



**Drainage in
heterogeneous urban
vegetation
environments**

H. Nouri et al.

Spatial and temporal distribution of drainage and solute leaching in heterogeneous urban vegetation environments

H. Nouri¹, S. Beecham², A. M. Hassanli³, and G. Ingleton⁴

¹Centre for Water Management and Reuse, University of South Australia, Adelaide, 5095 SA, Australia

²School of Natural and Built Environments, University of South Australia, Adelaide, 5095 SA, Australia

³Shiraz University and Centre for Water Management and Reuse, University of South Australia, Adelaide, 5095 SA, Australia

⁴Recycled Water in SA Water Corporation, Adelaide, 5095 SA, Australia

Received: 13 May 2013 – Accepted: 14 May 2013 – Published: 29 May 2013

Correspondence to: H. Nouri (hamideh.nouri@unisa.edu.au, hamideh.nouri@mymail.unisa.edu.au)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

Deep percolation enhancement from recycled wastewater irrigation may contribute to salt accumulation and water table elevation that can ultimately cause soil and ground water degradation. The spatial and temporal variation of drainage rate and solute leaching were investigated in an urban park containing heterogeneous landscape plants that were irrigated with recycled wastewater. Field monitoring was undertaken at Veale Gardens in the Adelaide Parklands, Australia. Based on the landscape variation in Veale Gardens, two landscape zones were defined: one being largely covered with turf grasses with few trees and shrubs (MG) with the second zone being mostly trees and shrubs with intermittent turf grasses (MT). Experiments were performed using two zero-tension lysimeters placed horizontally 100 cm below ground to monitor the spatio-temporal behaviour of drained water and nutrient loadings for four seasons. The outcomes showed a large spatial and temporal variation of drainage quantity and quality in the MT and MG zones. The low vegetation cover in the MG zone resulted in more drained water than in the high vegetation cover (MT zone). In both zones, more drainage water was collected in winter than in other seasons. This is in spite of the input water showing a maximum rate in summer. The seasonal salinities measured in the two lysimeters showed very similar trends with the lowest salinity rate in autumn with the levels increasing through winter and spring. Chemical analyses of the leachate solute indicated no detrimental impact from using recycled wastewater during the study period.

1 Introduction

Most soils in urban green spaces have lost their natural horizons and morphological features, and quite often top soils have been removed and refilled (Jim and Chen, 2008; De Kimpe and Morel, 2000). As a result, the spatial heterogeneity of soil physical, chemical, and biological characteristics is generally higher than for native soils.

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Insufficiencies and obstacles in understanding soil conditions undermine a sound judgement of urban soils (Jim, 1998). Improving the knowledge of soil biochemical properties assists in understanding nutrient cycling in urban soils (Lorenz and Kandeler, 2005) and subsequently prevents either inadequate or excessive input applications e.g. fertilization (Rosen et al., 2008). Lassaletta et al. (2012) concluded reducing surplus N fertilization as the most promising management system.

It is of interest to study drainage rates and solute transfers beyond the effective plant root zone since this can help in understanding the soil water balance status, availability of nutrients in the leachate as well as the risk of nutrient loading to the ground water. Appropriate interpretation of water and soil test results is subject to collecting representative water and soil samples. The choice of sampling method of drained water is of great importance. Several studies have been conducted in agriculture and forestry that may provide useful information for urban soil studies (Jim, 1998). 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 mixed vegetation urban green spaces (Nouri et al., 2012). High spatial and temporal variability of vegetation species, canopy covers and microclimates in urban landscape vegetation leads to a high variability of soil water characteristics and soil water accessibility. This introduces more complexity and uncertainty in quantification of drained water and nutrient leachate. Soil water sampling from undisturbed soil in a heterogeneous landscape environs with the purpose of systematic investigation of quantity and quality of drainage can be achieved by in-situ soil water collectors. However, it should be noted that in-situ sampling may not be spatially representative of a large area so the results are often restricted to small observation sites such as plots or small fields.

Investigation of nutrients in drained water has been undertaken since around 1850. A number of techniques and geometries of leachate collection devices have been tested and reviewed over recent decades (Hangen et al., 2005; Moreno-Jiménez et al., 2011; Parizek and Lane, 1970; Yoo, 2001; Weihermuller et al., 2007). The most

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

common inexpensive approaches are soil coring, suction cup (Hagedorn et al., 1999), suction plate (Kosugi and Katsuyama, 2004), wick lysimeter (Jabro et al., 2008), and zero-tension plate lysimeter (Peters and Durner, 2009; Robison et al., 2004). These studies have demonstrated the importance of soil profile characteristics in determining the infiltration rate of irrigation and/or precipitation as well as nutrient mobilization. An undisturbed soil profile can retain the natural soil structure (Goss et al., 2010) but disturbed soil can introduce artificial soil properties and changes in some natural conditions such as water paths and solute movements (Cameron et al., 1992). Of some concern is nutrient leaching beyond the root zone into ground water, which can potentially lead to ground water pollution (Goss et al., 2010). This is even more critical when recycled wastewater is used for irrigation (Tanji et al., 2007). There are numerous benefits in using recycled water for irrigation, including the low cost (when compared to other sources, particularly in an urban area), consistency of supply (regardless of season, climatic conditions and associated water restrictions), and general consistency of quality. Irrigation of recycled wastewater is also considered as a means for plant fertilization and particularly nutrient supplementation. This approach carries with it a risk of soil and water pollution through excessive wastewater application (Pandey and Srivastava, 2010). Hence, a detailed understanding of soil water conditions is essential for effective utilization of wastewater for irrigation.

This paper describes a field investigation using zero-tension pan (also known as equilibrium-tension) lysimeters. This was due to the advantages of pan lysimeters compared to other methods, including low complexity of design, 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 collects the drained water, measuring drainage volume and solute leaching simultaneously below an undisturbed soil column (Weihermuller et al., 2007; Robison et al., 2004; Zhu et al., 2002). It minimizes the surrounding matric potential fluctuations and potential bypass flow resulting in the conservancy of natural and regular

percolation patterns if sprinkler irrigation is uniformly applied in an area larger than the lysimeter area (Lehr et al., 2005).

Different materials such as stainless steel, glass or ceramic can be used for the collection 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 fill material in the tray has a substantial impact on the water potential gradient and water bypass (Weihermuller et al., 2007). The main sources of errors in pan lysimeters derive from diversion in water flow around the lysimeter as well as the complexity of installation.

This research is focused on the seasonal variation of drainage and solute leaching in a public park containing heterogeneous urban landscape vegetation that was irrigated with recycled wastewater. Two pan lysimeters were designed and installed in two different landscape zones. The field monitoring was undertaken for four seasons from December 2011 to November 2012. The outcomes were compared to study the effect of landscape vegetation changes on the spatio-temporal behaviour of drained water and nutrient availability in the leachate. Moreover, the volume of drainage was measured for the purpose of developing a detailed soil water budget for the study site. The rate of nutrient removal by leaching was investigated in order to propose an effective urban landscape management regime.

2 Materials and methods

2.1 Study area

The study was carried out in Veale Gardens within the Adelaide Parklands, South Australia (Fig. 1). Veale Gardens has an area of 9.6 hectares irrigated by treated (recycled) wastewater from the Glenelg wastewater treatment plant that is delivered to the Adelaide Parklands through the Glenelg to Adelaide Parklands (GAP) scheme. GAP

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

recycled water is subject to strict quality standards and has been assessed as class A recycled wastewater (Martin et al., 2008).

Adelaide has a mean annual rainfall of 549 and 1600 mm of pan evaporation per annum (BOM, 2010). It experiences warm summers (December–February) with a mean maximum temperature of 29.5 °C in February and fairly cold winters (June–August) with a mean minimum temperature of 7.5 °C in July.

Veale Gardens contains more than 60 different species, size, and type of landscape trees and shrubs and a broad coverage of Kikuyu turf grasses. Kikuyu is a dominant species in most Australian parks due to its adaptability and invasiveness (Tanji et al., 2007). There were two types of vegetation cover on the site consisting of areas dominated by grasses and areas dominated by a mixture of different species of trees and shrubs accompanied by grasses.

A preliminary soil survey was conducted using EM38 soil mapping that provided rapid field measurement of apparent electrical conductivity (Hossain et al., 2010; Padhi and Misra, 2011). This enables development of an Electrical Conductivity (EC) soil map through geostatistical analysis in ArcGIS (Rodríguez Martín et al., 2006; Sarangi et al., 2006; Huang et al., 2013; Li et al., 2012). In October 2011, adjacent to each lysimeter, two bores were drilled down to 2 m and two intact core samples (50 mm internal diameter) were extracted for soil physical and chemical analysis. Standard methods were followed for sample preparation, packaging, labelling and storage (Handreck and Black, 2002). Based on the soil EC map, soil sample analysis and landscape variation in Veale Gardens, two different zones of low and high EC and two landscape zones of mostly grasses with few trees and shrubs (MG) and mostly trees and shrubs covered with intermittent grasses (MT) were defined. The experiments were performed on two zero tension lysimeters containing undisturbed soils placed horizontally 100 cm below ground to study the volume and quality of drainage as a function of time and space in two zones of MT and MG. In this study, in order to minimize the effect of spatial heterogeneity of soil salinity on the outputs in the initial stage of field work, the experiment was run in the low EC zone (less than 1.2 dS m⁻¹).

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract Introduction

Conclusions References

Tables Figures

⏪ ⏩

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2.2 Zero-tension lysimeter design and installation

The method of installation of the zero-tension lysimeter involved the excavation of a trench with a backhoe down to a depth of 150 cm which is mostly below the effective root zone of the plants (Fig. 2a). A small cavity of dimensions 120 cm × 55 cm × 30 cm was excavated in the long side wall of the trench at a horizontal distance of 100 cm from the edge of the trench (Fig. 2b). The cavity was precisely levelled in all five walls to prevent adding tension to the system (Fig. 2c). A galvanized metal tray of size 120 cm × 55 cm with geotextile on top (Fig. 2d) 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 above lying soil (Fig. 2e). 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 (Fig. 2f). The drained water was collected in the buried bucket through a rigid PVC pipe and two access tubes (Fig. 2g). 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 (Fig. 2h). The backfilled soil was compacted by a leg rammer in layers to prevent soil subsidence (Fig. 2i).

The leachate was collected in buckets below the drainage compartments and was regularly extracted from the buckets to the flask by a vacuum hand pump (Fig. 3). The volume and salinity of collected water in each bucket was measured monthly during the period December 2011 to November 2012.

3 Results and discussion

3.1 Field and laboratory measurement of soil properties

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 Fig. 4. Two positions in the low

HESSD

10, 6695–6721, 2013

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

A high spatial variation in drainage rate was noted over the monitoring period in both MG and MT. The differences in lysimeter performance mainly could be related to the heterogeneity of vegetation or/and soil characteristics. The variation in landscape plants will have led to differences in evapotranspiration, canopy interception rates and root distribution. Root distributions in the MT zone were denser and deeper due to its mix of trees, shrubs and turf grasses and this will have led to higher moisture uptake rates. These results are in line with those of Cattán et al. (2007) and Naeth et al. (2011) who investigated the spatial variability of percolation fluxes in heterogeneous vegetation covers. In terms of soil characteristics, a higher percolation rate and lower available water capacity was expected in the sandy loam soil (MT) compared to the silty loam soil (MG). However, the results indicated a minimal effect on drainage variations from the different soil properties compared to the much stronger influence of vegetation heterogeneity.

A strong positive correlation coefficient of 0.90 was found between drainage rate collected from MG and MT. This confirms that they had a similar trend of drainage volume within the four seasons of the study period (Fig. 5).

Remarkably, the minimum drained water was collected in summer in both lysimeters. Also, the maximum input water, aggregated from irrigation and rainfall, was observed in summer which means that plant uptake of water was very high in this season particularly in the MT zone. 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 an increased leachate fraction in winter.

3.3 Water quality of solute leaching

The differences in drainage rates associated with variation in vegetation landscape zones lead to differences in leachate solute quality. The electrical conductivity of each water sample was measured using an EC meter to quantify the salinity of solute

leaching within the study period. The salinities were tested monthly and the seasonally, and averaged values are reported in Table 3.

A comparison of seasonal salinity for zones MG and MT indicated a strong positive correlation ($R = 0.97$) with the lowest salinity in autumn for both lysimeters. No correlation was found between seasonal drainage volume and seasonal salinity in either lysimeter.

Drained water quality and nutrient availability was analysed for each season for certain chemical characteristics including pH, EC, Sodium Adsorption Ratio (SAR), Total Dissolved Solids (TDS), potassium, nitrite, nitrate, total nitrogen, total phosphorus, and ionic balance. Soil pH was monitored with an automated system (PC Titrate) using pH 4.5 for indicating the total alkalinity end-point. Soil salinity and TDS were determined in an aqueous extract of a 1 : 5 soil-water suspension at 25 °C using an EC meter. Total phosphorus was measured using a Discrete Analyser. Nitrate was reduced to nitrite by way of a cadmium reduction column followed by quantification by the Discrete Analyser. Nitrite was determined separately by direct colorimetry. Total N was analysed using a traditional Kjeldahl digestion followed by determination by Discrete Analyser. The Ionic Balance was calculated based on the major Anions and Cations. The major anions were determined using the PC Titrate and Discrete Analyser. Major cations were measured using an inductively coupled plasma atomic emission spectroscopy (National Environment Protection, NEPM – Assessment of Site Contamination, 1999).

The importance of macronutrients (N, P, and K) is due to their fundamental role in plant functionality. Nitrogen is a component of protein and enzymes and controls almost all biological processes (Arauzo et al., 2010; Rafizul and Alamgir, 2012). Phosphorus is responsible for energy transfer in the plant, plant development, and photosynthesis (Djodjic et al., 2000). Potassium regulates the water usage of plants and their resistance to diseases (Kolahchi and Jalali, 2007). 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

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



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).

The drained water samples were sent to a NATA accredited laboratory (National Association of Testing Authorities, Australia) for water quality analysis. The results of the laboratory tests are shown in Fig. 6 with each column representing the average of two samples. For zone MT, the amount of collected leachate was too small to allow an accurate nutrient analysis. However, water salinity was measured in a diluted sample in the MT zone (Fig. 3). Figure 6 shows the water quality analysis for the MG zone. Hence, investigation of the temporal variation of all water quality parameters apart from salinity was not possible in MT zone.

The recommended practical long-term trigger concentration levels for Adelaide Parklands irrigation (ANZECC and ARMCANZ, 2000) are 54.5 mgL^{-1} for Total N, 6.8 mgL^{-1} for Total P and 29.5 mgL^{-1} for K. From a comparison of the results in Fig. 6 with these trigger values, it can be concluded that there is little risk of nutrient (N, P and K) build up or nutrient contamination of ground or surface waters. These results are consistent with findings of a previous SA Water Corporation study (Martin et al., 2008).

3.4 Cumulative nutrient leaching

The distribution variation of drained water creates fertigation variability. Precision irrigation and fertigation management necessitates considering the spatio-temporal variability of leachate volume and characteristics that are associated with variation of nutrient loading. The seasonal nutrient leaching in zone MG is illustrated in Fig. 7.

The cumulative nutrient loadings (g) were calculated using nutrient loading rates (mgL^{-1}) in a total volume of drained water in a season (L). The results showed the highest nutrient loadings were in either winter or spring. The sources of drained water were rainfall in all four seasons and recycled wastewater in spring, summer and autumn. Therefore irrigation should not have influenced nutrient loading to the ground water during the winter season. For the rest of the year, the main source of the total input

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



water was recycled wastewater applied by irrigation. However, the measured loading rates were less than long-term safe trigger levels for nutrients. The seasonal variation of leached nutrients through drainage in Veale Gardens is presented in Table 4. These results will be useful for park management, particularly for formulating fertilization schedules.

4 Conclusions

This study has examined the spatial and temporal variation of drainage quantity and quality in a heterogeneous urban vegetation environment. Differences in vegetation landscape cover lead to variations in evapotranspiration and canopy interception rates as well as differences in depth, density and distribution of vegetation roots. This is likely to be the cause of the higher drainage collection rates in the low vegetation cover (MG) zone compared to the high vegetation cover in the MT zone, which contained dense trees and shrubs and intermittent turf grasses. The results of the soil physical analysis indicated a minimal effect from differences of soil properties compared to the much stronger influence of vegetation heterogeneity on drainage variations. This is in contrast with the finding of Wohlfart et al. (2012) that found that soil properties are the strongest factors explaining heterogeneity of nutrient loading.

However, investigation of the seasonal variation in drained water quantity showed similar trends in both lysimeters with the highest drainage rate in winter time. This trend is despite the maximum rate of input water which was collected in summer. As expected, in summer most input water fulfils plant water needs through evapotranspiration while in winter as a consequence of dormancy in most plants, the evapotranspiration rate decreases markedly, which results in a higher leachate fraction in winter. Interestingly, there was no relation between seasonal drained water volume and seasonal salinity rates in either of the lysimeters.

The input water from irrigation and rainfall not used by plants and passed through the root zone may carry some nutrients into the ground water. This could potentially be

HESSD

10, 6695–6721, 2013

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

- Cattan, P., Voltz, M., Cabidoche, Y. M., Lacas, J. G., and Sansoulet, J.: Spatial and temporal variations in percolation fluxes in a tropical Andosol influenced by banana cropping patterns, *J. Hydrol.*, 335, 157–169, doi:10.1016/j.jhydrol.2006.11.009, 2007.
- De Kimpe, C. R. and Morel, J.-L.: Urban soil management: a growing concern, *Soil Sci.*, 165, 31–40, 2000.
- Djordjic, F., Ulén, B., and Bergström, L.: Temporal and spatial variations of phosphorus losses and drainage in a structured clay soil, *Water Res.*, 34, 1687–1695, doi:10.1016/S0043-1354(99)00312-7, 2000.
- Goatley, M.: *Urban Nutrient Management Handbook*, edited by: Hoffman, B. A. and Guinn, L., Virginia Cooperative Extension, Virginia State, 2011.
- Goss, M. J., Ehlers, W., and Unc, A.: The role of lysimeters in the development of our understanding of processes in the vadose zone relevant to contamination of groundwater aquifers, *Phys. Chem. Earth*, 35, 913–926, doi:10.1016/j.pce.2010.06.004, 2010.
- Hagedorn, F., Mohn, J., Schleppei, P., and Fluhler, H.: The role of rapid flow paths for nitrogen transformation in a forest soil: a field study with micro suction cups, *Soil. Sci. Soc. Am. J.*, 63, 1915–1923, 1999.
- Handreck, K. A. and Black, N. D.: *Growing Media for Ornamental Plants and Turf*, UNSW Press, Australia, 560 pp., 2002.
- Hangen, E., Gerke, H. H., Schaaf, W., and Hüttl, R. F.: Assessment of preferential flow processes in a forest-reclaimed lignitic mine soil by multicell sampling of drainage water and three tracers, *J. Hydrol.*, 303, 16–37, doi:10.1016/j.jhydrol.2004.07.009, 2005.
- Hossain, M. B., Lamb, D. W., Lockwood, P. V., and Frazier, P.: EM38 for volumetric soil water content estimation in the root-zone of deep vertosol soils, *Comput. Electron. Agr.*, 74, 100–109, doi:10.1016/j.compag.2010.07.003, 2010.
- Huang, L., Wang, H., Li, Y., and Lu, S.: Spatial distribution and risk assessment of phosphorus loss potential in urban–suburban soil of Lishui, China, *Catena*, 100, 42–49, doi:10.1016/j.catena.2012.08.011, 2013.
- Jabro, J. D., Kim, Y., Evans, R. G., Iversen, W. M., and Stevens, W. B.: Passive capillary sampler for measuring soil water drainage and flux in the vadose zone: design, performance and enhancement, *Appl. Eng. Agric.*, 24, 439–446, 2008.
- Jim, C. Y.: Urban soil characteristics and limitations for landscape planting in Hong Kong, *Landscape Urban Plan.*, 40, 235–249, doi:10.1016/S0169-2046(97)00117-5, 1998.

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

- Jim, C. Y. and Chen, W. Y.: Pattern and divergence of tree communities in Taipei's main urban green spaces, *Landscape and Urban Plan.*, 84, 312–323, doi:10.1016/j.landurbplan.2007.09.001, 2008.
- Kolahchi, Z. and Jalali, M.: Effect of water quality on the leaching of potassium from sandy soil, *J. Arid Environ.*, 68, 624–639, doi:10.1016/j.jaridenv.2006.06.010, 2007.
- Kosugi, K. and Katsuyama, M.: Controlled-suction period lysimeter for measuring vertical water flux and convective chemical fluxes, *Soil Sci. Soc. Am. J.*, 68, 371–382, doi:10.2136/sssaj2004.3710, 2004.
- Lassaletta, L., Romero, E., Billen, G., Garnier, J., García-Gómez, H., and Rovira, J. V.: Spatialized N budgets in a large agricultural Mediterranean watershed: high loading and low transfer, *Biogeosciences*, 9, 57–70, doi:10.5194/bg-9-57-2012, 2012.
- Lehr, J., Keeley, J., Lehr, J., and Kingery, T. B.: *Water Encyclopedia: Ground Water*, John Wiley & Sons Inc., Hoboken, New Jersey, 2005.
- Li, H., Shen, W., Zou, C., Jiang, J., Fu, L., and She, G.: Spatio-temporal variability of soil moisture and its effect on vegetation in a desertified aeolian riparian ecotone on the Tibetan Plateau, China, *J. Hydrol.*, 479, 215–225, doi:10.1016/j.jhydrol.2012.12.002, 2012.
- Lorenz, K. and Kandeler, E.: Biochemical characterization of urban soil profiles from Stuttgart, Germany, *Soil Biol. Biochem.*, 37, 1373–1385, doi:10.1016/j.soilbio.2004.12.009, 2005.
- Moreno-Jiménez, E., Beesley, L., Lepp, N. W., Dickinson, N. M., Hartley, W., and Clemente, R.: Field sampling of soil pore water to evaluate trace element mobility and associated environmental risk, *Environ. Pollut.*, 159, 3078–3085, doi:10.1016/j.envpol.2011.04.004, 2011.
- Naeth, M. A., Chanasyk, D. S., and Burgers, T. D.: Vegetation and soil water interactions on a tailings sand storage facility in the athabasca oil sands region of Alberta Canada, *Phys. Chem. Earth*, 36, 19–30, doi:10.1016/j.pce.2010.10.003, 2011.
- Nouri, H., Beecham, S., Kazemi, F., and Hassanli, A. M.: A review of ET measurement techniques for estimating the water requirements of urban landscape vegetation, *Urban Water J.*, doi:10.1080/1573062x.2012.726360, in press, 2012.
- Padhi, J. and Misra, R. K.: Sensitivity of EM38 in determining soil water distribution in an irrigated wheat field, *Soil Till. Res.*, 117, 93–102, doi:10.1016/j.still.2011.09.003, 2011.
- Pandey, A. and Srivastava, R. K.: Role of dendropower in wastewater treatment and sustaining economy, *J. Clean. Prod.*, 18, 1113–1117, doi:10.1016/j.jclepro.2010.02.026, 2010.
- Parizek, R. R. and Lane, B. E.: Soil-water sampling using pan and deep pressure-vacuum lysimeters, *J. Hydrol.*, 11, 1–21, doi:10.1016/0022-1694(70)90111-3, 1970.

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

- Peters, A. and Durner, W.: Large zero-tension plate lysimeters for soil water and solute collection in undisturbed soils, *Hydrol. Earth Syst. Sci.*, 13, 1671–1683, doi:10.5194/hess-13-1671-2009, 2009.
- Rafizul, I. M. and Alamgir, M.: Characterization and tropical seasonal variation of leachate: results from landfill lysimeter studied, *Waste Manage.*, 32, 2080–2095, doi:10.1016/j.wasman.2012.01.020, 2012.
- Robison, W. L., Stone, E. L., and Hamilton, T. F.: Large plate lysimeter leachate collection efficiency for water being transported from soil to ground water, *Soil Sci.*, 169, 758–764, 2004.
- Rodríguez Martín, J. A., Arias, M. L., and Grau Corbí, J. M.: Heavy metals contents in agricultural topsoils in the Ebro basin (Spain), application of the multivariate geostatistical methods to study spatial variations, *Environ. Pollut.*, 144, 1001–1012, doi:10.1016/j.envpol.2006.01.045, 2006.
- Sarangi, A., Madramootoo, C. A., and Enright, P.: Comparison of Spatial Variability Techniques for Runoff Estimation from a Canadian Watershed, *Biosyst. Eng.*, 95, 295–308, doi:10.1016/j.biosystemseng.2006.06.002, 2006.
- Weihermuller, L., Siemens, J., Deurer, M., Knoblauch, S., Rupp, H., Gottlein, A., and Putz, T.: In situ soil water extraction: a review, *J. Environ. Qual.*, 36, 1735–1748, doi:10.2134/jeq2007.0218, 2007.
- Wohlfart, T., Exbrayat, J.-F., Schelde, K., Christen, B., Dalgaard, T., Frede, H.-G., and Breuer, L.: Spatial distribution of soils determines export of nitrogen and dissolved organic carbon from an intensively managed agricultural landscape, *Biogeosciences*, 9, 4513–4525, doi:10.5194/bg-9-4513-2012, 2012.
- Yoo, C.: Sampling of soil moisture fields and related errors: implications to the optimal sampling design, *Adv. Water Resour.*, 24, 521–530, doi:10.1016/s0309-1708(00)00033-6, 2001.
- Zhu, Y., Fox, R. H., and Toth, J. D.: Leachate Collection Efficiency of Zero-tension Pan and Passive Capillary Fiberglass Wick Lysimeters, *Soil Sci. Soc. Am. J.*, 66, 37–43, doi:10.2136/sssaj2002.3700, 2002.

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Table 1. Records of drained water from lysimeter MG and input water (mm).

Lys MG	Summer	Autumn	Winter	Spring
Seasonal drainage (mm)	1.33	24.75	206	95.51
Seasonal irrigation (mm)	331.11	123.8	0	177.28
Seasonal rainfall (mm)	78.8	160	262.7	53.7

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Table 2. Records of drained water from lysimeter MT and input water (mm).

Lys MT	Summer	Autumn	Winter	Spring
Seasonal drainage (mm)	0	0.022	25	0.025
Seasonal irrigation (mm)	403.27	150.82	20	215.91
Seasonal rainfall (mm)	78.8	160	262.7	53.7

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 3. Seasonal salinity of drained water from two lysimeters.

Salinity (dS m^{-1})	Summer	Autumn	Winter	Spring
Lys MG	4.82	1.33	2.1	2.96
Lys MT	NA*	0.85	1.14	1.91

* NA: not available.

HESSD

10, 6695–6721, 2013

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Table 4. Total drained (lost) nutrients in Veale Gardens through drainage (kg ha^{-1}).

Drained water characteristics	Summer	Autumn	Winter	Spring
TDS	41.7	213.8	3605.0	1833.6
Potassium	0.2533	2.7225	24.7197	9.5499
Nitrite	0.0002	0.0025	0.0207	0.0095
Nitrate	0.0008	0.0247	0.0207	0.0286
Total N	0.0147	0.0742	0.2067	0.5730
Total P	0.0035	0.0223	0.0618	0.1241

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

HESSD

10, 6695–6721, 2013

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

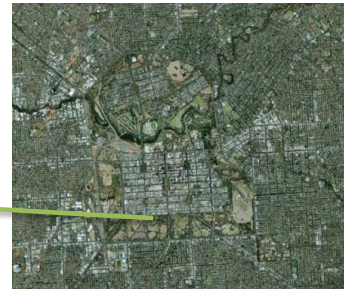


Fig. 1. Veale Gardens in the Adelaide Parklands.



2-a



2-b



2-c



2-d



2-e



2-f



2-g



2-h



2-i

Fig. 2. Pan lysimeter installation, **(a)** trench excavation, **(b)** cavity digging, **(c)** cavity levelling, **(d)** lysimeter tray, **(e)** placing the tray, **(f)** placing the collecting bucket and connect the tray and bucket by a PVC pipe, **(g)** PVC pipe and access tubes, **(h)** plastic sheet for protecting the cavity, **(i)** compacting the backfilled soil.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)





Fig. 3. Extracting water samples from a buried lysimeter.

HESSD

10, 6695–6721, 2013

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**Drainage in
heterogeneous urban
vegetation
environments**

H. Nouri et al.

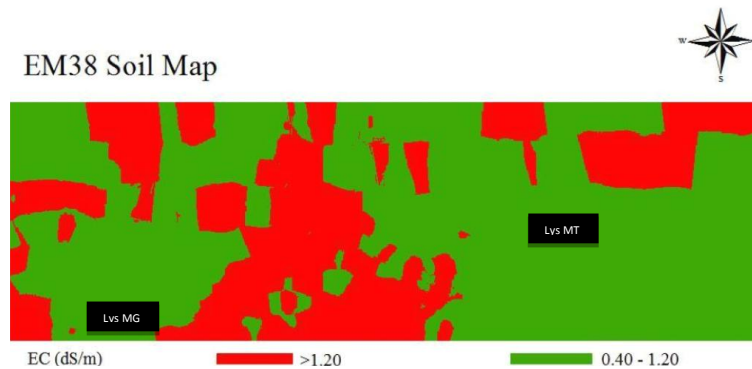


Fig. 4. EM 38 soil map of Veale Gardens showing lysimeter positions.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

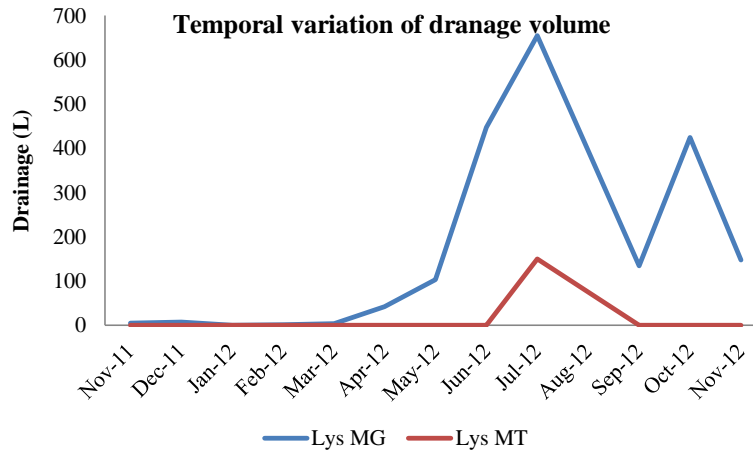


Fig. 5. Monthly variation of drainage in MG and MT zones.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

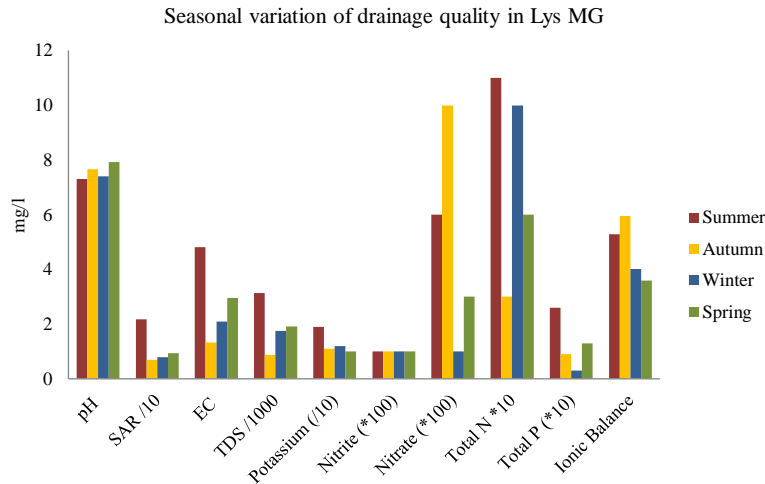


Fig. 6. Seasonal variation of solute leaching in zone MG.

[Title Page](#) | [Abstract](#) | [Introduction](#) | [Conclusions](#) | [References](#) | [Tables](#) | [Figures](#)

[⏪](#) | [⏩](#) | [◀](#) | [▶](#)

[Back](#) | [Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

Drainage in heterogeneous urban vegetation environments

H. Nouri et al.

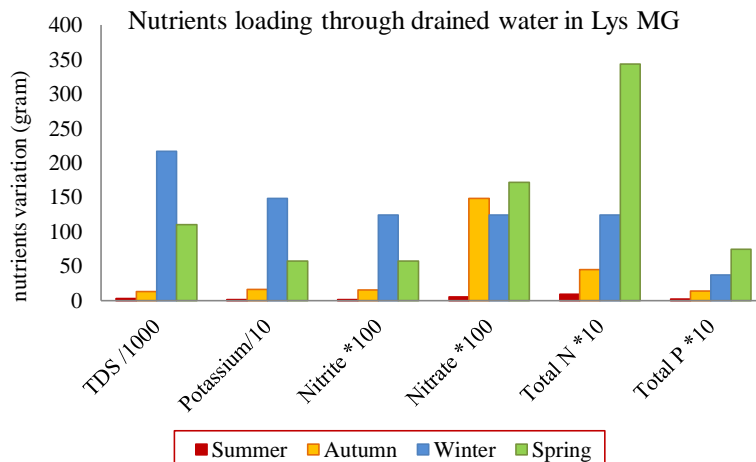


Fig. 7. Seasonal nutrient leaching through cumulative drainage.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)