International Journal of Applied Environmental Sciences
ISSN 0973-6077 Volume 9, Number 4 (2014), pp. 2033-2049

http://www.ripublication.com

The Effects of Elements Mass Balance from Turf Grass Irrigated with Laundry and Bathtub Greywater

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Abstract

Greywater reuse is increasing as a measure to mitigate declining potable water supplies in many arid and semi-arid countries. In Perth, Western Australia, garden irrigation with greywater has grown popular for householders to keep their plants sustained, especially during long hot summers. However, the sandy soils of the Swan Coastal Plain allow for the rapid transport of contaminants through the soil profile, potentially affecting the underlying shallow aquifer. Hence, this study was conducted to determine the nutrient leaching from the couch grass (*Cynodon dactylon L.*) sod, on a free-draining sandy soil, irrigated with laundry and bathtub greywater. The experiment was used a modified aquarium tank and the irrigation was sourced from the family house following: (i) irrigating with 100% potable water as a control (TW) (ii) irrigating with untreated full cycle laundry water (LGW) (iii) irrigating with untreated bathtub water (BGW). Nine elements; salts: Na and Cl; macronutrients: P, K, Ca, Mg; and micronutrients: B, Al and Zn and their leaching was assessed by measuring their mass balance. Irrigation with LGW and BGW in sand resulted in significant leaching of some Mg and Al. The mass balance showed an increased amount of stored Na, Cl, P and K in the soil at the end of the study. There was an increase in salt content (Na, Cl) and B uptake that affected turf grass growth. Consequently, the turf grass requires the addition of the losses nutrients in the turf grass fertilization programme to supplement growth.

Keywords: greywater reuse, mass balance; elements, laundry, bathtub, sandy soil, turf

Introduction

Turf grasses are well suited for greywater irrigation, particularly considering the range of salt concentrations that turf can tolerate. Nutrients in greywater are expected to increase crop yields while pathogen levels are low (Jackson *et al.*, 2006). Greywater contains salts: Na and Cl; macronutrients: P, K, Ca, Mg; and micronutrients: B, Al and Zn, which are beneficial to turf grass (Carrow *et al.*, 2001). However, there are elevated amounts of B, salt (Na and Cl) and P in greywater from detergents and cleaning materials. The relatively low water-holding and nutrient-retention capacities of the sandy soils pose a particular challenge for water and nutrient management of turf grass. There is limited information about greywater irrigation on lawns (Roesner, Yaling *et al.*, 2006) in a sandy environment.

In water scarce countries with a relatively dry continent, heightened public awareness of this fact has led to an increasing trend in the use of greywater for irrigation in households (Gross, 2005; Radin et al., 2013). This is partly due to the notion that greywater is of better quality than wastewater and therefore does not need such extensive treatment. However, some adverse environmental impacts have been observed regarding the environmental risks surrounding gardens irrigated with greywater (Radin et al., 2012; Radin et al., 2013). A major concern with greywater reuse in sandy soil environments, such as on the Swan Coastal Plain of Perth, Western Australia, is the excessive leaching of nutrients to surrounding water bodies, especially groundwater resources. In Australia, using untreated greywater during the drought and water restrictions in sewered areas with manual bucketing and diverter valve are permitted in most states (Maxey, 2005). The composition of nutrients in greywater disposed directly to the soil. Nutrient management in this area needs to be addressed due to the potential for nutrients leaching into the nearby wetland, estuary and the vulnerability of the shallow aquifer.

Hence, this study assesses turf grass growth as affected by laundry and bathtub greywater, using scheme water as a control. The study focuses on irrigation of turf grown on sandy soils, making it relevant for the sandy soils typical of the Swan Coastal Plain, Western Australia. The approach uses a controlled tank experimental mass balance to determine the amount of nine selected elements (salt and nutrients) flowing into and out of the tanks over a 24-week study period. The aim was to determine whether greywater can sustain turf grass growth or whether it adversely affects turf quality and soil stability.

Materials and Method

Soil and site

The top 200mm of soil from the Spearwood dune system of the Swan Coastal Plain in Western Australia was collected during September 2009 from a residential backyard in Hamilton Hill, Western Australia (32.08^{o}S, 115.77^{o}E), 23km southwest of Perth CBD. The residence was occupied by 2 adults and 2 children. The soil at the experimental site was approximately 97% sands as characterised in **Table I**. According to Barton *et al.* (2006), soil from this kind of site has low chemical fertility and biological activity. After collection; samples were air-dried for 5 days, passed through a 2mm sieve to remove any pebbles or non-soil material, and stored at room temperature before use.

Table I. Soil physical characteristics used in the tank experiment. Soil samples (n = 3) were taken from 0-15cm depth.

Org Carbon (%)	Water content (%)	Sand Fraction (%)		Sand (%)	Silt (%)	Clay (%)
	(5 d storage)	Fine (20-212 μm)	Coarse (212-2000 μm)			
0.43	0.45	49.35	47.48	96.70	0.61	2.19

Setting up tanks

Aquarium tanks with dimensions 45cm (height) x 25.5cm (width) x 25cm (length) were chosen as they would enable the dispersion behaviour of turf grass after irrigation to be observed easily. All the tanks were placed under the shade to prevent the influence from the rainfall irrigation, which only greywater irrigation was considered. The bases were modified with a 10mm diameter hole and outflow pipe from which leachate was collected into a 250mL plastic container located under each tank, as shown in **Figure 1**. Soil was packed into each tank to a bulk density of 1.31g/cm^3, the density measured at the collection site in the field. This *in-situ* bulk density was determined by pushing a 30cm soil corer into the soil where the turf was later to be laid. The area around the pipe was then excavated and a plastic disk slid across the base of the pipe to seal it. In the lab, the soil samples were dried at 60^{o}C for two days. The bulk density (ρ_b) was calculated according to:

$$\rho_b = \frac{\text{Sample dry weight}}{\mathit{Depth} \times \frac{\pi D^2}{4}} \qquad \text{Equation 1}$$

Where

ρ_b = the *in-situ* bulk density (g/cm^3)

Sample dry weight = the mass (g) of the soil core after two days of oven drying at 60^{0}C

Depth = the length of the soil core taken (cm)

D = the soil corer inside diameter (cm).

The total mass of soil (kg) required was 36.84kg to fill the tank and the *in-situ* density was calculated according to:

$$\text{Tank soil mass} = \frac{\text{Tank soil filled volume}}{1000} \times \rho b \qquad \text{Equation 2}$$

Soil was added to the tank in ten equal increments, each one tenth of the total *Tank Soil Mass*. Each incremental layer was leveled and compacted with a wooden block to a thickness one tenth of the tank soil filled height (2.7cm) to maintain a uniform density throughout the tank depth.

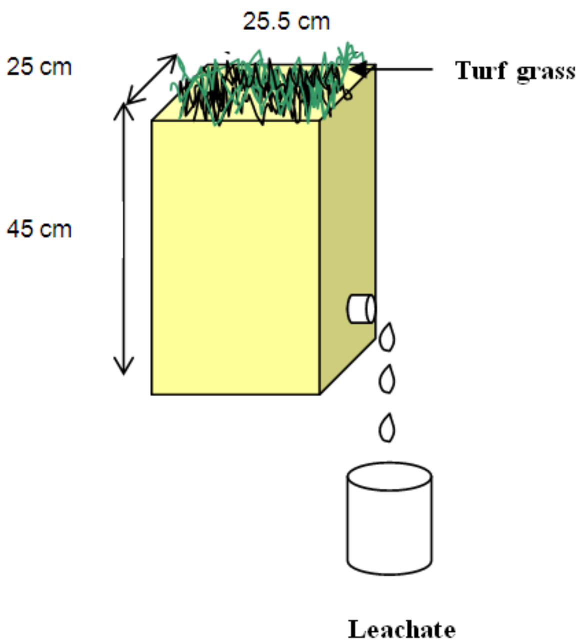

Figure 1. Schematic diagram of tank experiment

The species of turf grass used was from the couch family *(Cynodon dactylon L.) sod*, also known as a *Bermuda* grass. Couch grass is a common lawn species in WA; it is known to be drought tolerant, water efficient and requiring relatively low maintenance (del Marco, 1990). Turf grass sod or turf grass rolls are a mature grass cover and obtained from a local nursery. The nutrient status of the turf grass was analysed before planting. Throughout the experiment, turf grass was grown without any fertilizer thus any nutrients were obtained solely from the laundry (LGW), bathtub (BGW) and scheme water (TW). Key properties of the soil and turf grass were characterized at the time of planting and are given in **Table II**.

Table II. Mean (± S.E.) of initial status of the selected salts and nutrients in the soil and turf, n = 3

	Soil	Turf grass
Salt	mg/kg	mg/kg
Cl	68.00 + 4.00	0.16 + 2.01
Na	30.40 + 1.06	0.08 + 1.45
Macronutrients	mg/kg	mg/kg
P	2.27 + 0.13	0.33 + 0.87
Ca	169.33 + 5.81	0.54 + 2.31
K	21.20 + 0.61	0.85 + 0.94
Mg	45.33 + 1.33	0.12 + 1.01
Micronutrients	mg/kg	mg/kg
Zn	4.80 + 0.46	123.65 + 0.56
Al	77.33 + 1.33	N/A
B	1.91 + 0.15	4.37 + 0.72

N/A = Not Analysed

Irrigation regimes

The irrigation water was (i) TW, scheme water, (ii) LGW, collected from the untreated laundry (full cycle) of the top-loader washing machine, (iii) BGW, collected from the children’s bath. LGW was collected three times a week from the washing machine (Hitachi, model PAF-1220P). A top-loader washing machine was selected because 71% of Perth households used this type (ABS, 2006). BGW was collected every morning after the children’s bath. TW, LGW and BGW were used daily to irrigate the turf grass.

The experiments were conducted in three replicates sampling collected from the house from October 2009 to March 2010. This period was chosen to cover the long dry summer season in Perth, where the use of greywater is significant. To reflect the worst-case scenario where no consideration would be given to using environmentally friendly products, the greywater was sourced from a resident selected for using regular detergents and personal cleaning products. These detergents were used without any fabric softener.

Irrigation was done daily, by hand. The water was poured on using a bucket so that the exact volume was known each time. This practice is acceptable for sandy soil in summer when the evaporation rate is high. Barton *et al.* (2006) state that turf grass in a Mediterranean type of climate generally requires regular irrigation. The irrigation regime for the first seven days was 3.5mm applied three times per day, followed by 5.0mm twice per day for the next 21 days. In Western Australia, a maximum allowable application rate of 10mm/day/m^2 is normally applied, assuming the free-draining sands typical of the Swan Coastal Plain (DOH, 2005). This figure should be sufficient to meet the peak water requirement. A crop factor of 0.8, multiplied by a maximum summer daily evaporation rate of 10mm suggests a peak irrigation requirement of 8mm per day. Thus the water needed for irrigation was 0.60mm or 35mL a day for each tank of the given size.

The remainder of the irrigation volumes were given each morning to replace 100% of the previous day's reference evapotranspiration (ET) derived from the weather station records as given in **Table III**. This irrigation regime is 'current Western Australia industry practice' for the establishment of turf during summer months. Rainfall was not considered in connection with additional leaching since the tanks were placed under a shelter. The monthly site temperature during the study period is given in **Table III**. During the summer of December 2009 – February 2010 in Western Australia the maximum temperature recorded was in January 2010 (34.4^{o}C), along with the highest total ET rate of 253.7mm.

Table III. Monthly (± S.D.) temperature, total evapotranspiration (ET) and total irrigation amount based on replacement of ET during duration of the experiments, October 2009 to March 2010.

Month	Monthly temperature ^{o}C		Total monthly evapotranspiration (ET)	Total monthly irrigation
	Min	Max	mm	Mm
Oct 2009	10.5 (4.07)	23.8 (4.26)	149.8 (1.25)	90.0
Nov 2009	11.9 (3.49)	26.8 (4.18)	105.8 (1.01)	63.5
Dec 2009	14.7 (3.34)	31.5 (4.58)	240.6 (0.82)	144.4
Jan 2010	17.8 (3.60)	34.4 (4.40)	253.7 (1.18)	152.2
Feb 2010	17.5 (3.80)	32.8 (4.46)	193.7 (1.36)	116.2
March 2010	16.7 (3.98)	30.9 (4.08)	173.2 (1.18)	103.9

Monthly temperature and ET observation is from Perth Metro Station, located 20.2 km from the site. Calculation of irrigation volumes based on tank size (0.6mm/tank). A rainfall volume is not included as all the tanks were placed under a shelter.

Sample collection and analysis

Samples of irrigation greywater (LGW, BGW), and TW; leachate; soil and turf grass tissue were analysed for salts and nutrients: sodium (Na), chloride (Cl), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), aluminum (Al) and boron (B). These elements were selected because they are dominant constituents in greywater and have a beneficial role in turf grass growth (Carrow *et al.*, 2001).

Soil

Soil samples were collected from the upper 10cm of each tank before irrigation commenced and were collected after 30, 90 and 180 days (Mohd-Kamil et al., 2010). Nine samples of 10g of soil were collected from each tank, placed in a clean plastic bucket, mixed, and sub-sampled. A single composite sample from each tank was submitted to the laboratory for analysis. All sampling holes were filled with clean soil from an undisturbed area of the field just beyond the experimental area. Soil elements were extracted using 0.05N HCl and 0.025N H_2SO_4 for the double acid extraction method following analysis by ICP-AES at a NATA accredited laboratory.

Plant tissue

Turf grass height was measured every month. Turf grass growth for the tank test was measured by the dry mass of the turf grass clippings from each tank. Turf grasses in all tanks were cut 30 and 180 days after planting, cutting the turf grass to 15mm height with hand-held scissors, drying at 65°C, weighing and submitting for elemental analysis. Turf grass tissues were digested using dry ashing method (Kalra, 1998); 0.5g of dry plant material was placed in the muffle furnace and heated to 450^{o}C. The ash then had 1N HNO_3 and 1N HCl added to it to dissolve the residue. Samples were then taken to the NATA accredited laboratory for ICP-AES analysis.

Mass balance

Mass balances for influent and effluent were determined by multiplying the concentration of nutrients by the volume of water. Mass balances in soil were determined by multiplying the concentration of soil nutrients by the volume of soil in the tank. Mass balances in turf were determined by multiplying the nutrient concentrations in the leaves and shoot samples by the total weight (dry weight) of the clippings after they were cut.

Statistical analysis

A one-way ANOVA was used on the mean of irrigation inflow and leachate, and on soil and turf grass nutrient concentrations. Significant differences between irrigation tanks when ANOVA suggested a treatment effect ($p < 0.05$). In the absence of significant interactions, means were separated using Tukey's Studentized Range Test. Differences between irrigation in the tanks are reported at $P < 0.001$.

Results and Discussion

Irrigation water quality

The quality of irrigation water - LGW, BGW and TW - was within the recommended limits, except that there was a slight increase of B in the LGW and BGW, as shown in **Table IV**. pH values in all irrigations types were found to be neutral, ranging from 6.4 to 6.6. As expected, the highest level of salt by EC measurement was found in LGW (960 μS/cm), followed by BGW (630 μS/cm), compared to TW (590 μS/cm). LGW irrigation had significant influence ($p < 0.05$) over the concentration of nutrients Na, Cl, B, K, P and Zn, whilst BGW irrigation showed a significant increase ($p < 0.05$) in nutrients Ca, Mg, K and Zn. SAR is 5.23 for LGW and 5.3 for BGW, exceeding the recommended limit of 5 (IME, 2003).

Table IV. Mean (± S.E.) values (n = 9) of irrigation water compared with range or maximum limit for irrigation. Samples were taken every 60 days. Concentrations are in mg/L unless stated otherwise.

	Tap water (TW)	Laundry water (LGW)	Bathtub water (BGW)	Recommended ranges or upper limits for irrigation purposes
pH	6.4 + 0.1	6.5 + 0.1	6.6 + 0.1	6.5-8.5[(a);(b)]
EC, µS/cm	590 + 20	960 + 60	630 + 20	950-1900 µS/cm[(a)], 1.4 dS/m[(b)]
Salts				
Na	48.50 + 2.86	146.67 + 8.82	80.33 + 0.88	<230 [(a)], 150[(b)]
Cl	40.00 + 8.16	180.00 + 5.77	130.00 + 1.23	250[(b)]
Macronutrients				
Ca	15.00 + 4.08	17.00 + 1.00	22.00 + 1.02	20-60[(d)]
Mg	3.90 + 0.24	4.37 + 0.07	5.17 + 0.03	10-25[(d)]
K	1.00 + 0.16	4.07 + 0.09	6.67 + 0.03	5-20[(d)]
P	0.02 + 0.07	0.31 + 0.03	0.23 + 0.05	<12(total)[(b)], 5 (total)[(b)], 0.1-0.4[(d)]
Micronutrients				
B	0.02 + 0.10	0.54 + 0.003	0.55 + 0.01	0.4[(b)]
Zn	0.02 + 0.003	0.01 + 0.001	0.03 + 0.002	2.00[(b);(c)]
Al	0.02 + 0.004	0.06 + 0.003	0.05 + 0.006	5.0[(b);(c)]
SAR*	4.98	15.25	5.33	4.0[(a)]; 5.0[(b)]

(a) ANZECC and ARMCANZ (2000); Myers *et al.*, (1999); (b) IME (2003); (c) Asano (1998), (d) Harivandi (1994)

* SAR = $\frac{Na}{\sqrt{Ca + Mg / 2}}$, Na, Ca and Mg in meq/L (calculated)

The concentrations of nutrients are largely dependent on the concentrations and quality of the water used for irrigation. Carrow and Duncan (1998) highlighted that the salts Ca, Mg, Na, K, and Cl are most commonly found in salt-affected soils. In this study, there are significant levels of these salts in LGW and BGW, compared to TW (**Figure 2**). High levels of EC (960 µS/cm or 0.96 dS/m) indicate the high level of salts contributed by LGW. This value is higher than reported by Misra *et al.* (2010), where the EC value was 653.3 ± 3.1 µS/cm in LGW. However, greywater salinity levels are within the acceptable range (0.65 - 1.3 dS/m) for the irrigation of moderately sensitive crops (ANZECC and ARMCANZ, 2000).

LGW contained elevated Na levels compared to BGW. The Na in the LGW results from its use of as a counter to several anionic surfactants used in powered laundry detergents (Jeppesen, 1996, Radin et al, 2013) and the use of Na and Cl in ion-exchangers. Washing detergents are also the primary source of the PO_4 found in greywater (Eriksson *et al.*, 2002; Christova-Boal *et al.*, 1996). P was used as a builder to adjust the water chemistry to a higher pH and bind hardness cations

(Tjandraatmadja *et al.*, 2008). This may explain why P is generally higher in LGW than in BGW, 0.31 and 0.23 mg/L, respectively.

Other nutrients in LGW are P, B and Al. Studies confirm that there are a broad range of these nutrients in Australian laundry detergents (Christova-Boal *et al.*, 1996; Patterson, 2004; Tjandraatmadja *et al.*, 2010; Tjandraatmadja *et al.*, 2008). In this study, concentrations of B were slightly higher in BGW than in LGW (**Table IV**). This can be supported by Tjandraatmadja *et al.* (2008), who had found 62% of B in Australian household and personal care products such as laundry liquid and body wash. In this study, the use of powdered laundry detergent may have contributed to the lower concentration of B in LGW.

Al is used in Na-Al-silicates to produce a multi-valent ion exchange capacity metal ion which cannot be bound by phosphate during the washing process (Schwuger and Smolka, 1976; Christova-Boal *et al.* 1996). Al in this form is insoluble in water and therefore is not considered detrimental to plant life (Christova-Boal *et al.*, 1996). However, the concentrations of these nutrients in greywater in this study are generally low. The quantity of zinc was attributed to specific sunscreen and anti-dandruff shampoo formulations (Tjandraatmadja *et al.*, 2008); zinc is also contained in common brands of household washing powders (Aonghusa and Gray, 2002). Comber and Gunn (1996) also noted that zinc (46.0%) from plumbing materials raised concern because significant amounts of Zn and other metals have been found in Irish sewage sludges. However, the concentrations of these micronutrients in the irrigation water during this study are within the recommended range or maximum value for irrigation waters.

Changes of pH and EC in irrigation water

The application of the LGW and BGW resulted in minimal pH changes between the inflow (irrigation) and outflow (leachate) solution. It was not significantly different: P = 0.626. The pH values were neutral and in the range of 6.5 to 6.6. The EC in the leachate increased about two-fold after irrigation with LGW and BGW (**Figure 2**). A high overall mean EC value was found in LGW, with values of 959 μS/cm (inflow) and 2,638 μS/cm (outflow).

Roesner, Qian *et al.* (2006) state that the pH of greywater is generally neutral, but tends to be slightly higher than the source water because of the addition of detergents (Christova-Boal *et al.*, 1996; Chan and Radin, 2013; Radin et al., 2014). The pH of wash cycle water, however, has been suspected of contributing a pH as high as 7.5 (Christova-Boal *et al.*, 1996) and 8.2 (Gross *et al.*, 2005). Analysis of the quality of TW, LGW and BGW used for irrigation and leachate in this experiment shows that greywater caused only a small change in pH, ranging from 6.4 to 6.6 (**Figure 2**). Similarly, a study by Misra and Sivongxay (2009) showed a small decrease in pH of 6.25 (irrigation water) and 6.51 (leachate). It also contained twice as much salt as TW, with Na as the dominant ion. The change of pH in LGW was expected as it was derived from the full cycle washing, whereas the rinse cycle diluted the salts in the final washing process.

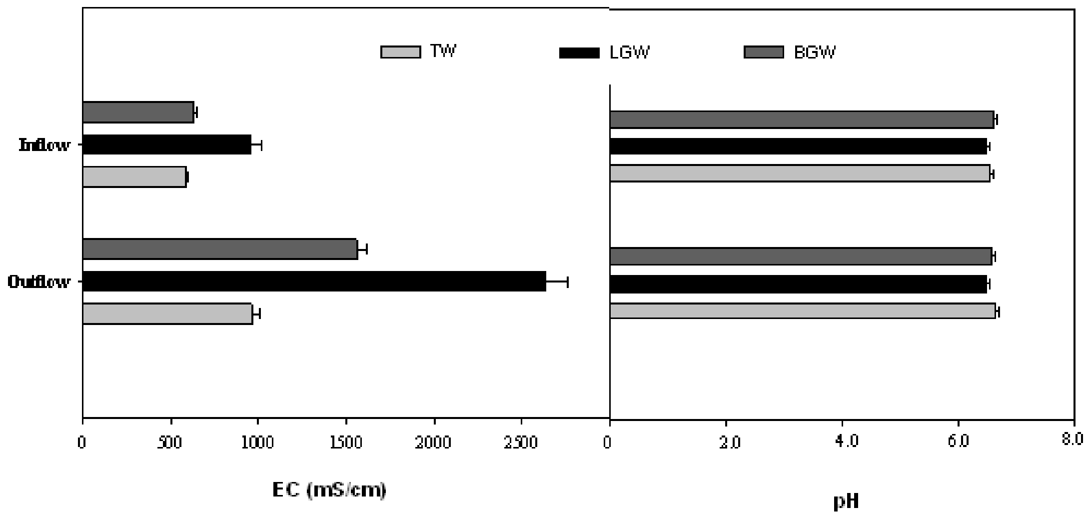

Figure 2. The overall mean EC and pH of inflow (irrigation) and outflow (leachate)

Mass balance ratio of nutrients

Salts and nutrients in greywater irrigation water are of concern because of their influence on turf grass growth. Turf grass needs macronutrients and micronutrients to support its growth. The macronutrient or primary nutrients N, P and K are required in large quantities among other nutrients. Carrow *et al.* (2001) suggest that these nutrients be added at 0.1 to 6.0% by dry weight of tissue at regular intervals. Here, only P and K were included even though previous researchers have recognized that untreated LGW and BGW carry relatively low levels of N. N is mostly concentrated in from excreta and kitchen sources, and is normally expected in greywater (Jefferson *et al.*, 2004; Eriksson *et al.*, 2002). Turf grass also needs the secondary nutrients Ca, Mg and S. Ca and Mg are normally supplied to the soil by the applying liming materials. Micronutrients or trace nutrients are required in very small amounts by plants, usually at 1.0 to 500 ppm (Carrow *et al.*, 2001). In this study, the micronutrients included are Zn, Al and B.

The total mass balance calculated for Na, Cl, P, K, Ca, Mg, B, Zn and Al in the couch turf grass for different irrigation types, TW, LGW and BGW, are shown in **Table V**. The mass balance for Mg was the highest, with 91% to 193% of the nutrient recovered in BGW. Al recovery was 59% to 87%; the highest was found in LGW. Mass balances for Ca, B and Zn were lower and ranged from 30 to 71%. Na concentrations were more variable owing to the high solubility of Na, with the highest recovery in BGW, resulting in overall recovery amounts of 17 to 38%. For Cl, P and K, the mass balance accounted for 5 to 40% recovery of the nutrients. The data confirm an increased amount of stored Na, Cl, P and K in the soil at the end of the study. Salt and nutrient uptake by turf grass was increased for Na, Cl, B and K. Micronutrient deficiency in turf grass uptake was observed for Ca and Mg.

Table V. Total mass balance (g) of the nine elements (salt and nutrients) in couch turf grass under TW, LGW and BGW irrigation in the 24-weeks study period

Irrigation type	Mass In				Mass Out				
	Irrigation	Soil	Turf	Total	Leachate	Soil	Turf	Total	Input/ Output
	g/tank								
				Sodium (Na)					
TW	0.77	1.12	0.002	1.89	0.46	10.86	0.01	11.32	0.17
LGW	2.46	1.12	0.002	3.59	3.20	17.54	0.02	20.76	0.17
BGW	1.35	1.12	0.002	2.47	0.81	6.53	0.01	7.36	0.38
	Chloride (Cl)								
TW	0.67	2.51	0.00	3.18	0.53	16.80	0.00	17.33	0.18
LGW	3.02	2.51	0.00	5.53	3.29	52.90	0.02	56.21	0.10
BGW	2.18	2.51	0.00	4.69	0.88	37.76	0.01	38.65	0.12
	Phosphorus (P)								
TW	0.00	0.08	0.01	0.09	0.00	0.56	0.02	0.58	0.16
LGW	0.01	0.08	0.01	0.10	0.00	1.76	0.01	1.78	0.05
BGW	0.00	0.08	0.01	0.09	0.00	1.41	0.02	1.43	0.07
	Potassium (K)								
TW	0.01	0.78	0.02	0.81	0.06	6.93	0.10	7.08	0.11
LGW	0.07	0.78	0.02	0.87	0.41	6.78	0.07	7.26	0.12
BGW	0.11	0.78	0.02	0.91	0.10	2.28	0.09	2.48	0.40
	Calcium (Ca)								
TW	0.24	6.24	0.01	6.49	0.06	17.14	0.01	17.21	0.38
LGW	0.29	6.24	0.01	6.53	0.34	11.40	0.00	11.74	0.56
BGW	0.37	6.24	0.01	6.62	0.11	9.38	0.01	9.50	0.71
	Magnesium (Mg)								
TW	0.06	1.67	0.002	1.73	0.02	1.89	0.005	1.91	0.91
LGW	0.07	1.67	0.002	1.75	0.06	1.83	0.004	1.90	0.92
BGW	0.09	1.67	0.002	1.76	0.02	0.91	0.006	0.94	1.93
	Boron (B)								
TW	0.00	0.07	0.00	0.07	0.00	0.23	0.00	0.23	0.30
LGW	0.01	0.07	0.00	0.08	0.01	0.25	0.00	0.26	0.31
BGW	0.01	0.07	0.00	0.08	0.00	0.18	0.00	0.19	0.43
	Zinc (Zn)								
TW	0.0002	0.18	0.0002	0.18	0.00	0.58	0.0003	0.58	0.30
LGW	0.0012	0.18	0.0002	0.18	0.00	0.46	0.0001	0.46	0.39
BGW	0.0006	0.18	0.0002	0.18	0.00	0.50	0.0003	0.51	0.35
	Aluminium (Al)								
TW	0.0002	2.85	N/A	2.85	0.01	3.79	N/A	3.80	0.75
LGW	0.0010	2.85	N/A	2.85	0.06	3.20	N/A	3.26	0.87
BGW	0.0008	2.85	N/A	2.85	0.03	4.85	N/A	4.88	0.59

N/A=Not analysed

Salinity and soil effects

The effects of salinity from LGW and BGW on soil are noted. They contribute to soil salinity through an increase in SAR and also as a major contributor to TDS. Reid and Sarkis (2006) stated that the SAR is correlated with the structural stability of the soil. SAR values for LGW and BGW were found to be 15.3 and 5.3, respectively. Both were high compared to the SAR value of 4 set by ANZECC and ARMCANZ (2000). A study carried out by Qian (2008) found that SAR of recycled wastewater from reuse sites ranged from 1.6 to 8.3. Gross *et al.* (2005) found that the SAR value of LGW irrigation was 2.36 compared to a SAR of 1 in a soil plot irrigated with greywater.

Long-term continuous use of water with high SAR negatively affects soil properties. There is a destruction of soil infiltration and permeability (Harivandi, 2000; Qian, 2008; Gross *et al.*, 2005). Gulyas (2007) claimed that overloading the garden with salt causes degradation of the soil structure and permeability, partly because salt is not degraded in the soil. Carrow and Duncan (1998) noted that high Na can destroy soil structure and thereby indirectly influence turf grasses via low water infiltration, poor drainage and low soil oxygen. Again, they noted that at high SAR value, ion imbalance can occur in some soils, leading to nutrient deficiencies of Ca, K, Mg, or P, which is in agreement with this study.

The relationship between soil salinity (EC) and its flocculating effects and sodicity (SAR) and its dispersive effects influence whether or not soil will stay aggregated or become dispersed under various salinity and sodicity combinations (Warrence *et al.*, 2002). Clay soils can hold more water and are slower to drain than coarse- textured soils. Small particles can pack closely together, block intervening spaces and prevent water from passing through. Sand particles are larger and therefore have larger pore spaces for water to pass through. The end result is that sandy soils can withstand higher salinity irrigation water because more dissolved salts will be removed from the root zone by leaching.

During the initial stage of irrigation with greywater a high infiltration rate and rapid drainage was observed, as expected with sandy soils. It seems there is initially a relatively low water storage capacity, as affected by cation exchange capacities (Thomas, 1971; Kopp *et al.*, 2004). The water moves through sandy soils' large pores at a high velocity (Carrow and Duncan, 1998). However, the high salt content in the irrigation water and frequent application tends to lower the drainage flow. Accumulations of salt tended to make the soil hydrophobic over the length of time taken for this study.

Saline irrigation of Australian soil risks accelerated sodification of soil layers unless soluble Ca and Mg minerals are present in the soil profiles to lower the SAR of the soil solution. This proposition agrees with the work of Al-Zu'bi and Al-Mohamadi (2008) where the concentration of Ca being much higher than that of Na resulted in only a very slight increase in SAR. They found that the concentration of bicarbonate ion in soil considerably increased, and became 8 to 9 times higher than before irrigation, contributing to a rise in total soluble salts in the irrigated soil. Therefore, soil fertility management such as calcium topdressing or other amendments and frequent aerification is needed to mitigate these effects. This would contribute to raising the concentration of total soluble salts in the irrigated soil.

Effects of salinity and boron on turf grass growth

In this study, elevated levels of Na, Cl and B in irrigation water resulted in increased salt leaching, soil salinity and increased salt concentration in turf grass tissue. Carrow *et al.* (2001) and Blaylock (1994) point out that Na, Cl and B have specific toxic effects on grasses, caused by direct contact with irrigation water and buildup in the soil. Na is highly susceptible to this as there is an insufficient negatively charged ion, from clay to interact with the positively charged cation. Gorham (2007) has shown that excess Na in solution is usually accompanied by Cl. As sandy soils have very low water-holding capacities and low cation exchange capacities, irrigation water rapidly infiltrates them. Soils with high levels of exchangeable sodium (Na) and low levels of total salts are called sodic soils. Leaching of B is greatest on acidic sodic soils that are sandy (Carrow *et al.*, 2001).

The elevated salt levels in LGW significantly impeded the vertical movement of irrigation water through the soil. The infiltration and drainage of LGW is significantly greater than BGW and TW. However, salts tend to accumulate and this study found a significant increase in soil salinity. This might be from a low level of degradable organic compounds and a slow soil microbial activity. The fact that no fertilizer was added during the experiment also contributed to the slow microbial activity and thus the increase in soil salinity. Many arid and semi-arid soils are salt-affected owing to insufficient leaching to remove the salts that accumulate over many years from weathering of minerals, groundwater and rain (Carrow and Duncan, 1998). Where annual rainfall is less than 380mm, salt-affected soils are prevalent.

Effects of salinity on P and K

Results show that the P level is low in the irrigation water but slightly increased in the soil and plants. P is one of the most reactive and immobile nutrients in soil. The high reactivity of P in soil leads ultimately to its conversion into sparingly soluble forms, resulting in low concentrations of P. Soil microbes release immobile forms of P to the soil solution and are also responsible for the immobilization of P (Schachtman *et al.*, 1998). However, Soldat and Petrovic (2008) claimed that sand-based root zones typically have very low P sorption capacities, and when they receive soluble fertilizers and have frequent irrigation, they discharge the P through subsurface drainage.

Conversely, K compounds are highly soluble in water, and K is withdrawn from solution by adsorption to cation exchange sites (Troeh and Thompson, 2005). Alfaro *et al.* (2004) state that K is a mobile ion in soils and consequently significant amounts can be lost by leaching. High Na Cl uptake competes with the uptake of other nutrient ions, especially K (Parida and Das, 2005; Carrow and Duncan, 1998), leading to K deficiency. K effects on soil structure are similar to the single-charged Na ion. However, little attention has been paid to K because its leaching does not directly result in eutrophication.

Imbalances of micronutrient Ca and Mg

The simultaneous presence of salts and nutrients in the root zone can influence ion uptake by plants and affect their chemical composition. High Na and Cl can be toxic to certain plants and can prevent Ca and Mg from reaching the plants (Stevens, 2006; Feigin, 1985). Ca is the main exchangeable base of clay minerals and is a major component of soils. Troeh and Thompson (2005) state that Ca dissolved in the soil solution can move by mass flow and by diffusion, but exchangeable Ca has a very low mobility. Monovalent ions such as Na^+ and K^+ are more mobile, because they are less strongly attracted to cation-exchange sites than Ca ions are. The displacement of Ca by Na, or other cations, can cause Ca deficiency, which may be observed as cupping of the youngest leaves, leaf tip burn of vegetables or bent over apices and inflorescences.

Conclusion

The growth of turf grass irrigated with greywater is determined by the level of elements such as P, K, Na, Cl, Ca, Mg, B, Al, and Zn. Irrigation with LGW and BGW in sand resulted in significant leaching of some Mg and Al. The mass balance showed an increased amount of stored Na, Cl, P and K in the soil at the end of the study. A significant reduction in soil hydraulic conductivity or infiltration was affected by LGW, followed by BGW after sequence irrigation indicating the potential salt accumulation in soil. There was an increase in salt content (Na, Cl) and B uptake that affected turf grass growth. Nutrient addition by means of fertigation (dosing) and flushing with freshwater are recommended when turf is irrigated with LGW and BGW.

Acknowledgement

We are deeply indebted to all staff and technician of School of Environmental Science, Murdoch University, Australia for the constant support during the work, for their guide and help on each experiment. The corresponding author wish to her PhD scholarship funder, Ministry of Higher Learning and Universiti Tun Hussein Onn Malaysia for the financial support given.

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