirement of a typical barley crop (Figure 1).

Nutrient availability following irrigation with reclaimed water

Potassium (K)

Figure 1 shows that a typical barley crop removes about 60 kg K ha^{-1} yr^{-1} from the soil (Cooke 1982). The K supplied by the irrigation water should meet this demand at Khirbet As Samra and falls just below the required amount at Ramtha. At Deir Alla, the K from the irrigation water contributes about 25 kg ha^{-1} yr^{-1} and it is likely that some supplementary

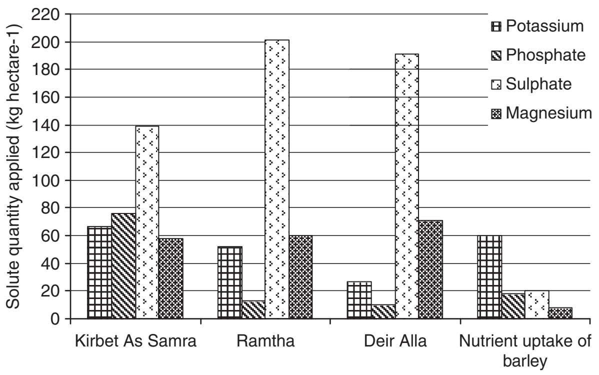

Figure 1 | Nutrient inputs and nutrient requirements of barley at the research sites (nutrient uptake of barley is based on data for the UK from Cooke 1982).

fertiliser would be required depending on the type of crop and the intensity of cropping.

Figure 2 shows how the application of reclaimed water to meet the crop water requirement appears to lead to an increase in the soluble K in the saturation extracts of soils irrigated with reclaimed water. The difference between the soils irrigated for one and two years compared with the unirrigated soil is very small but the application of reclaimed water for 18 years does appear to raise the soluble K concentration substantially. These data suggest that the amount of K being applied at Khirbet As Samra in the irrigation water exceeds the crop demand leading to the accumulation of K, particularly at the site irrigated for 18 years. The accumulation may also be a response to the clay mineralogy at this site which is dominated by smectites, kaolinites and illites (Khresat and Taimeh 1998). Illites, vermiculites and chlorites selectively adsorb large amounts of exchangeable K (Archer 1988) which means that K additions may become held on the soil exchange sites where they can more readily enter the soil solution.

Table 1 | Concentration of plant beneficial ions in the irrigation water at each of the research sites based on field sampling and available data from (GTZ 2005; Al-Zu'bi 2007; Ammary 2007; Bashabsheh 2007)

	Potentially plant beneficial ions in the irrigation water (mg L^{-1})				
Location	Sulphate (SO_4)	Calcium (Ca)	Pottassium (K)	Magnesium (Mg)	Phosphate (PO_4)
Khirbet As Samra (reclaimed water from Khirbet As Samra waste water treatment plant)	65.09	44.55	31.32	27.22	35.63
Ramtha (Reclaimed water from Ramtha waste water treatment plant)	104.66	49.71	32.97	34.19	6.80
Deir Alla (reclaimed water from Khirbet As Samra blende with freash surface runoff)	90.78	50.09	15.74	31.39	21.74
Tap water (Amman)	52.90	56.47	5.63	20.61	4.13

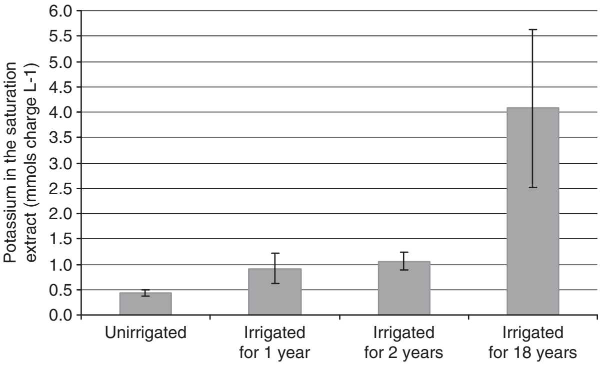

Figure 2 | Potassium in the soil solution (saturation extract) of soils from Khirbet As Samra irrigated for 1, 2 and 18 years compared to an unirrigated control (error bars show standard error from the mean).

Phosphorus (P)

This element is often limited in agricultural soils due to the low solubility of inorganic phosphate ($H_2PO_4^-$ and HPO_4^{2-}) and its strong sorption to soil particles which removes it from the soil solution (Rowell 1996). The data in Figure 1 suggest that about 10 kg ha^{-1} yr^{-1} phosphate will be applied to the soil at Ramtha and Deir Alla, while at Khirbet As Samra almost 70 kg ha^{-1} yr^{-1} is received. This corresponds to data from Mexico which show that 81 kg ha^{-1} yr^{-1} of phosphorus is supplied by wastewater (Jimenez 2005). A barley crop removes about 18 kg ha^{-1} yr^{-1} (Cooke 1982) and so at Khirbet As Samra this demand is met by the water. While the low solubility and strong sorption of P will reduce the availability of this element to plants, it is important to note that the characteristics of the water may prevent soil sorption and loss from solution. This is because the available data suggest that the irrigation water has high $NaHCO_3$ content (Carr 2009). Because $NaHCO_3$ exchanges with HPO_4, a greater proportion of $HPO_4{}^-$ will remain in solution, making it more available to the plant (Curtin and Naidu 1998).

Figure 3 shows how at Khirbet As Samra and Ramtha plant available P increases with the onset of irrigation with reclaimed water. This is likely to be occurring through both the addition of P from the irrigation water, and from the rise of $NaHCO_3$ in the soil solution and on the soil exchange sites leading to a higher exchangeable P fraction.

Sulphate and magnesium

Sulphate ($SO_4{}^{2-}$) is in high quantities in the irrigation water, and approximately 200 kg ha^{-1} yr^{-1} have been applied at Ramtha and Deir Alla. Barley removes about 20 kg SO_4 ha^{-1} yr^{-1} (Cooke 1982), which means that the quantities being applied to the soil at all the sites exceed the crop requirements. The high pH of the soils also means that sulphate stays in the soil solution rather than being adsorbed onto the soil particles (Curtin and Syers 1990). The water therefore meets the requirement of most crops including vegetables. Barley removes about 8 kg ha^{-1} yr^{-1} of magnesium (Mg) (Cooke 1982) and Mg exceeds 50 kg ha^{-1} yr^{-1} at all sites. The excessive quantities of SO_4 and Mg may result in reduction in productivity but further work would be necessary to explore and quantify this hazard.

Farmer awareness and management of nutrients in reclaimed water

The water and soil data have shown that the application of reclaimed water raises the nutrient capacity of the soil. In order to manage and benefit from the 'free' nutrients in the water the farmer must be aware that they are present and

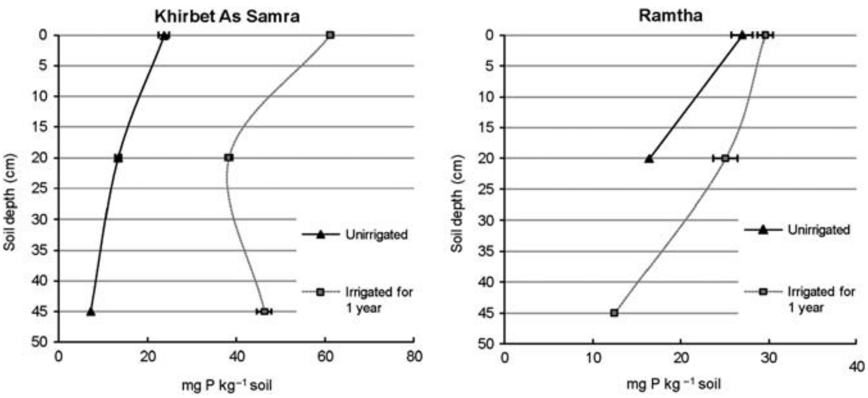

Figure 3 | Plant available phosphorus in unirrigated soil and soil irrigated for one year with reclaimed water at Khirbet As Samra and Ramtha (error bars show standard error from the mean).

reduce the inorganic fertiliser inputs accordingly. The interviews suggested that just 45 per cent of the direct reuse farmers were aware that the water contained plant nutrients and subsequently reduced their use of inorganic fertilisers. This low rate of awareness to nutrients among the direct users was surprising because these farmers are located directly around the treatment plant and are aware that they are using reclaimed water, however, this result may be due to the interview methodology. As not all direct reuse farmers were questioned directly on their awareness of nutrients, any comments that the farmer made with reference to inorganic fertiliser application were taken to indicate that the farmer was not aware the water had nutrients. As such, the number of direct reuse farmers aware of the nutrients is likely to be underestimated though it is important to consider that a high proportion of direct reuse farmers may not fully appreciate the nutrient capacity of the water, perhaps due to a limited provision of information about the water quality. The following quotes show that several of the direct reuse farmers were aware of a reduction in agricultural productivity due to enhanced treatment of the wastewater at Ramtha wastewater treatment plant following the upgrade of this plant. This demonstrates that many farmers were aware of the nutrient content of the water, even if they could not quantify the amount:

> 'Since the upgrade of the wastewater treatment plant from primary to secondary, the natural fertiliser in the water has decreased. This means there is now an additional expense of adding fertiliser.'
>
> 'Before the upgrade of the plant we didn't add manure to the soil. Now we have to add manure as there is less fertiliser in the water.'
>
> 'The water is good. But now we need to use much more fertiliser since the water treatment plant was upgraded two years ago.'
>
> 'Before, when I was irrigating alfalfa the plants survived for five years. Now I have to plant a new crop every two years because the water is better treated now and so the plant productivity is lower.'

Seventy-four per cent of farmers who were using reclaimed water indirectly in the Jordan Valley were aware that the water contained nutrients. There was no significant difference in awareness between large- and small-scale farmers, which suggests that awareness is not connected to economic situation.

The GTZ have been providing training to farmers on nutrient management in the Jordan Valley and several of the farmers interviewed had attended this training. Of those that had not done the training, several farmers were aware from their own experience and experimentation that the water contained nutrients and recognised the financial benefits. Several indirect reuse farmers said that although they were aware that the water had nutrients they also applied fertilisers because the fertiliser sales representatives were very persuasive. As one farmer explained:

> 'I went to the training just a few days ago. But then the fertiliser company reps came here and persuaded me to buy fertilisers.'

Further reasons for over-fertilising were given by another farmer:

> 'I know that I over-fertilise. When the price of cucumbers is high I'll add more fertilisers. I will try and use less fertilisers. But when the price of cucumbers is high it's a psychological thing to add fertiliser as I wish for the best productivity.'

In the case of indirect reuse farmers the nutrient content of the water appears to be considered, but many factors influence whether inorganic fertilisers are also applied. Information on the exact nutrient content of the water would be of value to farmers to allow them to better plan their fertilisation schedules, however, the psychological factors and persuasiveness of sales agents also need to be considered when providing information to farmers in order that these issues are acknowledged and overcome.

The direct reuse farmers appeared to have a higher regard for the beneficial nutrients than the indirect reuse farmers. This is likely to be a result of the type of agriculture and the investment requirements at each site. In the Jordan Valley, high added value agriculture is practiced whereby fruits and vegetables are cultivated which require high outlay costs in the form of seeds, pesticides, plastic green houses and drip irrigation systems. Reclaimed water is viewed negatively by most farmers as it clogs the drip emitters of the irrigation system and may reduce the productivity due to the salinity of the water (Carr 2010). In contrast, directly around the treatment plants, fodder crops of alfalfa or barley are grown with low-cost flood irrigation. Problems with pipe clogging or salinity build up are therefore not experienced as the higher volume of water applied to the soil prevents salinisation and the nutrient content of the water is viewed as an additional benefit.

CONCLUSIONS

This research has shown that reclaimed water contains substantial quantities of plant beneficial nutrients which can reduce the requirement for inorganic fertiliser additions, depending on the type of crop and intensity of yield. Data on soil nutrient concentrations have shown that continual application of reclaimed water appears to raise the soil nutrient content with regards to phosphorus and potassium which should enhance the productivity of the soil. Awareness on the part of farmers of the nutrients in reclaimed water is essential in order that inorganic fertiliser additions are managed on the farm to maximise yields, minimise farm expenditure and prevent a loss of productivity due to the over-supply of nutrients. The interviews with farmers have shown that 75 per cent of indirect reuse farmers in Jordan are aware that the irrigation water contains plant beneficial nutrients. However, the interviews have suggested that the management of nutrients on the farm is influenced by a number of factors including the type of crops being cultivated, the provision of training in nutrient management and information to farmers on the quality of the irrigation water. This work suggests that all aspects of the agricultural system need to be considered when determining the most appropriate strategy on the farm for the effective management of water reuse for irrigation.

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