The effect of irrigation using recycled waters obtained from MBR and IDAL wastewater treatment systems on soil pH and EC under kikuyu grass (*Pennisetum clandestinum*) production

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ABSTRACT

The main objective of this study was to determine the effect of irrigation using three different types of waters, namely treated wastewater through membrane bioreactor (MBR) system, treated wastewater via intermittently decanted aerated lagoon (IDAL) process and tap water (TW) on soil pH and electrical conductivity (EC) under kikuyu grass production. No fertilizer was added during the study period (1 year). Irrigation waters and water and soil samples extracted from different soil depths were analysed in laboratory. Considerable changes occurred in soil characteristics over the study period under various treatments. Soil pH increased more than 1 unit under irrigation with treated wastewater produced by the IDAL system while soil irrigated with treated wastewater from the MBR treatment system showed little change and TW irrigated soil evidenced a slight decrease when compared to pH at the beginning of the study. There was also a remarkable increase recorded for $EC_{1:5}$ of top soils irrigated with treated wastewaters compared to the initial EC of the soil. The results from this study highlighted the benefits of irrigation with treated wastewater from the MBR system due to its lower cost of treatment compared to the IDAL process while providing additional nutrients such as nitrogen and phosphorus from the wastewater for plant growth.

Key words | intermittently decanted aerated lagoon, membrane bioreactor

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INTRODUCTION

Treated wastewater is a reliable water source for reuse in various areas to confront water shortages (Pedrero *et al.* 2010). Using recycled water for irrigation can be beneficial in terms of preventing natural water resources contamination, saving water resources, saving wastewater treatment and recovering nutrients (Angelakis & Bontoux 2001; Rahman *et al.* 2016). The effect of treated and untreated wastewaters in different agricultural systems has been reported by many researchers around the world (Pettygrove & Asano 1984; Sheikh *et al.* 1987; Chakrabarti 1995; Gori *et al.* 2000; Manios *et al.* 2006; Castro *et al.* 2009; Costa *et al.* 2011; Pedrero *et al.* 2012; Minhas & Yadav 2015). Proper management of wastewater irrigation and regularly monitoring the soil parameters can ensure safe and successful usage of recycled water for irrigation over long periods (Qian & Mecham 2005; Rattan *et al.* 2005; Rusan *et al.* 2007; Xu *et al.* 2010; Rahman *et al.* 2015). Recycled water can be listed in different categories based on its chemical characteristics as a result of the level of treatments that wastewater goes through. In this study the effect of irrigation with two types of treated wastewaters produced under a membrane bioreactor (MBR) treatment process

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and an intermittently decanted aerated lagoon (IDAL) system on soil pH and electrical conductivity (EC) under kikuyu grass production was investigated. Tap water was used as the control water. Mean values of quality parameters for irrigation waters are considered. No fertilizer was used during the study.

Soil pH is considered as one of the most important parameters that can be affected when using recycled water for irrigation. Plant growth is affected by soil pH in different ways. Soil pH can impact nitrification, denitrification and glucose mineralization in the soil atmosphere (Tabatabai & Olson 1985). It has been reported that nitrogen mineralization can be processed efficiently in the pH range of 5.5–7. Soil pH values below 5.5 can result in faster leaching of plant nutrients compared to soils with pH values of 5.5–7.0 (Ward 2015). On the other hand, soil pH values higher than 7 can limit the availability of some plant nutrients, causing a reduction in plant production. For example, phosphorus can be available to the plant mostly at a pH value between 6 and 7. Similarly, micro-nutrients such as iron, manganese, zinc, copper and cobalt are less available to the plant at a pH above 7 (Seelig 2000).

An inconsistent soil pH has previously been reported when different types of wastewater were used for irrigation. Those who reported the increase in soil pH attributed this to factors such as high pH values of effluent and availability of high levels of cations such as sodium, calcium and magnesium in irrigation waters (Schipper *et al.* 1996; Sparling *et al.* 2006; Gwenzi & Munondo 2008). On the other hand, other researchers reported a soil pH decrease as a result of wastewater application (Mohammad & Mazahreh 2003; Rattan *et al.* 2005) and this decrease was explained as a result of either acidic characteristics of sewage effluents or the process of nitrification in the presence of high amount of ammonium in the wastewater, which resulted in providing hydrogen ions in the soil. No significant effect on soil pH when irrigated with wastewater was recorded by Khan *et al.* (2008).

Another issue associated with the use of wastewater for irrigation is the addition of large amounts of salts to the soil because treated wastewater typically contains 200–300 mg/L of total dissolved solids (Muyen *et al.* 2011). Soils with saturated extract electrical conductivity (EC_{SE}) over 4 dS/m, generally, are defined as saline soils. However, different plants depending on their salinity tolerance can be affected at half and twice this value of EC_{SE} (Bernstein 1975).

Kikuyu grass (*Pennisetum clandestinum*) used in this study is known to have a moderate salinity tolerance up to 4 dS/m (Havilah *et al.* 2005) and can also grow well in soil with moderate acidity of pH 5–7 (Dickenson *et al.* 2004; Clark 2007). Kikuyu grass is a C4 tropical grass and is widely used in sports fields, as well as pastures, public areas and golf course fairways (Brede 2000; Fulkerson 2007). A large number of studies have been carried out in terms of kikuyu grass production with the application of fertilizer (Awad *et al.* 1976; Hacker & Evans 1992; Fulkerson *et al.* 1999; Gherbin *et al.* 2007; Botha *et al.* 2008).

The specific objectives of this study were to investigate (1) the effect of different types of treated wastewaters with significant differences among their main nutrients such as nitrogen and phosphorus on soil pH and (2) the impact of moderate level of salinity in treated wastewater in the presence of different levels of nutrients and salts on soil EC at different soil depth.

MATERIALS AND METHODS

Experimental design

Experimental set-up has been explained thoroughly in Shahrivar *et al.* (2019). Briefly, three identical stainless steel columns were filled with the pre-prepared soil of loamy sand texture. Initial physicochemical properties of the soil are given in Table 1.

The schematic set-up of the columns is illustrated in Figure 1. As shown in Figure 1, the columns regarding their

Table 1 | Selected physicochemical properties of the soil

Soil properties	**Value**
Sand (%)	88.1
Silt (%)	6.0
Clay (%)	5.9
Texture class	Loamy sand
Bulk density (kg/m^3)	1,340
$pH_{1:5}$	5.5
$EC_{1:5}$ (dS/m)	0.04

size (450 mm diameter and 600 mm height) are considered as bigger columns compared to the other laboratory-scale lysimeters used for soil–plant studies. The GS3 sensors are able to measure bulk EC, volumetric water content and temperature of the soil. Data from the sensors were collected via the connection of GS3 sensors to a data logger.

The columns were equipped with three water extractors adjacent to their respective GS3 sensors in 100, 300 and 500 mm of the columns (Figure 1). Water samples were extracted from different soil depths using these samplers in conjunction with the suction pumps. Finally, kikuyu grass from a nursery was laid on top of the columns and irrigated with the respective irrigation waters to ensure the grass survived and established.

Irrigation waters

Treated wastewaters used for this study were collected from Pennant Hills Golf Club's wastewater treatment plant and Richmond Sewage Treatment Plant, both located in Sydney where the former uses an MBR system and the latter one implements an IDAL system system for wastewater treatment. MBR is a secondary treatment of the wastewater process that combines a membrane process with a biological process (Judd 2010); an IDAL system is an advanced treatment of wastewater for removing nutrients, particularly nitrogen. In this system, all processes including sedimentation, biological treatment and clarification take place in one reactor (Ngo *et al.* 2007). Tap water (TW), which was provided by the Sydney Water Corporation to the Sydney Metropolitan area, was used at the control water in the study.

Both treated wastewaters used in the study provide disinfection stages at the end of their treatment processes to remove microorganisms, including bacteria, viruses and parasites like *Giardia* and *Cryptosporidium*, which are harmful to public health. Chlorine is a powerful disinfectant used in both wastewater treatment plants for this purpose.

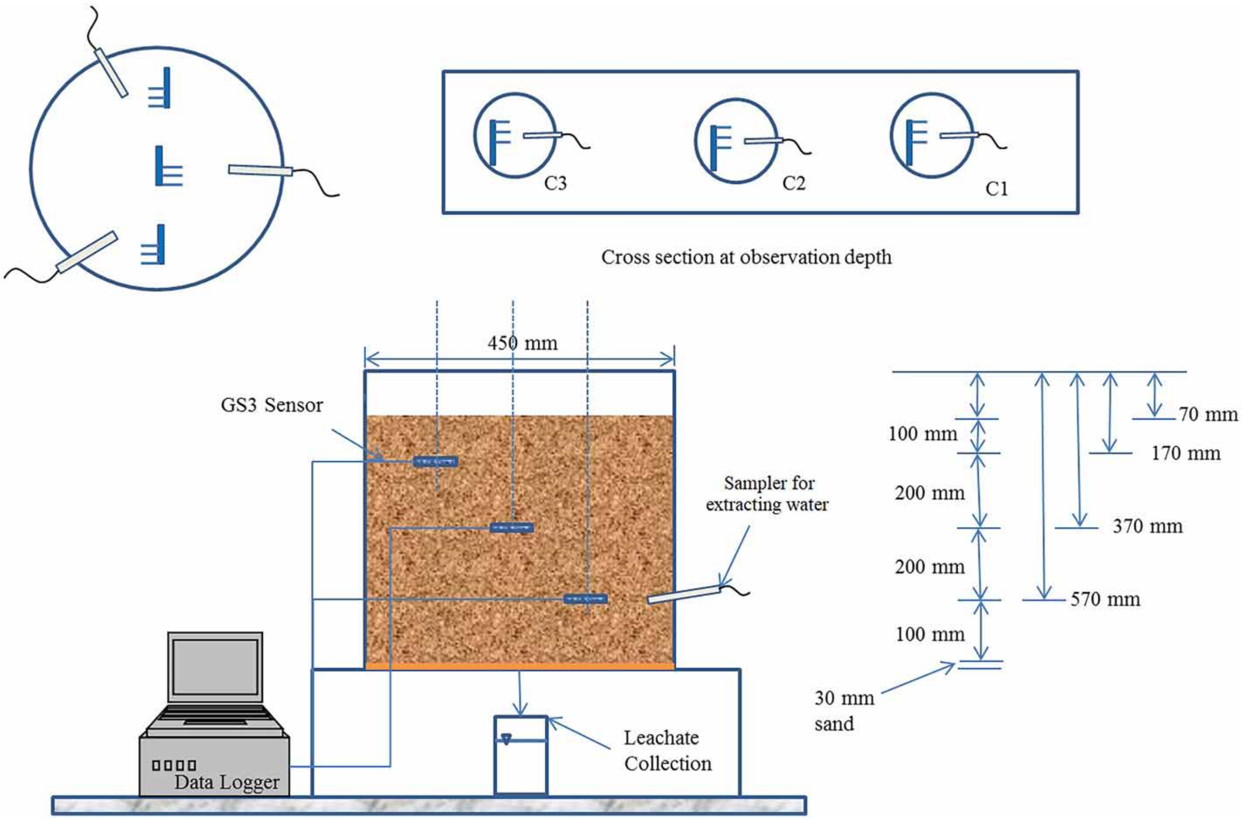

Figure 1 | Schematic set-up of the columns (Shahrivar *et al.* 2019).

Irrigation scheduling

Data from GS3 sensors in conjunction with collected data from the weather station installed at the study area were used to identify the interval of irrigation and the amount of water to be applied to the columns. Due to the loamy sand having a field capacity of 19% and an available water content of 9%, the soil moisture content was maintained at over 15% to avoid any water stress for the grass. Figure 2 illustrates the irrigation scheduling and climatic conditions during the study. Daily evapotranspiration (ET) for kikuyu grass was calculated as (Allen *et al.* 1998):

$$ET = K_C \times ET_0 \tag{1}$$

where ET is daily evapotranspiration for kikuyu grass (mm/day), K_C is kikuyu grass monthly crop coefficient (Connellan 2013) and ET_0 is reference crop evapotranspiration (mm/day) from weather station.

Soil and water analysis

EC and pH of irrigation waters were analysed using respective meters. Total nitrogen (TN) and total phosphorus (TP) were analysed using the persulfate digestion method. Persulfate digestion method is a very effective and practical way for simultaneous analysis of TN and TP in water samples. Samples after digestion were analysed using the discrete analyser (Gallery, Thermoscientific) in the form of NO_X–N (NO_2^- and NO_3^-) and PO_4^{3-}, respectively (APHA 1995). Main cations (Ca, K, Mg and Na) were measured by inductively coupled plasma–optical emission spectrometry (ICP–OES, Agilent Technology 700 series). Pore waters extracted monthly from three different depths of the columns and were analysed for pH, EC and other parameters similar to irrigation waters. At the end of the study period, the columns were dismantled and soil samples from different depths were collected. After removing all the roots from these samples, they were analysed for different parameters, including pH ($pH_{1:5}$) and EC ($EC_{1:5}$), using soil analysis methods proposed by Rayment & Lyons (2011).

RESULTS AND DISCUSSION

Characteristics of irrigation waters

Table 2 summarizes the mean values of irrigation water quality parameters. It can be seen that irrigation waters have different characteristics based on the treatments they have gone through. MBR-treated wastewater has high concentrations of nitrogen and phosphorus compared to other irrigation waters. By comparison, both treated wastewaters have considerably higher values of sodium than TW and that causes higher levels of sodium adsorption ratio (SAR) in treated wastewaters. The SAR is considered a monitoring factor for determining the sodium hazard associated with an irrigation water application (Lesch & Suarez 2009). It is defined as the ratio between sodium and two other cations in the irrigation water (calcium and magnesium) and is calculated as:

$$SAR = Na^{+}/\sqrt{(Ca^{2+} + Mg^{2+})/2} \tag{2}$$

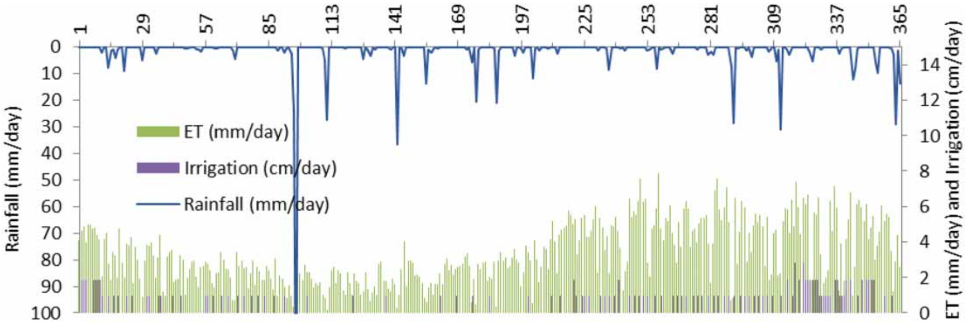

Figure 2 | Irrigation scheduling and climatic conditions.

Table 2 | Mean values of selected parameters of irrigation waters

Parameters	**MBR**	**IDAL**	**TW**
pH	7.25 ± 0.41	7.52 ± 0.35	7.25 ± 0.46
$EC_{25^\circ C}$ (dS/m)	0.99 ± 0.18	0.93 ± 0.073	0.26 ± 0.026
TN (mg/L)	15.33 ± 3.28	0.90 ± 0.32	0.58 ± 0.33
TP (mg/L)	5.55 ± 2.10	1.31 ± 0.75	0.48 ± 0.44
Ca^{2+} (mg/L)	29.59 ± 5.51	16.10 ± 1.70	20.33 ± 4.61
K^+ (mg/L)	25.69 ± 7.28	28.58 ± 8.14	7.74 ± 5.42
Mg^{2+} (mg/L)	11.57 ± 3.39	26.04 ± 4.62	7.30 ± 2.57
Na^+ (mg/L)	143.37 ± 31.23	113.68 ± 25.57	18.87 ± 5.51
SAR	5.67 ± 0.21	4.08 ± 0.62	0.91 ± 0.15

The concentrations of Na^+, Ca^+ and Mg^+ in Equation (2) are expressed in milliequivalent per litre (mEq/L). Irrigation waters with high SAR levels can cause high levels of sodium accumulation in the soil over time, which can adversely affect soil infiltration and also lead to soil crusting, poor aeration and poor plant production (Lesch & Suarez 2009).

Comparison of the EC and SAR values listed for the irrigation waters in Table 2 with irrigation water quality categorized by Ayers & Westcot (1985) indicates that the soil sodification risk for all three types of irrigation waters in the current study is considered as slight to moderate.

Soil-water pH

Extracted water pH from different depths of the soil varied seasonally from column to column. Figure 3 shows seasonal pH values from 10 (Figure 3(a)), 30 (Figure 3(b)) and 50 cm (Figure 3(c)) depths of the soils irrigated with different types of irrigation waters. As it can be seen from the graphs, the pH in soil irrigated with treated wastewater produced by IDAL remained higher than the two other irrigation waters with values over pH 7 in 10 cm depth of the soil throughout the study.

Considering that the highest concentration of grass root is in the top soil, variation in soil characteristics in this area can important in relation to the impact on grass growth and production. As mentioned before, kikuyu grass is known to grow well at the optimum pH 5–7 (Dickenson *et al.* 2004; Clark 2007).

Soil-water EC

Similar to pH, extracted water EC varied seasonally from depth to depth among the treatments. The seasonal EC values from 10, 30 and 50 cm depth of the soils irrigated with different types of irrigation waters are illustrated in Figure 4. It is obvious that soils irrigated with two types of treated wastewaters have high levels of EC throughout the study time in different depths of the columns compared to the soil irrigated with TW.

Soil pH and EC ($pH_{1:5}$ and $EC_{1:5}$)

At the end of the study, soil samples were collected from various depths of the columns. Analysis of soil samples showed similar results compared to soil-water analysis during the study in terms of pH and EC. Figure 5 shows the change of soil pH and EC from different depths of the columns.

These parameters of soil and their effect on kikuyu grass production have been comprehensively discussed in Shahrivar *et al.* (2019). In brief, a high concentration of cations in conjunction with a low level of nitrogen may have led to higher pH values of soil irrigated with IDAL treated wastewater. This high value of pH can limit the

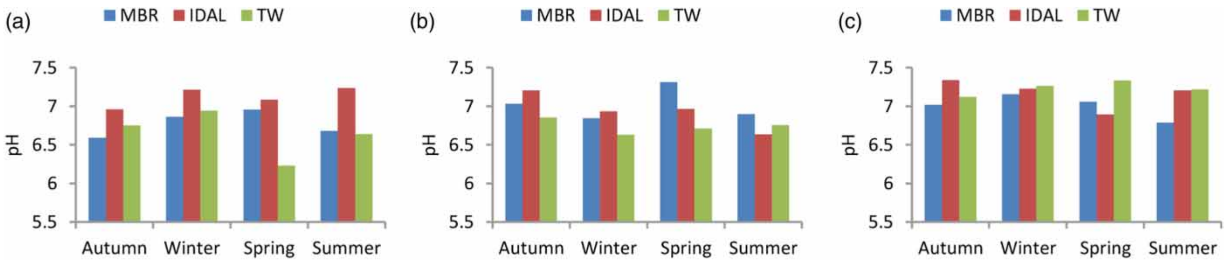

Figure 3 | Seasonal variation in soil-water pH extracted from (a) 10 cm, (b) 30 cm and (c) 50 cm depth of the columns.

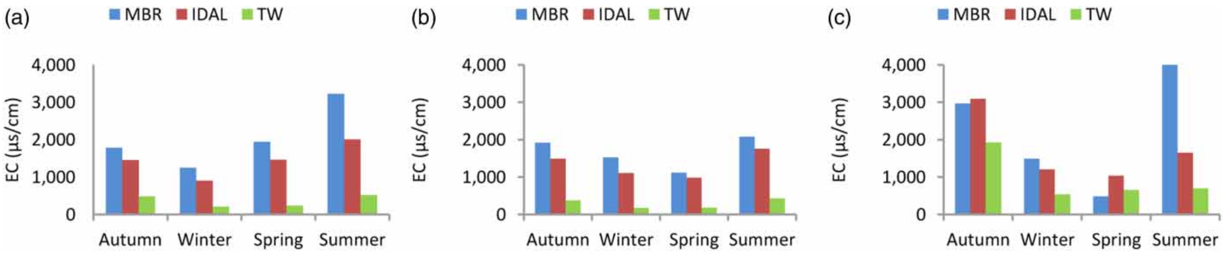

Figure 4 | Seasonal variation in soil-water EC extracted from (a) 10 cm, (b) 30 cm and (c) 50 cm depth of the columns.

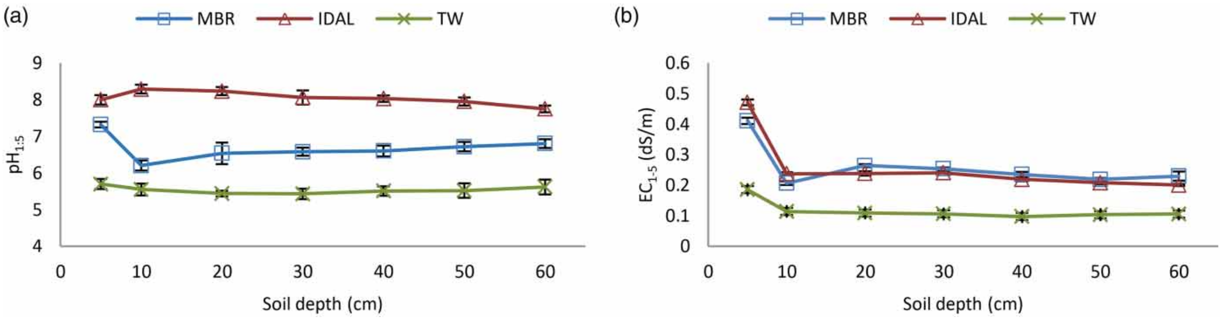

Figure 5 | (a) Soil pH ($pH_{1:5}$) and (b) EC ($EC_{1:5}$) in different depths of soil irrigated with different irrigation waters.

kikuyu grass growth, which is known to grow optimally at pH 5–7. The results were short term in duration; however, they can adversely affect the plant growth during a period when these undesirable conditions are present.

CONCLUSIONS

Soils irrigated with treated wastewaters resulted in higher values of EC compared to the control, particularly due to their high concentration of sodium. Although these increases can be short term in duration, high levels of EC can affect the plant growth under deficient nutrient conditions.

Irrigation with treated wastewater produced by the IDAL system resulted in higher values of soil pH at different depths. The value of pH increased over a relatively short time period suggesting that the plant growth may be affected if the system is used over a longer period. The results of the current study have shown that the wastewater produced by the IDAL system costs more and, due to the lack of valuable nutrients and higher values of EC, was not ideal for irrigation of kikuyu grass.

Results of this study indicated that treated wastewater obtained from the MBR system can be a more suitable source of irrigation water for urban areas because it supplied the grass with a constant and low dosage of valuable nutrients. This has several benefits, such as savings in the cost of treatment, recovery of nutrients from wastewater and prevention of pollutants being discharged into urban waterways. However, disinfection of wastewater to remove the harmful bacteria, viruses and parasites in wastewater treatment plants is crucial to ensure that there is no risk to public health. Furthermore, by regular monitoring of soil parameters and proper management of irrigation it would be possible to use the treated wastewaters for irrigation in a safe and successful way.

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