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Evaluation of soil chemical properties irrigated with recycled wastewater under partial root-zone drying irrigation for sustainable tomato production

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ABSTRACT

Recycling of wastewater is becoming more popular in order to augment the inadequate irrigation supplies and meet the growing water demands for agriculture in arid regions of the world. This study investigated the environmental impact of deficit irrigation regimes on soil properties with five scenarios using recycled wastewater (RW), fresh tap water (FW), and a blend of RW and stormwater (BW). The five irrigation scenarios were applied to tomato plants growing in pots and included: (i) full irrigation (FI); (ii) partial root zone drying (PRD) irrigation at 75% of FI involving irrigation of only one part of the root zone, while the other part was exposed alternately to soil drying (PRD 75); (iii) PRD irrigation at 50% of FI (PRD 50); (iv) conventional deficit irrigation (DI) at 75% of FI applied on both sides of the root zone (DI 75); and (v) DI at 50% of FI (DI 50). Among the different irrigation scenarios, the PRD 75 treatment led to the lowest level of salinity for the surface soil layer. The PRD reduced TN in the soil compared with DI, while the water source significantly increased soil TN and TC with RW by 4% and 7%, respectively, compared with FW under FI. However, the irrigation scenarios and water sources did not show significant differences in the sodium absorption ratio (SAR), but PRD could reduce SAR compared with DI when using water with a high sodium concentration, such as RW.

1. Introduction

Water scarcity is one of the factors affecting sustainable agricultural production in many nations (UN, 2006). For example, in Australia, water scarcity is one of the factors limiting economic growth in the agricultural sector (ABS, 2005). Improved water management practices such as crop selection and enhanced irrigation methods are important in the agricultural sector to preserve fresh water sources and to protect ecosystems. This can be achieved by improving water-use efficiency and utilising alternative water supplies such as municipal recycled wastewater (RW) and stormwater for irrigation. In addition, use of wastewater sources for irrigation reduces the amount of water that needs to be extracted from fresh water sources (USEPA, 1992).

Sodicity is an important issue for soil that needs to be considered when irrigating with RW (Marecos do Monte and Asano, 1998; Bond, 1998; Surapaneni and Olsson, 2002). Soil permeability can be affected by the high sodium content in RW, thus resulting in unsustainable environments for plant growth (Abdel-Dayem, 1999). Normally, sodium (Na^+) replaces exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) by mass action if its concentration is high in irrigation water, and this can cause poor aeration due to reduced permeability (Stevens et al., 2003; Hassanli et al., 2008; Muyen et al., 2011).

Addition of total nutrients and salts to soil depends on the quantity of water applied and the concentration of elements in the RW. Reducing irrigation applications over the crop cycle will also decrease the leaching of nutrients from the root zone, resulting in less groundwater contamination and reduced fertiliser requirements in the field. Deficit irrigation (DI) is an irrigation method applied to the entire root zone, in which the plant receives less water than the potential evapotranspiration (Liu et al., 2006). DI is seen as having potential for sustainable production (Geerts and Raes, 2009). While DI sometimes results in lower yields, the yield reduction can be controlled by efficient management of water resources. The main benefit of DI is that it improves water use efficiency (WUE) for crop production. In areas where water is the most limiting factor for agricultural production, expanding

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water productivity may be much more profitable for farmers than expanding yields (Geerts and Raes, 2009). Moreover, reduced irrigation water applications may be favourable for crop production as it can result in reduced crop disease, reduced nutrient leaching from the root zone and increased soil aeration. This in turn can lead to reduced use of pesticides, water and fertilisers, thus reducing the cost of production (Garabet et al., 1998; Cicogna et al., 2005). In other words, DI aims to stabilise production and achieve maximum water productivity rather than maximum crop production (Chaves et al., 2007). However, salt leaching from the root zone is lower under DI than under full irrigation (FI) (Kaman et al., 2006) resulting in salt accumulation which will be more likely to occur when irrigating with low quality water or saline water such as RW. For example, if irrigation water EC is above 2–3 $dS\,m^{-1}$, tomato plants start to lose yield in most environmental conditions (Cuartero and Fernández-Muñoz, 1999), therefore efficient irrigation management is recommended to avoid salinisation.

Another water-saving irrigation technique is partial root zone drying (PRD), which involves the irrigation of only one part of the root zone, while the other part is exposed alternately to soil drying (Dry and Loveys, 1998; Stoll et al., 2000). Marschner (1995) reported that low soil-water content due to PRD may limit nutrient availability due to its effect on nutrient distribution and solubility. Liang et al. (1996) concluded that the PRD method enhanced secondary root growth, thereby increasing the plant's ability to absorb water and nutrients from the soil and thus improving nutrient-use efficiency. In a similar study, Wang et al. (2009) reported that the total nitrogen content of plants was significantly higher in PRD than in DI. Yang et al. (2012) reported that PRD improved the Vitamin C and soluble sugar contents in tomato fruits but reduced the content of organic acid. Sun et al. (2013) found that in relation to DI, PRD significantly increased tissue N content with no impact on tissue C content in potato crops. However PRD led to more C and N losses in soil due to greater mineralisation of soil organic C and N. Qi et al. (2013) studied the effect of PRD and secondary-treated wastewater with and without the addition of chloride on soil nitrogen and they found that PRD improved nitrogen use efficiency. However, there have been no reports on the effect of PRD and different water qualities on soil properties. In terms of water savings, the PRD method has been adapted to a wide variety of horticultural and agronomic crops to enhance WUE (Wang et al., 2010a; Jovanovic et al., 2010; Yang et al., 2012, 2013).

To ensure the success of RW use in agricultural systems, it is important to optimise productivity, reduce the adverse effects of nutrient and salt leaching into the environment, and to protect soil as well as surface water and groundwater sources. Because of the opportunities that PRD offers and the concerns of using RW mentioned in this section, it is important to study and evaluate the effects of PRD irrigation and water quality on soil. The main objective of this paper is to determine the effects of irrigation water source and irrigation scenarios involving DI and PRD on soil chemical properties during a tomato growing season in a glasshouse experiment.

2. Materials and methods

2.1. Plant and experimental conditions

The experiments were undertaken under glasshouse conditions at the Mawson Lakes campus of the University of South Australia (−34.9290°S, 138.6010°E). The temperature in the glasshouse was set at: 25 ± 2.5°C and 20 ± 2.5°C during days and nights, respectively. The maximum and minimum relative humidity were 66% and 26%, respectively. The plant growth experiment was conducted

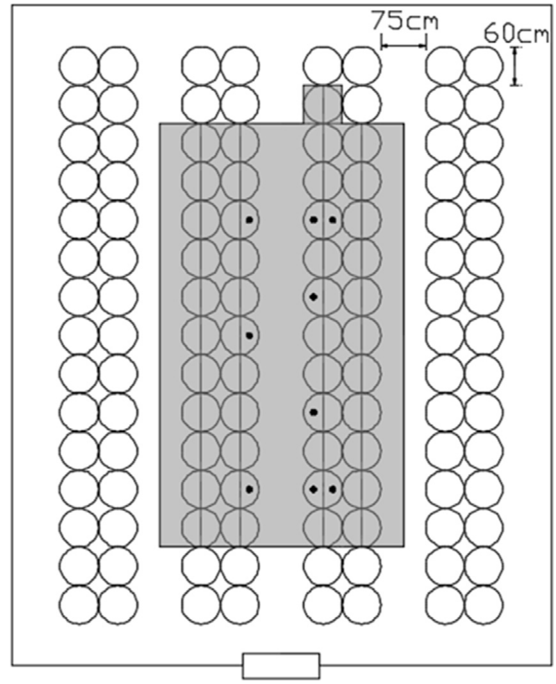

Fig. 1. Glasshouse layout: the shaded pots are where experimental soils were sampled the unshaded are pots were used to eliminate marginal effects, the dark dots show the locations of the moisture sensor access tubes.

using large PVC container pots (60 cm diameter and 75 cm deep). Fig. 1 shows the glasshouse layout. The pots were divided into two equal zones using plastic sheets to prevent water movement between the two zones. The experimental soil was a homogenised sandy soil developed for gardening. It had a bulk density of 1.32 $g\,cm^{-3}$, porosity of 32% and field capacity of 30%. The main chemical and physical characteristics of the soil are shown in Table 1. One tomato plant (*Lycopersicon esculentum* Mill. var. "Azmier") was transplanted into each container at the end of their initial growth stage (30 days after germination) according to FAO56 (Allen et al., 1998).

2.2. Experimental design and irrigation treatments

The tomato plants were hand-irrigated with three different water qualities, namely recycled wastewater (RW) from the Bolivar wastewater treatment plant, fresh tap water (FW), and a blend of RW and stormwater (BW). The physical and chemical characteristics of the three irrigation waters are presented in Table 2. Irrigation was applied twice per week with sufficient water volumes to restore the soil moisture to field capacity (FC) at each irrigation event. The forms of fertilisers used were calcium nitrate for nitrogen and "Hydroflex T 8-9-39" for NPK. Fertilisers were applied continuously with irrigation water. To ensure that all treatments received the same amount of nutrients, the fertiliser concentrations were calculated and adjusted based on each irrigation scenario.

A randomised block design was followed and the treatments consisted of three different water sources (main plots) and five irrigation scenarios (sub-plots). Each treatment was replicated three times, with a total of 45 pots. All pots were watered to reach FC before transplanting the plants. The experiment started with FW and full irrigation for all plants. Ten days after transplanting, the three different irrigation water sources were applied based on the following scenarios:

i. Full water requirement (FI) for both sides of the root zone (RZ).