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Elemental Mass Balance of Na, Cl and B for the Turf grass Irrigated with Laundry and Bathtub Greywater

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ABSTRACT

Reusing greywater from laundry and bathtub is an option for residents wanting to keep their gardens and lawns green, especially when water restrictions are in place during summer period. The present study was carried out to evaluate the effects of laundry and bathtub greywater irrigation in sands on the growth of couch grass (*Cynodondactylon L.*) sod in a tank experimental study. Untreated laundry and bathtub greywater collected from a residential home were monitored for sodium (Na), chlorine (Cl) and boron (B), as these elements are dominant in household detergent and cleaning products. The turf grasses were planted in the modified aquarium tank with triplicate for each irrigation type. Irrigation sources included (i) 100% potable water as a control (TW) (ii) untreated full cycle laundry water (LGW) (iii) untreated bathtub water (BGW) over 24 weeks. The reduction on soil hydraulic conductivity was tested using double rings infiltrometer. A mass balance was carried out to determine the amount of Na, Cl and B flowing into and out of the tank. The results showed that the high salt (Na, Cl) and B content was significant in laundry greywater compared to bathtub. Irrigation with laundry and bathtub greywater without fertilizer addition was insufficient to sustain the turf growth. Long-term use of laundry and bathtub greywater can lead to Na, Cl and B accumulation in the soil and subsequent uptake by the turf grass. Consequently, the turf grass requires an addition of nutrients in its fertilization program in order to sustain the turf grass growth.

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INTRODUCTION

Greywater, which corresponds to wastewater produced from bathing, showering, and laundry is an immense resource for garden irrigation in regions of water scarcity. By the early 21st century, there are already acute water shortages in large parts of Australia, Asia, Africa, and the United States. In Perth, Western Australia (WA), winter rainfall has declined by 15% since 1975, reducing run-off into metropolitan dams and estuaries by more than 50% (Barron, 2008). This has resulted in extremely high water demand between the growing city and nature requirements. With water restrictions in place, people are looking for ways to reuse wastewater from all possible sources so that a significant amount of fresh water can be saved. Among these strategies, greywater has gained attention as a resource, owing to its low level of contamination compared to blackwater, because of the exclusion of toilet water. Moreover, greywater enables water provision to be ‘climate independent’. This, combined with an increasing community interest in water conservation, has led to reusing of greywater.

The Western Australia Code of Practice of the use of greywater specifies that untreated greywater can be applied manually, by using a bucket to collect water from the bath or shower or by a diversion system to water lawns and gardens, without a permit from the council (Maxey, 2005; DOH, 2005; DOH 2010). Of the land uses in urban landscape, turf is preferred for irrigate with greywater. This is due to the fact that most turf grasses can tolerate the elevated levels of salts and constituents normally found in greywater. A major problem with the use of greywater for irrigation is the widespread use of it, untreated, for watering the lawn and garden. Greywater regulation has been developed mainly to safeguard public health. Despite the regulations, the increasing use of greywater on gardens has become unsustainable (Maimon *et al.*, 2010; Anda *et al*., 2010; Mohamed *et al*., 2012; Mohamed *et al*., 2013), because of the increasing number of household chemicals (Erikssonet *al.*, 2009). The

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direct discharge of untreated laundry and bathroom greywater has becoming one of the factors of river pollution in many unsewered areas in developing countries (Mohamed *et al*., 2014a). Therefore, an improved understanding of the effects of greywater reuse on direct disposal to the environment is required.

The mental perception that greywater contains relatively low pathogen level and nutrient levels compared to wastewater causes the increasing use of greywater for house lawn irrigation. Therefore, overloading the lawn with greywater has sometimes occurred. However, this practice results in an increased need for salinity tolerant turf grass, particularly the levels of (Na), chlorine (Cl) and boron (B) from laundry and bathtub greywater (Mohamed *et al*., 2014b.Lazarova and Asano (2004) claimed that the most common phytotoxic ions in municipal effluents are B,Cl and Na. Large quantities of B can be toxic to plants and typically come from water softeners, cleaners and detergents, largely in the form of sodium perborate, which is commonly used for whitening purposes. B can be toxic at levels only slightly greater than those required by plants for good growth. According to ANZECC (1992), B concentration lower than 1 mg/L is essential for plant development but higher levels can cause problems in sensitive plants. Lazarova and Asano (2004) later indicated that B can be found in urban wastewater at concentration levels as high as 5 mg/L with an average of 1 mg/L. Gross (2005; 2008)'s study found greywater's B concentrations to average at 1.3 mg/L – levels which may limit the growth of plants. Moreover, sandy soils pose a particular challenge for water and nutrient management for turf grass due to the relatively low water holding and nutrient retention capacities of these substrates. There is however very limited information on greywater irrigation on landscape plants or their effects to filtration such as on peat (Chan *et al*., 2014) and most is short term (Roesner *et al.*, 2006; Chan and Mohamed, 2013).

The objective of this study was to study the effects of common elements found in laundry and bathtub greywater; Na, Cl and B to the growth of turf grass in tank experimental over 24 weeks study period. The approach used was a mass balance to determine the amount of Na, Cl and B flowing into and out of the tank experiments. It is whether it can sustain turf grass growth or conversely has an impact on turf quality and soil stability.

MATERIALS AND METHOD

Soil and site:

Soil (top 200 mm) from the Spearwood dune system of the Swan Coastal Plain in Western Australia (McArthur and Bettenay, 1960) was collected from a residential home's backyard in Hamilton Hill, Western Australia (32.08 ^{0} S, 115.77 ^{0} E), 23 km south west of Perth CBD. The residential house was occupied by 2 adults and 2 kids. The soil at the experimental site was sandy (97%). Barton*et al.* (2006)'s refer the soil from this site contained low chemical fertility and biological activity. After collection; samples were air-dried for 5 days, passed through a 2.0 mm sieve to remove any pebbles or non-soil material, and stored at room temperature before use.

Tank Experimental Approach:

Experimental approach was using a modified aquarium tanks at the study site. The tanks were constructed using the aquarium tank with dimension of 45cm x 25.5cm x 25cm (height x width x length). Aquarium tanks were used to visually assist in the observation of dispersion behavior of turf grass applied with different irrigation water. The base of the tank was modified with a small hole, 10 mm, funneled into a central exit point from which leachates were collected in a 250 mL plastic container located under each tank. Soil was packed into each tank at a bulk density (1.31 g cm^{-3}) as measured at the collection site in the field.

Turf grasses used were a family lawn of couch grass *(Cynodondactylon L.) sod*, also known as a bermudagrass. The selection of couch grass was due to commonly lawn species used in Western Australia, excellent drought tolerance, water efficient and relatively low maintenance requirements (del Marco, 1990). Turf grass sod or turf grass roll was a mature grass cover obtained from the nursery. Throughout the experiment, turf grasses were not added any fertilizer thus the nutrient was sourced from TW, LGW and BGW.

Three replications were subjected to each of the following irrigation practice: (i) 100% potable water (control), TW (ii) untreated laundry water (full cycle), LGW (iii) untreated bathtub water, BGW generated from the house starting from October 2009 to March 2010. To reflect the worst case scenario when the lawn supplied without environmental friendly products, the greywater reused is sourced from a resident that employed regular detergents and personal cleaner products. The detergents were used without any fabric softener. Key properties of the soil and turf grass were determined in the laboratory to characterize the soil used, and the properties at the time of planting and after harvest are given in Table 1.

Sample collection:

Irrigation water (inflow) and leachate (outflow):

LGW was collected three times a week from the top loader washing machine (Hitachi, model PAF-1220P). About 71% of the Perth households used a top loading washing machine (ABS, 2006). BGW was collected daily after the morning kids' bath. TW, LGW and BGW were used for turf grass irrigation in daily basis. The irrigation water quality changes were recorded every 60 days. The leachate samples from each tank were collected daily from the polyethylene bottles placed in the under-tank outflow tubing system. The volumes of leachates from each tank were measured 24 h after irrigation (i.e. before daily irrigation). Later, leachate samples were combined, transferred to clean polyethylene containers, labeled and stored at 4^0C in a cooler to give a weekly total for each tank. Samples then transported to the laboratory for analysis. pH and EC were measured daily.

Table 1: Na, Cl and B status in soil and turf before commencement of the tank experiment. Ca and Mg were measured for SAR identification. Soil samples (n=3) were taken from the 0-15 cm depth. Turf grass tissues (n=3) were taken after bought from turf nursery.

	Soil (mg/kg)	Turf grass
Salt		
Cl	68.00 ± 4.00	0.16 ± 2.01 %
Na	30.40 ± 1.06	0.08 ± 1.45 %
Macronutrients		
Ca	169.33 ± 5.81	0.54 ± 2.31 %
Mg	45.33 ± 1.33	0.12 ± 1.01 %
Micronutrients		
B	1.91 ± 0.15	4.37 ± 0.72 mg/kg

***Soil*:**

Soil samples were collected from the upper 10 cm of each tank before the irrigation commenced and were collected after *30, 90* and *180* days. Nine samples contained 10 g 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.

***Plant Tissue*:**

Turf grass tissue quality was assessed visually each 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 harvested at *30* and *180* days after planting. Tank clippings were collected by cutting the turf grass to 15 mm height by hand-held scissors, drying at 65°C, weighed and submitted for analysis of nutrient.

Sample analysis:

Samples of irrigation water (TW, LGW and BGW), leachate from the tank outflow, soil and plant were analyzed for Na, Cl and B. These elements were selected based on its dominant concentration found in LGW and BGW. Irrigation water as the inflow in the tank and leachate discharges from the tank were sent to the Marine and Freshwater laboratory (MAFRL), Murdoch University for elemental analysis using ICP-AES. Soil and turf grass tissue were analyzed by the CSBP laboratory using Australian Laboratory Handbook of Soil and Water Chemical Methods (Rayment and Higginson, 1992). Both MAFRL and CSBP are NATA (National Association of Testing Authorities) registered for analytical procedures.

Calculation of mass balance:

The Na, Cl and B mass flux into the tank system was calculated using irrigation and the concentration of nutrients in TW, LGW and BGW. The mass flux out is calculated using infiltration rates and the concentration of nutrients in the leachate. Soil and tissue testing are also used by many turf grass managers to determine fertilization needs. The calculation of mass balance is shown as below:

Inflow = Outflow **(Equation 1)**

Mass in (Q_1 C_1) + soil + turf tissue = Mass out (Q_0 C_0) + soil + turf tissue **(Equation 2)**

RESULT AND DISCUSSION

LGW and BGW irrigation water quality:

The quality of irrigation water is an important factor for the management of turf grass growth and soil fertility. Na, Cl and B concentration in irrigation water quality for TW, LGW and BGW was observed to be within the recommendation limits of water used for irrigation presented in Table 2. The pH values in all irrigations were neutral. The highest EC was found in LGW indicating the high range of salt content, followed by BGW and TW, 960 ± 60 µS/cm, 630 ± 20 µS/cm and 590 ± 20 µS/cm, respectively.

Some studies have confirmed that broad range of Na, Cl and B content in Australian laundry detergents (Christova-Boal*et al.*, 1996; Patterson, 2004; Tjandraatmadja*et al.*, 2010; Tjandraatmadja*et al.*, 2008). The primary source of sodium salt is from the washing powders. They work as a bulking agent to exchange the divalent hardness cation during the washing process. The replacement of divalent cations with Na generates saline greywater. Boron analysis was included as it is present in many laundry detergents and is known to have acute toxicity to plants. Boron was typically comes from water softeners, cleaners and detergents, largely in the form of sodium perborate, mainly used for whitening purposes. (Tjandraatmadja*et al.*, 2008) found 62% of B in toilet cleaners, laundry liquid and body wash of Australian household and personal care products tested. In this study, BGW was found slightly increased in B concentration compared to LGW (Table 2). However, the concentrations of other elements were slightly lower in BGW compared to LGW except on Ca^{2+}. The use of body wash, shampoo added with mineral may contribute the level of elements as also mentioned in Mohamed *et al.*, 2014c)

Long term irrigation with LGW and BGW has significant increased in sodium adsorption ratio (SAR) values. The dramatic increased of SAR value of 15.25 in LGW found in this study compared to SAR value of 4 set by ANZECC and ARMCANZ(2000). SAR value of 4 can negatively affect plant growth and soil structure. Higher SAR was primarily contributed from sodium, compared to calcium and magnesium in irrigation water and is provide an indication to the structural stability of the soil.

Table 2: Chemical constituents of TW, LGW and BGW compared with maximum limit for irrigation. Ca and Mg were measured for SAR identification. Samples were taken every 60 d, n=9 of each irrigation sample.

	Tap water (TW)	Laundry water (LGW)	Bathtub water (BGW)	Recommended ranges or upper limits for irrigation purposes
pH	6.54 ± 0.06	6.48 ± 0.05	6.59 ± 0.06	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 ± 0.00	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$^{(d)}$
Micronutrients				
B	0.02 ± 0.10	0.54 ± 0.003	0.55 ± 0.01	0.4$^{(b)}$
SAR*	4.98	15.25	5.33	5.0$^{(b)}$

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

* SAR: sodium adsorption ratio (calculated)

An infiltration rate, *K*, test was commenced to further test the effect of different irrigation on infiltration in sand. Changes of the hydraulic conductivity were used as an indication of soil stability changes. A significant reduction in of leaching volumes was severely affected by LGW of 13.48 m/day, followed by BGW of 16.29 m/day, in comparison with tap water (TW), 19 m/day as seen in Fig. 1.As salts are not degraded in the soil, overloading the garden with salt causes degradation of the soil structure and permeability. Critically, long-term and continued use of water with a high salt content causing low soil infiltration rates (Carrow and Duncan, 1998; Qian, 2008; Mohamed *et al*., 2014b).

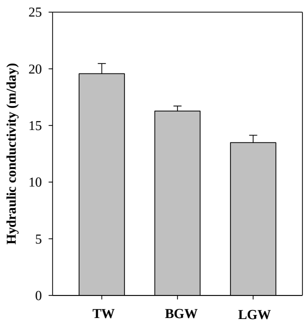

Fig. 1: Saturated infiltration rate (as measured by the double ring infiltration method) of laundry (LGW), bathtub (BGW) and tap water (TW) into tanks. Results are based on 3 replicates.

Na, Cl and Boron Mass Balance:

The Na and Cl mass balance is shown graphically in Figure 2-4. In this study, high levels of Na, Cl and B in irrigation water were found to corresponding to an increase of soil salinity, salt leaching and turf grass tissue content. This is supported to the fact that Na is highly susceptible to as there are insufficient negatively charged layer (ions), from clay to interact with positively charged cation. Gorham, (2007) stated the excess may result in high concentrations of Na ions in solution, usually accompanied by chloride (Cl^-). This study has found significant increase in soil salinity. This might be due to the low level content of degradable organic compounds in sandy soil resulting in a slower soil microbial activity, in addition no fertilization being added throughout the experiment.

The presence of high levels of salts Na, Cl found through this study indicates the toxic effects to the turf grass growth. According to Blaylock, (1994) and Stevens, (2006), the general effect of soil salinity on plants is called an osmotic effect. This means that salts increase the energy with which water is held in the soil. The plant must use energy to get water that would otherwise be used for growth, flowering or fruiting. When soil salinity exceeds a plant's tolerance, growth reductions occur. Observation made in this study (Fig. 6) that turf grass established well after 8 weeks of study. However, the reduction occurred after 12 weeks and the growth was ended after 16 weeks of study period.

As salt concentration increases in the soil occurred, water becomes increasingly difficult for the plant to absorb. A plant can actually die from water stress or drought in a moist soil if the salt concentration becomes high enough. Carrow and Duncan, (1998) added that high Na^+, often in conjunction with Cl^-, can induce a number of detrimental responses in plants. In leaf and root tissues, Na^+ can accumulate in cell wall micropores where carboxyl groups (R-COO^-) attract positively charged cations (i.e., Na^+). Especially in leaves, this leads to dehydration, reduced turgor and death of cells. The evident form of this injury is leaf burn at the tips or margin can be seen in the turf grass growth after 16 week (Fig. 6 (c)). Stevens, (2006) stated that elevated Cl levels can cause foliar injury to crops and cause increase uptake by plants of heavy metals, cadmium from soil. Carrow*et al.*, (2001) addedCl is a component of many salts that can be directly toxic to leaf tissues and roots; more often it reduces water availability by enhancing total soil salinity.

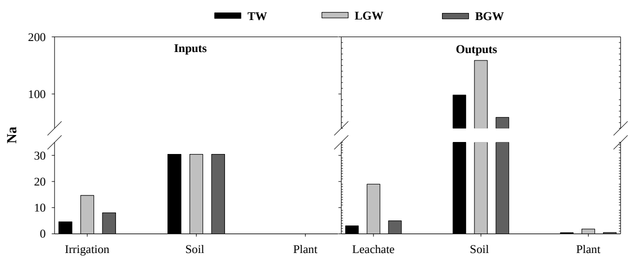

Fig. 2: Mass Balance ofSodium (Na) in mg/week .

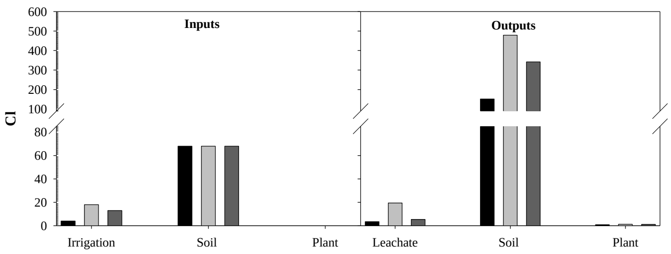

Fig. 3: Mass Balance ofChlorine **(**Cl) in mg/week.

For micronutrient, B was found to be likely to Na and Cl in this study. However, turf grass growth was severely affected by B as the higher concentration was found in turf tissue (Fig. 4). In this study, irrigation water contains slightly lower B, 0.54 mg/L and 0.55 mg/L in LGW and BGW, respectively. Gross (2006)'s study found B concentrations in the greywater averaged 1.3 mg/L and that it may limit the growth of plants. Many researchers suggest that plants exhibit toxicity problems when the concentration of B exceeding 2 mg/L. However, probable sequence irrigation with B over long period tends to become accumulated in turf grass tissue as shown in Fig. 4. B leaching was occurred as the concentration in leachate sample was higher than irrigation water. According to Prasad and Power (1997), B is soluble and tends to accumulate where salts accumulate is highly mobile in soils. Boron can be leached from soil by rainfall or irrigation leaching fractions. However, leaching can be difficult because B is often adsorbed onto soil particles, requiring about three times more water than higher soluble species such as Cl^- and Na^+. Stevens*et al.*, (2003) studied B in irrigation waters and soil in a reclaimed water system in South Australia. Reclaimed water from the scheme had a higher concentration of B (average of 0.36 mg/L). In the subsoil, irrigation with reclaimed water led to decreases in B concentration and probably a result of B leaching.

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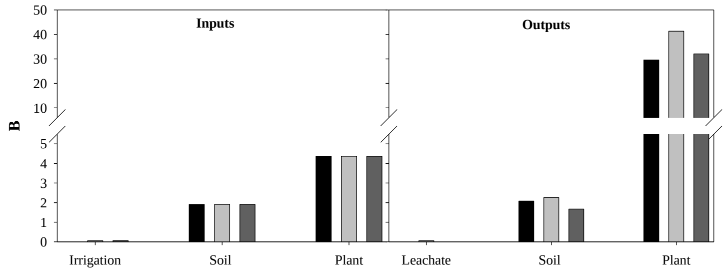

Fig. 4: Mass Balance ofBoron **(**B) in mg/week.

Physical analysis of Turf Grass Growth:

The height of turf grasswas observed to be higher in LGW at the start of the experiment (Figure**5**).It continued to grow until week 4 and then the height decreased gradually until the end of the study period. The height of the turf grass after being irrigated with BGW was higher than LGW, which it can reach 25 to 27 cm until 16-week of study. However, the growth of the turf grass was mostly affected after being irrigated with LGW with the maximum height of 22.5 cm in Week 8 before it decreased until the end of study period. The physical observation of turf condition is further illustrated in Figure**6**. Irrigation with LGW and BGW resulted in turf grass growing well for the first 2 months, but gradually dying off after 16 weeks, which may be due to insufficient nutrients to sustain the growth.

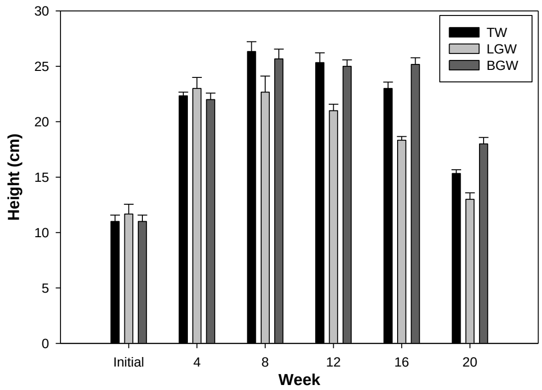

Fig. 5: Height of turf grass initially and after being irrigated with LGW, BGW and TW; mean of three replicates (± S.E.)

(a) After 4 week **(b)** After 8 week **(c)** After 16 week

Fig. 6: Turf grass growth in untreated laundry (LGW) tanks.

Conclusion:

Irrigation of turf grass with laundry (LGW) and bathtub (BGW) was shown a significant reduction in infiltration rate by LGW (13.48 m/day), followed by BGW (16.29 m/day) after sequence irrigation indicating the potential salt accumulation in soil. There was an increase in salt content (Na, Cl) in after irrigated with LGW and BGW, but it is obvious increment in LGW with the concentration of 160 mg/week and 480 mg/week, respectively. The level of B uptake was increased in turf grass growth irrigated with LGW of 40 mg/week. This was particularly evident that high salt content affected the turf grass and soil stability. It is suggested that irrigation with LGW in particular needs nutrient adding in fertilization management to sustain the turf growth.

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