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Does plant diversity in biofilters affect stormwater runoff quality and quantity?

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This nursery paper reports on the outcomes of a research trial that examined the effects of increased plant diversity (number of species) on the quality and volume of runoff from biofilters. Biofilters are small plantings incorporated into streetscapes and are used to remove pollutants such as metals, nutrients and sediments from stormwater. The purpose of the trial was to investigate whether biofilters with increased plant diversity, especially those which include monocots will be most effective at reducing stormwater volume and improving quality. This research was undertaken at The University of Melbourne by Prudence Hucker as part of her Honours degree in Natural Resource Management. Her research was supervised by Dr Claire Farrell and was made possible by direct funding from NGIA through the Nursery Industry Research & Development Levy.

Introduction

Urbanisation combined with large expanses of impervious surfaces (roads, roofs and pavement) results in increased stormwater runoff into urban waterways, causing them to become polluted (Chen et al. 2009; Davis et al. 2003). Stormwater may contain heavy metals, sediment and high levels of certain nutrients, which disrupt the ecological function of waterways (Dougherty et al. 2006 in Chen et al. 2009). In order to improve stormwater quality, water authorities have been incorporating technologies such as biofilters or raingardens (vegetated soil filters) into streetscapes across the USA and more recently in Australia (Davis et al. 2003; Somes and Crosby 2007; Kazemi et al. 2009).

Biofilters may remove heavy metals, reduce nutrient loads and reduce sediments from initial stormwater flows in order to restore runoff volumes to pre-development levels (Blecken et al. 2009; Davis et al. 2006; Hatt et al. 2007). In general, biofilters are small plantings (usually 2% of the catchment area), incorporated into streetscapes, where stormwater runoff from car parks and roadside curbs is directed. Runoff captured in these biofilters is then detained for a short period of time before filtering through a sandy-loam growing media and into the existing stormwater piped system (Chen et al. 2009; Somes and Crosby 2007) (Figure 1).

Historically, plant selection in biofilters has predominately focussed on drought tolerant, native species such as Carex or Juncus (Somes and Crosby 2007) which are usually planted as monocultures (Read et al. 2008). However, recently it has been suggested that biofilters with mixed species (i.e. species diversity) are better at reducing stormwater volumes and improving stormwater quality (Read et al. 2010).

Although there is limited research on plant diversity effects on stormwater quality in biofilters, research in green roof systems has been mixed and shows that mixed species may (MacIvor et al. 2011) or may not (Monterusso et al. 2004) effect runoff water quantity. This suggests that research in this area requires greater focus to ascertain what species and combinations of species are best suited for enhancing water quality.

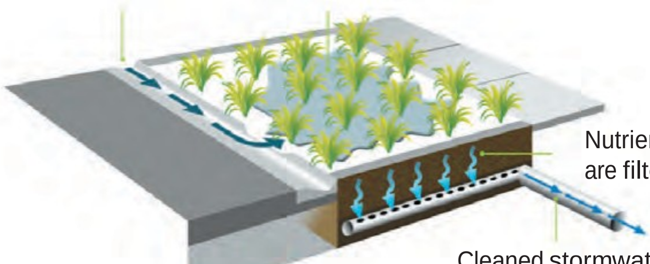

Figure 1. *Design of a typical biofilter, showing how nutrients and heavy metals are filtered from stormwater (modified from Kingston City Council, 2010).*

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It has been demonstrated that biofilters with little or no vegetation can increase nutrient concentrations in runoff (Hatt et al. 2007). Research has shown that different plant types vary in nutrient uptake and generally, monocot species are more effective at removing nitrogen than dicots (Weisner and Thiere 2010; Read et al. 2008). As nitrogen is used for plant growth there are also negative relationships between runoff nitrogen concentrations and plant root length, root depth and root mass (Read et al. 2010). Consequently, species selection is very important when designing biofilters to maximize their efficiency.

The purpose of this study was to determine whether increasing plant species diversity in biofilters improves stormwater quality and reduces stormwater volumes. We hypothesised that treatments with high biodiversity, especially those which include monocots will be the most effective plantings. Although a range of water quality parameters were tested, only nitrogen results are presented here.

Methods

The experiment was conducted in autumn through to early winter 2011 in a greenhouse at The University of Melbourne, Burnley campus, Australia. Biofilter modules were constructed to mimic the components of streetscape biofilters at an experimental level to allow for replication of the different species mixtures. A total of 59 biofilter modules were constructed with 56 planted modules and 3 bare un-planted modules to measure the effects of substrate on stormwater quality. Within the planted modules there were 14 types of planting mixtures: 4 single-species plantings; 6 two-species plantings; and 4 three-species mixtures. There were four replicates of each treatment, with one replicate harvested at the start of the experiment before stormwater application began, to get initial biomass (root, shoot and stem dry weights) and leaf area. Each biofilter contained a total of 6 plants, with 3 plants of each species in the two species plantings, and 2 plants of each species in the 3 species plantings.

The biofilter module design is shown in Figure 2. Modules were filled with biofilter substrate (Keysborough mix), over a 100 mm layer of blue metal to allow for drainage.

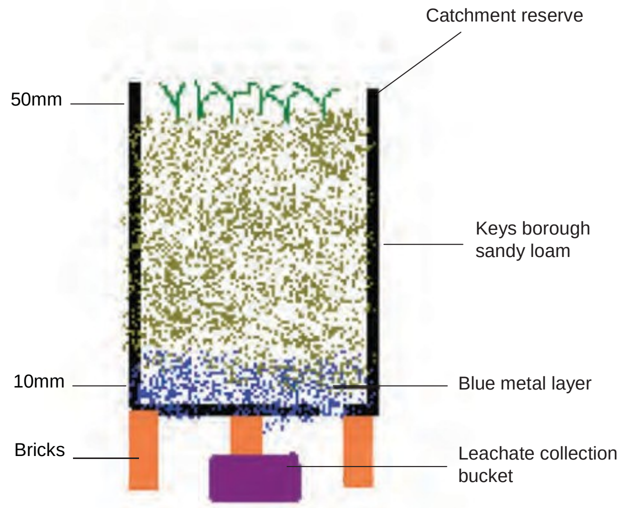

Figure 2. *Diagram illustrating biofilter design and a photo of the bifilter module in the glasshouse.*

The biofilter substrate was a commercially available sandy loam recommended for use in biofilters. The substrate had an EC1:5 of 0.208 ppm and a hydraulic conductivity of 193 mm/hr, which were within WSUD soil guidelines for biofilters (Somes and Crosby 2007). Agricultural liquid lime ™ was applied at a 1:50 ratio of liquid lime to water to neutralize the pH to a value between 6.9 to 7.2 Each biofilter module had a 50 mm clearance at the top of each biofilter to allow for ponding during stormwater application. Modules were raised 250 mm off the ground and a 1 2mm hole drilled in the bottom allowed for drainage and runoff water collection.

Four species commonly planted in Australian biofilters (Read et al. 2008; Somes and Crosby, 2007) were used in the experiment; Dianella revoluta R.Br, Mentha australis R. Br, Myoporum parvifolium R. Br and Isolepis nodosa Rotth. I. nodosa, M. australis and M. parvifolium were obtained from St Kilda Indigenous Nursery Co-operative (SKINC) and D. revoluta from Victorian Indigenous Nurseries Co-operative (VINC).

During establishment, plants were irrigated twice a week to container capacity with tap water. Plants were then irrigated for a further one month with synthetic stormwater or tap water on alternate watering days to acclimatize plants to stormwater. The synthetic stormwater was based on Read et al. (2008) with the exception of sodium nitrate and dibasic sodium phosphate, which were used as per Denman (2009). Sediment was not added.

After establishment, modules were irrigated with stormwater only (3.9 liters of synthetic stormwater) three times a week for a 4 week period. Runoff water volumes were measured after each irrigation event and determined by weight after each irrigation event when runoff was complete. On the final stormwater application 100 ml of leachate was collected from each biofilter module for water quality analyses. Samples were analyzed by Segmented Flow Analysis for total N, NH4N and NO3N at the Creswick School of Forestry, The University of Melbourne.

Statistical analyses

Runoff quantity and quality between monocot and dicot treatments and bare vs. 1, 2 or 3 species mixtures were analysed with one-way ANOVA using Minitab version 16 ™ software. Regression analysis between runoff quality (nitrogen concentrations) and plant biomass (leaf mass fraction (LMF), root mass fraction (RMF), leaf mass area (LMA) and root:shoot) were also analysed.

Results

There was significantly lower runoff from monocot plantings than from dicot plantings ($P = 0.036$). Monocot plantings had far greater root biomass than dicots ($P < 0.001$). In terms of species mixtures, only single species plantings lowered runoff quality when compared to bare biofilters ($P = 0.038$). However, single species plantings were not significantly different from two or three species mixtures, despite three species plantings having greater root biomass than single species plantings or two species mixtures (P = 0.453). Monocots also had greater LMF (P = <0.001) and LMA (P = <0.001) whereas, root:shoot was higher in dicots (P = 0.001). The number of species planted in each module had no effect on any of these traits. Runoff quantity was not correlated with any of these biomass measures (data not shown).

Nitrogen concentrations in runoff were significantly lower in monocots than dicots (P = 0.05). There was no effect of the number of species. Increased nitrogen concentrations in runoff were weakly correlated with reduced LMA (P = 0.03), LMF (P = 0.05) and RMF (P = 0.01).

Discussion

Plant type influenced runoff volumes in this experiment with monocot species mixtures (Dianella revoluta and Isolepis nodosa) having reduced runoff compared with dicot species mixtures (Myoporoum parvifolium and Mentha australis). Although plant biomass measurements were not strongly related to runoff quantity, reduced runoff from monocot species mixtures was likely due to greater root mass and leaf area. Rooting depth may also explain these differences as dicot roots were situated predominately near the surface of the biofilter modules with little deep root penetration. This may have reduced the plants ability to access water throughout the biofilter profile resulting in increased runoff (Hatt et al. 2009.). Our results indicated that runoff quality was not correlated with biomass measures and may relate to the relatively short experimental period and cool growing season.

Increased plant diversity did not improve biofilter performance in this study. Increasing the number of species in biofilters had no effect on runoff volumes with biofilter modules containing 2 or 3 species having the same amount of runoff as single species mixtures, despite greater total leaf area and total root mass in more diverse plantings. Increasing plant biodiversity also had no effect on nitrogen concentrations in runoff. However all planted biofilters had lower nitrogen concentrations than bare biofilters, and these concentrations were significantly lower than applied concentrations. As nitrogen is a primary macronutrient and is essential for plant growth, it is not surprising that uptake occurred, reducing runoff concentrations in vegetated biofilters (Crawford and Glass. 1998).

There were only weak negative correlations between nitrogen concentration and plant biomass, with lower nitrogen concentrations in plants that had high root or leaf biomass. This contrasts with Read et al.'s (2010) study, where they found strong negative correlations between nitrogen and root traits such as root mass. Our study may not have shown strong relationships due to the short experimental period compared with 2 years for Read et al.'s (2010) study.

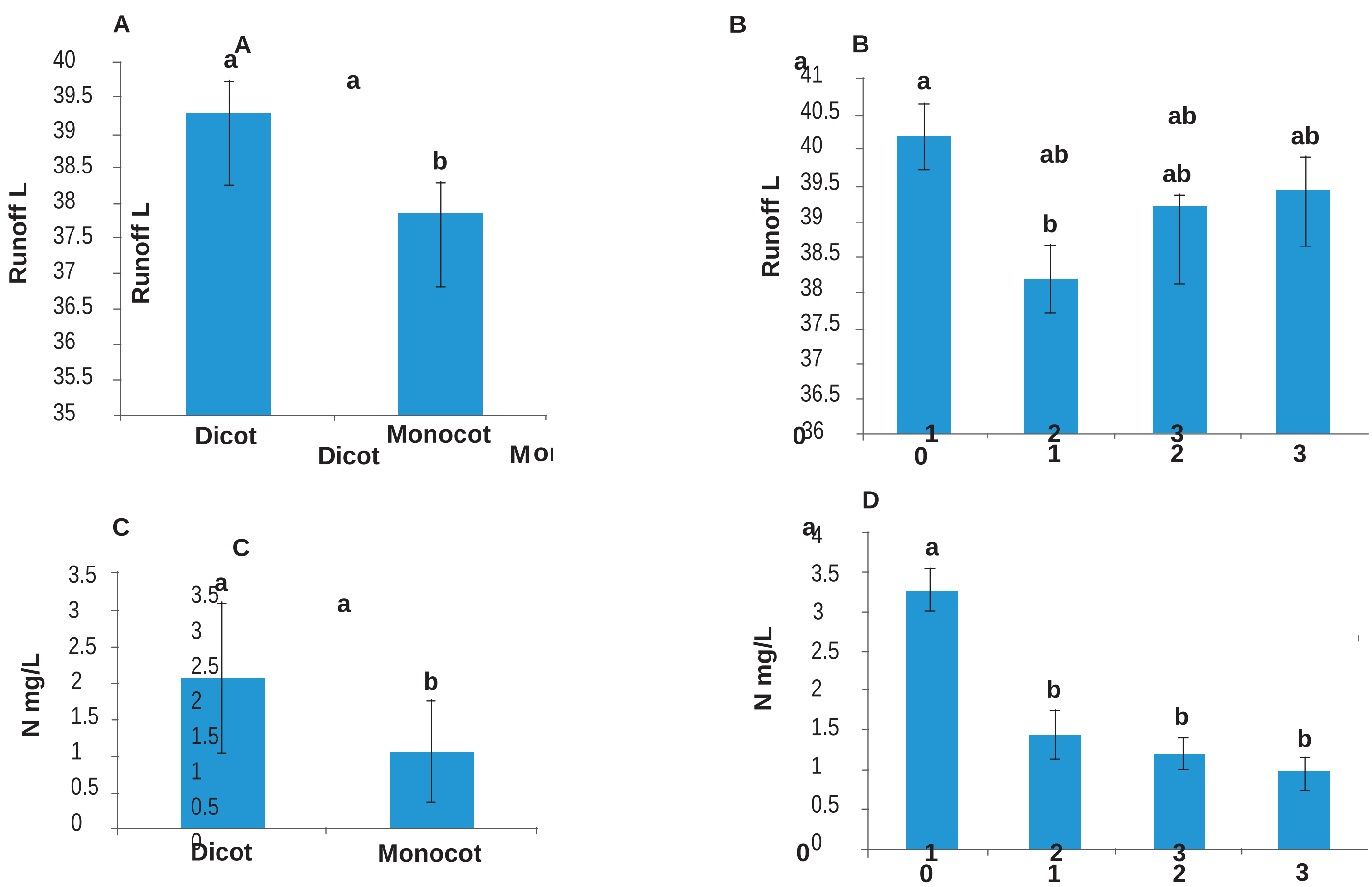

Figure 3. Stormwater runoff volumes from biofilter modules planted with dicot or monocot species (A) and from mixed plantings with 0 (bare), 1, 2 or 3 species (B). Stormwater runoff nitrogen concentrations (mg/L) from biofilter modules planted with dicot or monocot species (C) and from mixed plantings with 0 (bare), 1, 2 or 3 species (D). (Mean ± SE; n = 3 for species mixtures and 9 for monocot and dicot species). Different lowercase letters above bars indicate significant differences.

Although our study did not show that increasing biodiversity improved performance of the biofilters in regards to stormwater runoff quantity and quality, plant biodiversity in urban plantings is important. Plant diversity can improve diversity of other organisms such as invertebrates and birds and provides diverse habitats and food sources (Kazemi et al. 2011). Biodiversity also acts as an insurance policy when one species fails due to changing conditions or disease (Somes and Crosby 2007).

This study only offers a snap shot of potential effects of increasing biodiversity in biofilters on stormwater quality and quantity. The experimental period of 4 weeks compared to other biofilter module studies did not allow for seasonal differences in plant growth and their impact on water quantity to be studied. Plants were also selected randomly from those currently planted in Australian biofilters and these species may not be the optimal species for determining the effects of biodiversity on biofilter function due to differences in life-form and size. Future studies should be carried out to investigate the effects of species mixtures on a far greater range of species for a longer duration. As this study found more differences in runoff quantity than quality, future studies should include these measurements as quantity reductions can also improve ecological function of receiving waters.

Conclusions and applicable outcomes

Generally, monocots were more effective than dicots in reducing runoff volumes and retaining nitrogen from stormwater. However increasing species diversity did not reduce runoff volumes or improve stormwater quality.

Plant biomass influenced runoff water quality with lower nitrogen concentrations in plantings with the greatest root mass or above ground biomass (leaves). In this study the most effective biofilter plantings for reducing runoff quantity and improving water quality were single species plantings of monocots. However, single species plantings are unlikely to be resilient to disturbance and do not contribute to increasing diversity within urban areas.

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