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Soil salinity and sodicity effects of wastewater irrigation in South East Australia

Zahida Muyen[a,*], Graham A. Moore[a], Roger J. Wrigley[b]

[a] School of Engineering, University of Melbourne, Parkville, VIC 3010, Australia
[b] School of Land and Environment, University of Melbourne, Dookie, VIC 3467, Australia

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ABSTRACT

Although 'sewage farming' or wastewater irrigation started in Australia in the latter parts of the 19th century, it was in the late 1960s that a considerable interest was revived in arid and semi-arid parts of the world due to scarcity of alternative water sources and the urgency to increase local food production. The practice has manifold benefits in the form of water conservation, nutrient recycling, surface and ground water pollution prevention. But for arid and semi-arid regions like many parts of Australia, while wastewater irrigation can be an attractive solution to irrigation water problems, it might not be the ideal solution for the common soil types encountered in these regions. Due to characteristic low rainfall, high evaporation and low leaching, these soils tend to have higher salt accumulations. This paper examines the soil salinity and sodicity effects of wastewater irrigation in soil types typical to South Eastern Australia and takes the soils of Western Treatment Plant (WTP) as a case study to highlight these issues.

1. Introduction

The importance of irrigation water quality in sustainable agriculture is evident from the history of irrigated agriculture in the Tigris-Euphrates Valley where over a period of 4700 years, a civilization emerged, flourished and disintegrated due to loss of agricultural yield resulting from salt accumulation in soil profiles (Rush, 1987). Tax records have shown that agriculture based on non-salt tolerant wheat gradually gave way to considerably more salt tolerant barley and then it disappeared. In Egypt, after 30 odd years of irrigation of land not subject to annual flooding with water from the Aswan High Dam a greater area of soils had become salinized than the previous 5000 years of irrigation (Wallace and Terry, 1998).

Salinity in Australian soils is dominated by NaCl (sodium chloride) salts. According to Isbell et al. (1983), "cyclic accession, mineral weathering, aeolian transport, irrigation water, deeper groundwaters or connate saline water derived from marine tertiary sediments contribute to the accumulation of NaCl in soil profiles". Leaching these soil profiles by irrigation water or rain leads to the formation of sodic soils. On the other hand, once formed, irrigating these sodic soils also leads to the buildup of Na salts, leading to the formation of saline-sodic soils. Since NaCl is the dominant salt in the soil profiles in Australia, any process that encourages the buildup of this salt in the profile inevitably leads to soil sodicity. Thus Rengasamy and Olsson (1993) pointed out, "irrigation management in Australia is closely linked with the management of soil sodicity".

To improve and sustain crop production in a saline environment, we can either improve and maintain the environment to suit the plant or we can select a particular plant to suit the environment, e.g. phytoremediation of sodic soils (Akhter et al., 2003; Kumar et al., 2004; Qadir et al., 2001, 2003, 2005; Qadir and Oster, 2002); revegetation (Ilyas et al., 1997; Tripathi and Singh, 2005) and plantation/afforestation (Bhojvaid et al., 1996; Dagar et al., 2001; Falkiner and Smith, 1997; Garg, 1998; Goel and Behl, 2002; Jain and Singh, 1998; Kaur et al., 2002; Mishra et al., 2002, 2004a,b; Singh et al., 1998; Singh, 1998). But as Sharma and Minhas (2005) concluded, the former has been tried more extensively with options such as the management of crops/sequences, irrigation water quality, leaching fraction, chemical, organic and even biological (Rao and Burns, 1991) amendments. Often these amendments are used in combinations and integrations as required by the particular site in question. Techniques of combination and integration often include interventions like appropriate crop/variety selection, blending and cycling of irrigation water.

2. Benefits of wastewater irrigation

Using potable water for irrigation is no longer a viable option in many countries around the world. With changing weather patterns, the reliability of rain is also a thing of the past. Prolonged droughts in many countries which are also heavily dependent on

* Corresponding author. Tel.: +61 3 8344 4291; fax: +61 3 8344 6215.
E-mail addresses: muyenz@unimelb.edu.au (Z. Muyen), grahamam@unimelb.edu.au (G.A. Moore), rwrigley@unimelb.edu.au (R.J. Wrigley).

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agricultural production have led to the search for alternative sources of irrigation water. One such increasingly popular source is treated or untreated wastewater. The reason for this popularity may vary from country to country, but would generally include: (1) a constant volume of irrigation water is available throughout the year, (2) if not used for irrigation, this water would have been safely disposed of into water bodies, (3) the organic matter and other nutrients present in these waters are invaluable to soils that are deficient in either or both.

Studies in many countries have shown that yields can be increased by irrigating with treated or treated wastewater. For example a 20,000 m^3/ha/year irrigation rate, with typical total nitrogen (N) and phosphorus (P) concentrations of 15 mg/L and 3 mg/L, respectively, corresponds to annual nutrient inputs of 300 kg/ha of N and 60 kg/ha of P (Mara and Cairncross, 1989). More importantly, these nutrients can add to the eutrophication risk of surface waters if not used for agriculture. Numerous studies (Abu-Sharar, 1996; Angin et al., 2005; Jones et al., 1993; Lehrsch et al., 2008; Lehrsch and Robbins, 1994, 1996; Robbins and Lehrsch, 1992, 1998; Stevens et al., 2003) have shown that treated or untreated wastewater has the potential to improve the structural properties of soils and at the same time, increase agricultural productivity.

3. Wastewater irrigation and reasons for concern

While the reuse potential for wastewater in irrigation is huge, there are reasons for concern when it is not carefully managed. Wastewater irrigation is part of a management system which includes facilities for conveying, treating, storing and disposing of wastewater. Environmental issues are associated with each of these components and the fate of tail water cannot be ignored. This might include irrigation induced runoff and rainfall runoff from the wastewater irrigation area resulting in eutrophication of surface water. Moreover, the management of an irrigation system dependent on wastewater needs to take into account the fact that the supply of this source is continuous and equal all through the year, but the demand for irrigation is cyclic. This type of irrigation system also involves major investments in land and equipment. When untreated, these waters would contain suspended solids at levels that may clog nozzles in the irrigation distribution systems. Apart from the challenges of infrastructure, the success of this type of irrigation system depends on the ability of the soil to integrate the water, nutrients, and any other contaminants that might be present. The very suspended solids that can provide beneficial humic material required by the soil can also clog the capillary pores in the soil. Bond (1998) lists the key limitations to sustainable wastewater irrigation as: "(i) excessive nitrate leaching to groundwater, (ii) salinity, and (iii) the effects of increasing soil sodicity on current and future land uses".

Concerns around this type of irrigation system however are not confined to the soil structural point of view but also the surrounding environment. The environmental concerns with wastewater irrigation include (Rowe and Abdel-Magid, 1995):

(i) improperly treated wastewater can create potential public health problems;
(ii) it has a potential for chemical (salts, nitrate, sodium, phosphorus, etc.) contamination of the ground and surface waters;
(iii) soluble constituents present in the treated or untreated wastewater could be at levels that possibly can be toxic to plants, they can also be stored in the soil profiles, or be leached and find their way to the groundwater. Also in some cases particularly in deep sandy soils, the fate of P becomes a limiting factor with its potential for leaching to the groundwater.

4. Wastewater irrigation and soil quality concerns

Once the infrastructure and environmental challenges of treated or untreated wastewaters are met, the soil structural concerns have to be addressed with significant diligence. The two principal concerns are soil salinity and sodicity.

4.1. Wastewater irrigation and soil salinity

Total Dissolved Solids (TDS) in treated wastewater typically range from 200 to 3000 mg/L (Feigin et al., 1991) and may even be higher in some cases. As a result, wastewater irrigation has the potential to add large amounts of salt to the soil. As Bond (1998) estimated, an annual application of 1000 mm of water with a (low) salinity of 500 mg/L of TDS could add 5 t/ha/year of salt. Unless leached out, salts accumulate through evapotranspiration to a concentration harmful to plants. For example, Aljaloud et al. (1993) showed that irrigating with wastewater increased crop (maize and sorghum) yield until a water salinity level of 2330 mg/L was reached, after which, the yield decreased. Hence it is important that wastewater irrigation is planned to allow satisfactory leaching to ensure adequate removal of salt from the root-zone. The study concluded that the production of forage crops using wastewater can be successful given that the leaching requirement for that particular soil type is maintained.

When designing a wastewater irrigation scheme, selecting the appropriate soil is as important as taking into account the effects of any climatic disparities from year to year. Salt accumulation in soil profiles resulting from seasonal and yearly changes in rainfall were demonstrated by Smith et al. (1996). Interestingly enough Bond (1998) suggested that if as a result of proper management, salt does not accumulate in the root zone and it is not leached to groundwater, in sufficiently porous soil profiles, "some salt can be stored between the root-zone and the watertable". The author was cautious in claiming such a theory by adding that there is a limit to the amount of salts a certain porous soil profile can store. With a limit of 6 t/ha for 1 m of the profile, it would require a "8 m of profile between the root-zone and the watertable" to store salt from "10 years of irrigation" at a salt contributing rate of "5 t/ha/year". This possibility is clearly not a long term solution. The author concluded that once there is significant buildup of salts in this profile, the salt can and will eventually reach goundwaters, it can even start to move laterally and cause off-site effects. Understanding the fate of salt is essential to understanding the sustainability of wastewater irrigation. Irrigation without appropriate drainage is recognized to be unviable. Drainage assists by exporting salt from the plant root zone, reducing waterlogging and is the principal technique for controlling watertables which can dictate prospects for leaching.

Recent experience of salt accumulation in red brown earth soils as water tables decline in the Goulburn Murray irrigation district indicate that clay dominant profiles can capture significant amounts of salt. As water tables rise these salts will be mobilized.

4.2. Wastewater irrigation and soil sodicity

Wastewaters usually have high concentrations of sodium compared to the other cations as well as high salinity. Treated wastewater, usually have a sodium adsorption ratio (SAR) ranging from 4.5 to 7.9 (Feigin et al., 1991). Using irrigation water high in salinity and SAR has the potential to increase the Exchangeable Sodium Percentage (ESP) of the soil. Many studies (Bower, 1959; Curtin et al., 1995; Harron et al., 1983) have shown that "the ESP generally increases linearly with SAR of irrigation water". Increased ESP brings with it the decline of soil physical properties, in the form of clay dispersion with subsequent collapse of soil structure, pore blockage, and eventually a decrease in soil permeability lead-