An assessment of the drainage quality and quantity associated with recycled wastewater irrigation in an urban park

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Abstract

Quantification of drainage to remove excess water from the soil profile and provide a suitable environment for vegetation has been developed over the years. Drainage estimation is fairly challenging particularly in the heterogeneous urban environs. This research studied the temporal variation of drainage rate and nutrient leaching in Veale Gardens of Adelaide Parklands, Australia. A zero tension pan lysimeter was installed in an urban mixed vegetation park to study the quantity and quality of leachate solute. EM38 soil mapping and spatial analysis allowed mapping of two EC zones. Temporal changes of volume and characteristics of drained water were studied in the low EC zone for two seasons of summer and winter. The outcomes showed that the volume of drained water in the summer time was considerably less than in the winter time. This is likely to be the cause of the winter dormancy in most plants and evapotranspiration reduction in winter time. Chemical analyses of leachate solute showed a significant drop in the values of EC, potassium, total N, total P, and ionic balance from summer to winter despite a large increase in SAR. In terms of nutrient loading during the study period, this work has shown that there would be very little impact from using recycled waste water compared to conventional water sources.

Keywords

Drainage; pan lysimeter; mixed vegetation; soil water monitoring

INTRODUCTION

Quantification of drained water and comprehensive analyses of solute transfer in the effective vegetation root zone have been investigated over recent years, but as yet there are no standard techniques in either case. Estimating drainage requires in-situ soil water collection from undisturbed soil which is quite challenging particularly in heterogeneous landscape environments. High variation in plant species, age, height, density and microclimate in urban vegetation strongly influence the spatial and temporal variability of soil water characteristics and soil water accessibility. This introduces more complexity and uncertainty in the drainage rate and solute leaching. But it should be noted that in-situ sampling is not spatially representative of a large area so the results are often restricted to small observation sites such as plots or small fields. The impact of available soil water sampling systems on vadose zone behaviour increases the uncertainty in selecting a representative sample (Peters and Durner 2009). This is even more problematic in the mixed vegetation of urban green spaces (Nouri et al. 2012). A number of strategies for sampling have been introduced and tested over the last few decades (Hangen et al. 2005, Moreno-Jiménez et al. 2011, Parizek and Lane 1970, Yoo 2001). Weihermuller et al. (2007) reviewed six techniques for in-situ soil water extraction including porous caps, porous plates, capillary wicks, lysimeters and resin boxes. The suitability of each device depends on the research goals, experimental design, cost, maintenance requirements and safety.

In this study, in order to measure the quantity and quality of captured water from drainage, zero tension pan (also known as equilibrium-tension) lysimeters were selected. This was due to the advantages of pan lysimeters compared to other methods, including low complexity design, inexpensive to construct and install, reduced disturbance of the soil during installation, and simple and cheap operation (Zhu et al. 2002). The zero tension lysimeter is a passive sampler in a pan shape, without large side walls, that freely collect the drained water, measuring drainage volume and solute leaching simultaneously below an undisturbed soil column (Weihermuller et al. 2007, Zhu et al. 2002, Robison et al. 2004). It minimizes the surrounding matric potential fluctuations and potential bypass flow resulting in the conservancy of natural and regular percolation patterns (Lehr et al. 2005). Different materials of stainless steel, glass, or ceramic can be used to make a tray.

The lysimeter is typically placed under the ground either at a shallow or deep depth, depending on the effective root zone of the plant (Donn and Barron 2012, Barron and Donn 2010). The filling material of the tray has substantial impact on the water potential gradient and water bypass (Weihermuller et al. 2007). The main sources of errors in pan lysimeters are from diversion in water flow around the lysimeter as well as the complexity of installation.

This research studied the temporal variation of drainage rate and solute leaching in a public park containing heterogeneous urban landscape vegetation. A pan lysimeter was designed and installed. The field monitoring was undertaken for two the seasons of summer and winter. The rate of nutrient removal by leaching is investigated in order to propose an effective urban landscape management regime.

MATERIALS AND METHODS

Of some concern is the nutrient leaching from drainage into ground water that possibly percolate excessive nutrient to the ground water table. This is even more critical when reclaimed waste water is used for irrigation, as it is in Veale Gardens. Potential ground water salination is another concern.

Study area

Field monitoring was undertaken at Veale Gardens within the Adelaide Parklands in the southeast of the city of Adelaide in South Australia. Veale Gardens has an area of 9.6 ha and is irrigated with recycled waste water. The park is fully covered by well-established Kikuyu turf grass; a dominant species in most parks due to its adaptability and invasiveness (Tanji et al. 2007). The park also contains more than 60 native and exotic tree and shrub species, predominantly Eucalyptus, Acacia and Poplar. Thirty years of meteorological records for Adelaide (1981-2010) collected by the Australian Bureau of Meteorology (BOM) show that Adelaide experiences warm summers (December–February) with a mean maximum temperature of 29.5ºC in February. Adelaide also experiences fairly cold winters (June–August), with a mean minimum temperature of 7.5ºC in July. The long-term average annual precipitation is approximately 549.1 mm with an average of 128 rainy days in a year and 1600 mm of pan evaporation per annum (BOM 2010).

Experimental design

EM38 soil mapping was employed for the preliminary soil survey. The results enabled the development of an EC soil map using geostatistical analysis in GS+ and spatial mapping through ArcGIS. Two bores were drilled down to 2 m and intact core (50 mm internal diameter) samples were extracted in October 2011. Standard methods were followed for sample preparation, packaging, labelling and storage. Soil samples were tested for texture, EC, pH and some nutrients. The effect of pH on nutrient availability was investigated based on the Figure. 1.

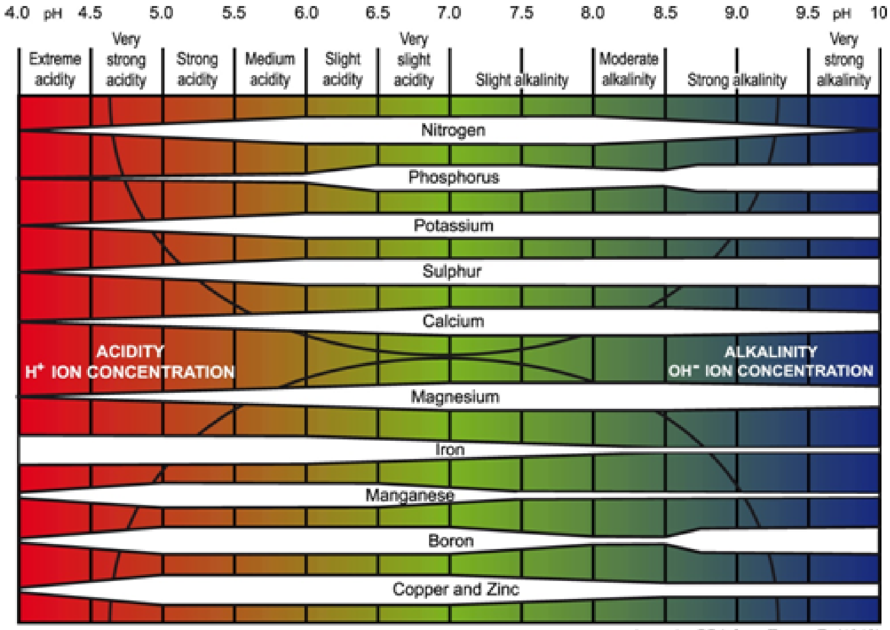

Figure 1. The effect of pH on nutrient availability (after Goatley, 2011)

Lysimeter installation

The method of installation of the lysimeter involved the excavation of a trench with a backhoe down to 150 cm depth which is mostly below the effective root zone of the available plants. A small cavity or hole of 120 cm × 55 cm × 30 cm was excavated in the long side wall of the trench with a horizontal distance of 100 cm from the edge of the trench. The cavity was precisely levelled in all five walls to prevent adding tension to the system. A galvanized tray of 120 cm × 55 cm with geotextile on top was precisely jacked up and fitted to the upper wall of the cavity in order to adequately maintain the capillary connection of the tray and soil above. The drainage collection bucket was placed at the base of the trench at a depth of 150 cm and a rigid PVC pipe connected the lysimeter tray to the collection bucket. The drained water was collected in the buried bucket through a rigid PVC pipe and two access tubes. To complete installation of the lysimeter, a plastic sheet was placed on the long side wall of the trench to protect the cavity from damage and to ensure separation of the undisturbed and disturbed soil. The backfilled soil was compacted by a leg rammer in layers to prevent soil subsidence (Figure 2). The collected water in the buried bucket and lysimeter pan was regularly extracted by a vacuum hand pump through access tubes.

Figure 2. Lysimeter installation

The experiment was performed on a zero tension lysimeter placed horizontally 100 cm below ground level to monitor the temporal behaviour of drained water. The drainage quantity and quality were measured from December 2011 to February 2012 (summer) and from June to August 2012 (winter). The leachate solute of the drained water was analysed for certain chemical characteristics including pH, SAR, potassium, nitrite, nitrate, total nitrogen, total phosphorus, and ionic balance. The importance of macronutrients (N, P, and K) is due to their important role in plant function. Nitrogen is a component of protein and enzymes and controls almost all biological processes. Phosphorus is responsible for energy transfer in the plant, plant development, and photosynthesis. Potassium regulates the water usage of plant and their resistance to diseases. The SAR measures the ratio of sodium to calcium and magnesium ions and can be used to evaluate the effect of irrigation on soil structure (Goatley 2011). Ionic balance represents the characteristics of the water in terms of principal dissolved salts.

The required nutrients for landscape plants vary widely due to the broad numbers of species of trees, shrubs and turf grasses. For instance, turf grasses need a large amount of nitrogen for green growth while most flowering plants need more potassium and phosphorus (Tanji et al. 2007). Optimum nutrient balances yield acceptable vegetation healthiness as well as assisting in water conservation.

RESULTS AND DISCUSSION

Soil characteristics

EM38 soil mapping and spatial analysis produced a soil zoning map for Veale Gardens. Two different zones of low and high EC are illustrated in Figure 3.

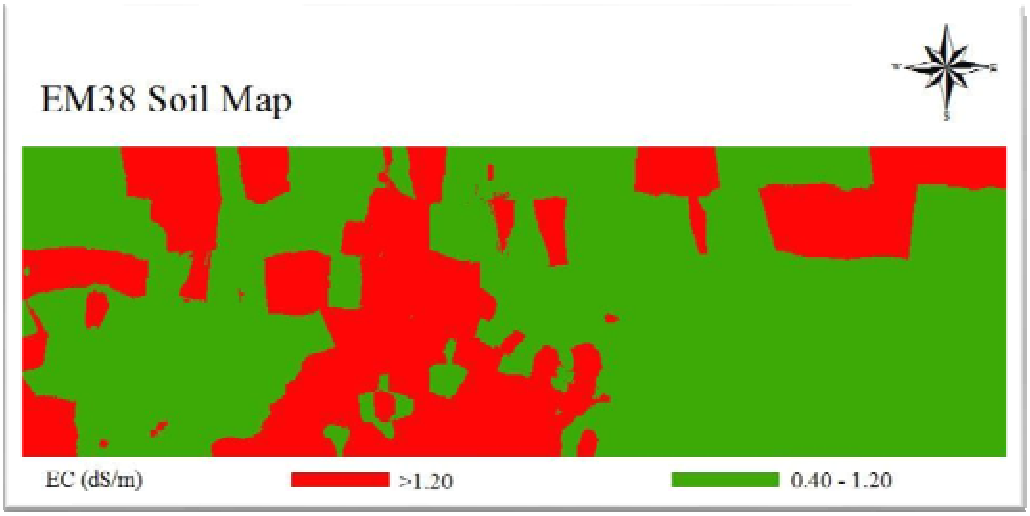

Figure 3. EM 38 soil map of the Veale Gardens and position of lysimeter

A point in the low EC zone was marked in the field and later tested by a service locator company to ensure there was no conflict with existing assets and services, particularly irrigation pipes. Soil samples taken from two bores immediately adjacent to the lysimeter showed a texture of silty clay loam from the ground to 150 cm and silt loam form 150 to 200 cm depth with a pH range of 8.0 to 8.5 and EC less than 1.2 ds/m. These results correspond well to an existing SA Water report (Martin et al. 2008). Goatley (2011) indicated that loamy texture is the most ideal soil for most turf grasses and landscapes to ensure adequate water accessibility and aeration. Moreover, moderate soil pH (6.5-7.5) provides a suitable environment for optimum biological activity and nutrient availability, particularly for potassium and phosphorus.

Soil water characteristics

The volume of the drained water was recorded monthly. Table 1 shows the volume of drained water in summer 2011-12 and winter 2012. Irrigation data were provided by Adelaide City Council (ACC), who manages Veale Gardens. Rainfall data for the nearest station (Kent Town, Station 023090) were downloaded from the Australian Bureau of Meteorology (BOM). Station 023090 is located on the east side of the city, 2.92km from Veale Gardens (http://www.bom.gov.au/climate/data/).

Table1. Records of drained water from the lysimeter and input water (Litres)

	Summer	Winter
Irrigation	198.67	0
Rainfall	37.44	157.36
Input water (irrigation + rainfall)	236.11	157.36
Volume of drainage	0.8	123.6

Water samples were sent to a NATA accredited laboratory for water quality analysis. The drained water was analysed for pH, SAR, potassium, nitrite, nitrate, total nitrogen, total phosphorus, and ionic balance. The results of the laboratory tests are shown in Table 2.

Table 2. Water quality in summer and winter

Water characteristics	Unit	Summer	Winter
pH	pH Unit	7.3	7.41
SAR	-	21.7	46.89
EC	ds/m	4.82	2.10
Potassium	mg/L	19	12
Nitrite as N	mg/L	<0.01	<0.01
Nitrate as N	mg/L	0.06	<0.01
Total Nitrogen	mg/L	1	<0.1
Total Phosphorus	mg/L	0.26	0.03
Ionic Balance	%	5.28	4.02

CONCLUSIONS

Considering the fact that input water from irrigation and rainfall to the field decreased from summer to winter, the volume of drained water in the summer time was considerably less than in winter time. The ratio of drainage water to the total input water varied from 0.34% in summer to 78.55% in winter. This indicates that in summer most input water fulfils plant water needs through evapotranspiration while in winter as a consequence of the dormancy in most plant species, the evapotranspiration rate decreases significantly which results in a very low leachate fraction in summer compared to winter. Moreover, in summer, 84% of the total input water was reclaimed wastewater applied by irrigation. This resulted in a significant increase in most nutrient concentrations in the leachate (Figure 4).

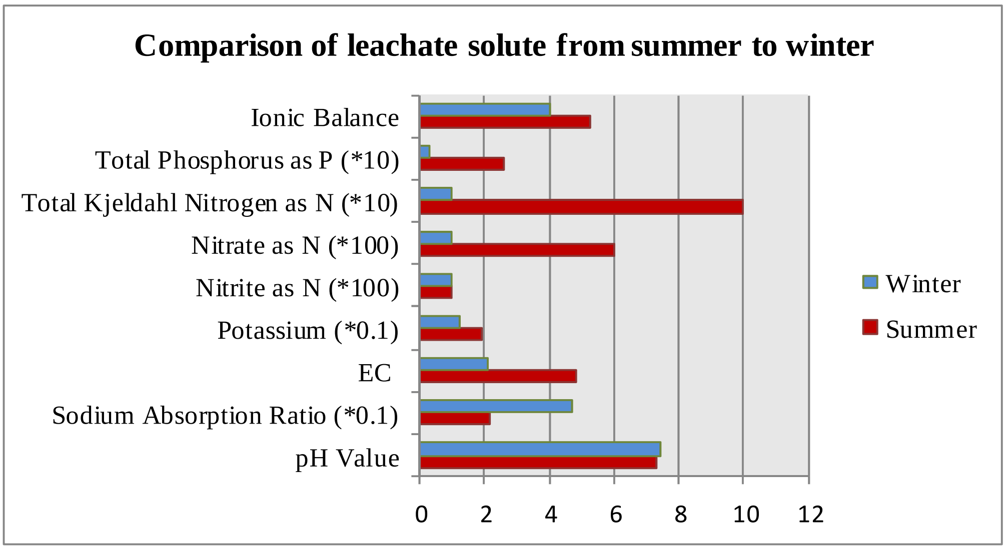

Figure 4. Seasonal changes in water quality

The seasonal nutrient loading through leachate solute is illustrated in Table 3. The results showed a significant decrease in the values of nutrient loading from winter to summer; TDS (98.8%), total N (93.5%), total P (94.4%), potassium (99%), nitrite (99.4%) and nitrate (96.1%). Considering the sources of drained water that varied from rainfall and recycled waste water in summer to only rainfall in winter showed a minimal role of recycled waste water in nutrient loading to the ground water.

Table 3. Nutrients loading through drained water

Load of nutrients (gr)	TDS	K	Nitrite	Nitrate	Total N	Total P
Summer	2504	15.2	0.01	0.05	0.8	0.21
Winter	216300	1483.2	1.24	1.24	12.4	3.71

In summary, a proportion of the input water from irrigation and rainfall was not used by plants and passed through the root zone carrying nutrients into the ground water. This could potentially be a matter of concern when reclaimed waste water is a main source of irrigation water (Tanji et al. 2007). However in Veale Gardens no irrigation with wastewater occurs in winter. Understanding of nutrient removal from soil by leaching can result in a more effective urban landscape management regime. In Veale Gardens, it is anticipated that the alkalinity of the soil results in lower availability of nitrogen and phosphorus but has no effect on potassium availability. The risk of nutrient loading resulting from irrigation with recycled waste water was investigated. The outcomes showed a minimal impact from use of recycled waste water in terms of nutrient loading to the ground water for the study period.

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