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Investigating the potential of vegetable cultivation in biofilters

Potentiel de la culture de légumes dans des biofiltres

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RÉSUMÉ

L'application de biofiltres pour le traitement des eau pluviales est bien compris par des études en cours pour améliorer la capacité de traitement non seulement pour améliorer la qualité des plans d'eau, mais aussi pour récolter l'eau pluviale traitée pour une utilisation non-potable. Cette étude examine le potentiel d'étendre l'utilisation de biofiltres pour l'agriculture urbaine. L'agriculture urbaine est un concept de plus en plus répandu dans les pays en développement et développés. Alors que l'agriculture urbaine a de nombreux avantages, son utilisation est limitée par la disponibilité des ressources en eau pour l'irrigation en particulier avec l'augmentation de la pression sur les ressources en eau. Cette étude examine l'utilisation de légumes dans des biofiltres utilisant l'eau pluviale en laboratoire pour déterminer l'absorption des métaux par des légumes en s'assurant que la fiabilité des biofiltres de traitement ne soit pas compromise. Les résultats de l'étude montrent que, bien que la concentration de métaux dans les parties comestibles des légumes sont inférieurs par rapport aux parties non comestibles, la concentration en métal dans les parties comestibles sont plus élevés que les lignes directrices de l'OMS / FAO. La rétention élevée des métaux présents dans le sol démontre le potentiel d'accroître la rétention des métaux dans le sol afin de réduire l'absorption des métaux par les plantes. Néanmoins, la fiabilité des biofiltres de traitement a été maintenue avec une absorption élevée de métaux, d'azote et de phosphore.

ABSTRACT

The application of biofilters for the treatment of stormwater runoff is well-understood with studies currently underway to further improve its treatment reliability not only for improving the health of water bodies but also for harvesting treated stormwater runoff for non-potable usage. This study investigates the potential of extending the use of biofilters for urban agriculture. Urban agriculture is a growing concept in both developing and developed countries. While urban agriculture has many benefits, it's practice is also limited by the availability of suitable water resources for irrigation, especially with increasing pressures on water resources. This study examines the use of vegetables in laboratory-scale stormwater biofilters to determine metal uptake by vegetables and to ensure that the treatment reliability of the biofilters is not compromised. The results of the study showed that while metal concentrations in the edible parts of the vegetables were lower compared to the non-edible parts, metal concentration in the edible parts are higher than WHO/FAO guidelines. The high retention of metals in the soil demonstrates the potential of increasing metal retention in the soil to reduce metal uptake by plants. Nevertheless, the treatment reliability of the biofilters was maintained with high metal, total nitrogen and total phosphorus removal.

KEYWORDS

Biofilters, urban agriculture, metals, crop safety, water quality.

1 INTRODUCTION

Biofilters have traditionally been used for the treatment of stormwater runoff and reducing peak flows. There are currently an increasing number of studies on understanding the processes involved in the removal of nutrients and pollutants to allow stormwater to be harvested for non-potable use (Hatt et al., 2007). Besides non-potable uses, biofilters can also potentially contribute to food production in urban areas or urban agriculture. Urban agriculture increasingly being practiced in both developing and developed countries and can be defined as "*an industry located within (intra-urban) or on the fringe (peri-urban) of a town, a city or a metropolis, which grows and raises, processes and distributes a diversity of agriculture products, using largely human, land and waste resources, products and services found in and around that urban area*" (FAO, 2008).

Uptake of urban agriculture is currently limited, in part due to the lack of water resources for irrigation. With increasing pressures on existing water resources, alternative water sources for irrigation must be investigated. While stormwater presents an alternative, the use of stormwater without pre-treatment may be limited by the presence of heavy metals, micro-pollutants, nutrients, sediments and pathogens (Fletcher et al., 2004). One way of approaching this problem is through the use of biofilters as a pre-treatment system. Among the concerns with using stormwater for agricultural irrigation is the uptake of heavy metals by plants. However, studies on the use of biofilters for urban agriculture remains limited, thus little is understood about the uptake of metals by plants in biofilters (Tom et al., 2013, Tom et al., 2014, Sun and Davis, 2007). While past studies showed that heavy metal uptake in plants occur at varying levels when receiving stormwater or wastewater as irrigation source, some gaps in knowledge still exists such as identifying metal concentration in the edible parts of vegetables grown in biofilter media and the resulting water quality of the biofilters. This study examines the potential of using biofilters for crop cultivation by analysing the safety of crops in terms of metal uptake while maintaining the treatment reliability of the biofilter system.

2 METHODS

A column study was conducted over nine weeks using five replicates of nine vegetable species and non-vegetated controls. The vegetable species used in this study were chosen based on their short growing time, root depth as well as their ability to remove nitrogen, phosphorus and heavy metals from the soil. The vegetable species used were Broad Beans, Kohlrabi, Kale, Lettuce, Mint, Mustard Spinach, Radish, Spinach Hector and Sweet Corn. The columns consists of five layers including gravel, coarse sand, fine sand and woodchips, fine sand and fertilized fine sand, with a 150mm submerged zone. The different components of the biofilter column and their proportion is as per Figure 1. The composition of the fertilized fine sand followed Australian biofilter design guidelines (FAWB, 2009). The biofilter columns were dosed with 2.25 L of semi-synthetic stormwater twice weekly to simulate typical sizing and climatic conditions for Melbourne, Australia.

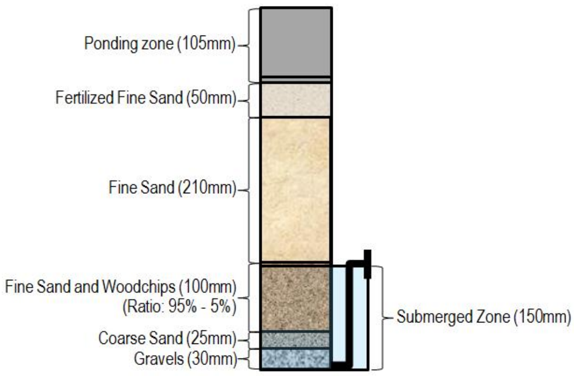

Figure 1. Schematic diagram of biofilter column

Water sampling was conducted twice throughout the experiment (on the 40th and 63rd day). Inflow and outflow samples were analysed for Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN) as well as seven heavy metals (chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), manganese (Mn) and cadmium (Cd)). Infiltration rates were also measured using the method adapted from the FAWB (2009) guidelines. Three out of five replicates for each plant species were sampled for metal concentration in plants and in the soil on the last week of the experiment. The data was analysed using Statistical Package for Social Sciences (SPSS 2015). Concentration factor was used in the comparison of metal concentration between plants to take into account the variability in metal concentration in the soils. It is calculated by dividing the metal concentration in plant parts by the metal concentration in the soil.

3 RESULTS

It was found that the concentration factor of metals in plants were significantly different between species and plant parts. As reported in the literature, this study also found that leafy vegetables (spinach, kale, mustard greens, lettuce) generally showed higher metal concentrations than legumes or root vegetables (Srinivas et al., 2009, Nabulo et al., 2010, Alexander et al., 2006). Concentration factors of all metals except for lead and chromium were higher in the roots (below-ground) than the shoots (above-ground) of plants (Figure 2). Radish showed higher metal accumulation in the shoots as compared to the roots of the plant. However, as the shoots of radish is not an edible portion of the plant, this does not pose a serious health hazard. On the other hand, higher chromium concentration in the shoots of all vegetables except for sweetcorn raises questions about the translocation ability of chromium and potential health risks associated with this. The higher concentration of chromium in the shoots of plants may be due to iron (Fe) deficiency in the soil which prevents the reduction of the more mobile Cr (VI) into Cr (III) or breakthrough of chromium resulting from high concentrations of chromium in the roots (Cary et al., 1977). However, as this study did not measure iron concentration in the soil as well as the chromium species present in the plants, a firm conclusion cannot be achieved.

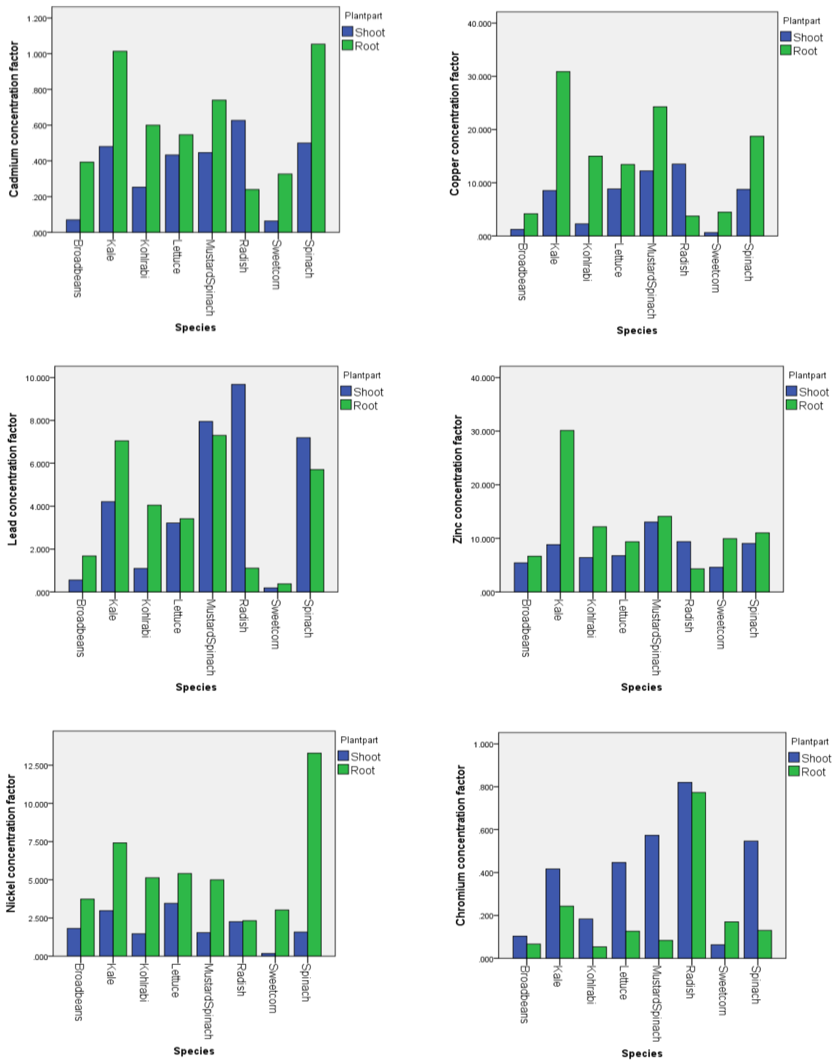

Figure 2. Metal concentration factor in the plants (above ground) and root (below ground) parts of eight vegetable species.

While most of the vegetables were not at a harvestable stage and broadbeans and sweetcorn did not fruit, a comparison was made between the WHO/FAO guidelines and the above-ground parts for the leafy vegetables and the below-ground parts for radish. It was found that Pb and Cd concentration in the edible parts of the vegetables are higher than the recommended maximum level (WHO/FAO 2015). This helps to provide an estimate of the metal concentration in the edible portions of vegetables although it is expected that as the plant grows, metal concentration in the plant similarly increases.

Metals were found to accumulate at a higher rate in the soil than in the whole plant as shown in Table 1. Sun and Davis (2007) also found that up to 97% of metal loads from inflow are retained by the soil in biofilters. As straining is the main process involved in metal removal, this demonstrates the potential of increasing metal retention in the soil and reducing metal uptake into the plants to reduce the harmful effects of high metal concentration in plants.

The use of vegetables in the biofilter columns were not found to have compromised the treatment reliability of the biofilters The biofilter columns were effective at reducing metal concentrations, with up to 70% removal rate, except for Chromium (38%). TN and TP removal in columns with vegetables were comparable with what is reported in the literature with an average concentration reduction rate of 47% and 61% respectively. TN averages were lowered by the inclusion of non-vegetated and mint columns in the analysis as mint did not grow during the study period and thus has similar TN reduction rate to a non-vegetated column.

Table 1. Concentration (mg) of metals in the total top 50mm of soil and whole plant.

Species	Copper (soil)	Copper (plant)	Nickel (soil)	Nickel (plant)	Zinc (soil)	Zinc (plant)	Lead (soil)	Lead (plant)	Chromium (soil)	Chromium (plant)
Broadbeans	1.57	0.01	0.92	0.00	3.01	0.02	0.70	0.00	0.98	0.00
Kale	0.79	0.01	0.42	0.00	2.28	0.02	0.52	0.00	0.83	0.00
Kolhrabi	0.88	0.01	0.37	0.00	1.54	0.02	0.55	0.00	0.76	0.00
Lettuce	0.73	0.01	0.38	0.00	2.52	0.02	0.57	0.00	0.80	0.00
Mustard Green	0.70	0.01	0.66	0.00	1.76	0.03	0.47	0.00	0.81	0.00
Radish	0.88	0.01	0.41	0.00	2.94	0.02	0.52	0.00	0.80	0.00
Sweetcorn	1.54	0.00	2.03	0.00	2.08	0.01	0.72	0.00	1.22	0.00
Spinach	1.15	0.02	0.51	0.00	3.35	0.04	0.58	0.01	0.83	0.00

4 CONCLUSION

This study demonstrates the viability of using vegetables as vegetation in biofilters. As Cd and Pb concentration in the edible parts of the vegetables are higher than the recommended maximum levels by WHO/FAO, further study is required to reduce metal uptake by the vegetables through increasing metal retention in the soil. The treatment reliability of the biofilters was maintained with TN and TP removal comparable to those of conventional biofilters. Overall, these results suggest that the use of biofilters in urban agriculture to provide multiple benefits is promising.

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