Improving biofilter media for urban agriculture crop production

Améliorer les médias filtrants pour la production agricole urbaineKT Ng[a], D McCarthy[a], B Hatt[a]

[a] Environmental and Public Health Microbiology Laboratory (EPHM Lab), Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia (kay.ng2@monash.edu)

RÉSUMÉ

En raison de l'expansion rapide de la population, la production alimentaire nécessite une quantité grandissante d'eau apte à l'irrigation. Cependant, à une époque où les sources d'eau potable diminuent et souffre de besoins grandissants, la recherche de ressources alternatives d'eaux pour l'irrigation est nécessaire. Les eaux pluviales représentent une source potentielle d'eau abondante dans les zones urbaines. Cependant, en raison des métaux lourds présents dans les eaux pluviales ainsi que le fait que les plantations peuvent absorber ces métaux, cela soulève des préoccupations quant à la sécurité des plantations irriguées avec des eaux pluviales de ruissèlement non-traitées. Cette étude examine l'utilisation de différentes modifications des sols utilisés dans les biofiltres afin de réduire la biodisponibilité des métaux. Dans cette étude, il a été constaté que les concentrations de métaux absorbés par les plantes étaient réduites grâce à ces modifications. Cependant, leur efficacité dépendait de nombreux facteurs, notamment le type de végétaux et le type de métal. L'hydroxyapatite s'est avérée efficace pour la réduction de Pb, tandis que la chaux s'est avérée plus efficace pour la réduction de Cd. Malgré cela, les concentrations de plomb dans la partie comestible des radis ont été estimée comme dangereuses pour la consommation car dépassant les valeurs guides de sécurité alimentaire fixées par l'Organisation Mondiale de la Santé. Bien que l'efficacité des biofiltres pour le traitement des eaux pluviales n'est pas été compromises par les modifications du sol ou l'utilisation de cultures légumières au lieu de plantes, des études supplémentaires sont nécessaires pour limiter encore davantage l'absorption de métaux par les légumes à long terme.

ABSTRACT

Food production in a rapidly expanding population requires a larger quantity of water for irrigation. However, in an era where competition for finite potable water resources is increasing, alternative water sources should be considered. Stormwater presents a potential source of water that is abundant in urban areas. However, stormwater is contaminated with a range of metals and vegetable crops are known to take up heavy metals, raising concerns about the safety of food crops irrigated with untreated stormwater. This study looks at the use of different soil amendments in biofilter media to reduce the bioavailability of metals. It was found that metal concentrations in plants were reduced with the use of amendments. However, the effectiveness of the different amendments was dependent on a range of factors, including plant type and metal type. Hydroxyapatite was found to be effective for Pb reduction while lime was found to be more effective for Cd reduction. Despite this, Pb concentrations in the edible portion of radishes exceeded food safety guidline values set by the World Health Organization, deeming them unsafe for consumption. While the stormwater treatment efficiency of the biofilters were not compromised by the addition of amendments or use of vegetable crops, further studies are required to further limit the uptake of metals by vegetables over the longer term.

KEYWORDS

Amendments, metals, stormwater, urban agriculture, water treatment

1 INTRODUCTION

With increasing water scarcity on a global scale and increasing demands for food from a growing population, the way water is used in the food production system needs to be reconsidered. Water reuse in urban agriculture is one possible way of reducing the pressures on potable water resources which can instead be used for other uses such as household or industrial use. Stormwater is a viable alternative source of water because it is abundant in urban areas and is typically directly discharged into waterways, resulting in severe degradation of waterway health. While it is a potential source of irrigation water, contaminants in stormwater such as heavy metals may pose human health risks if taken up by food crops. Therefore, if stormwater is to be used for food production, a treatment system needs to be in place that can function as both a stormwater treatment and food production system.

Biofilters are vegetated filtration systems that have traditionally been used for stormwater treatment. However, there is also the potential for increasing their multi-functionality by vegetating these systems with edible plants. Combining stormwater biofilters with urban agriculture not only addresses the issue of water for irrigation but can also increase the functionality of a single land area. Nevertheless, a study by Ng et al. (2018) demonstrated that metal contamination of vegetables irrigated with stormwater can occur. The metal concentrations in the edible portions of vegetables irrigated with stormwater often exceeded the guidelines set by the World Health Organization (WHO) (World Health Organization, 1996) and Food Standards Australia New Zealand (FSANZ) (Food Standards Australia New Zealand, 2011) (Ng et al., 2018). To ensure that stormwater can be safely used for crop production in urban agriculture, crop safety with respect to metal uptake needs to be improved. Studies on soil remediation have identified the use of various soil amendments on reducing the bioavailability of metals and hence subsequent uptake by plants (Cunningham et al., 1995, Chlopecka and Adriano, 1997). This presents an opportunity to use soil amendments in biofilter media to increase heavy metal retention within the filter media. The aim of this study was to investigate the use of different filter media amendments to reduce metal uptake by crops cultivated in biofilters.

2 METHODS

The selection of filter media amendments depends on the target metals as different metals have different properties and therefore different processes are involved in metal binding. The two metals which are the focus of this study is Pb and Cd since these metals were previously identified as potentially problematic (Ng et al., 2018). A literature review was conducted to determine the three amendments to be tested in this study; zeolite, hydroxyapatite and lime. These amendments were added to standard biofilter media at either 2% (w/w) zeolite, 1.8% (w/w) hydroxyapatite and 1% (w/w) lime and tested using laboratory-scale biofilter columns (Figure 1). The preparation of the standard biofilter media follows the Australia biofilter design guidelines (Payne et al., 2015). The columns were dosed with either 2.25L of semi-synthetic stormwater or mains water twice a week for three months. The dosing volume was calculated based on the climatic conditions in Melbourne, Australia (average annual rainfall = 532.5 mm, average no. days with >1 mm rain = 94 days) (Australian Government Bureau of Meteorology, 2016) and a biofilter sized to 2% of the impervious catchment area. A mains water control was included to provide an indication of plant background Cd and Pb concentrations while the use of stormwater in unmodified filter media columns provided an indication of metal uptake in plants without the use of amendments. Each of the biofilter columns were planted with either broad beans, kale or radish, representing a fruiting, leafy and root vegetable with five replicates of each configuration.

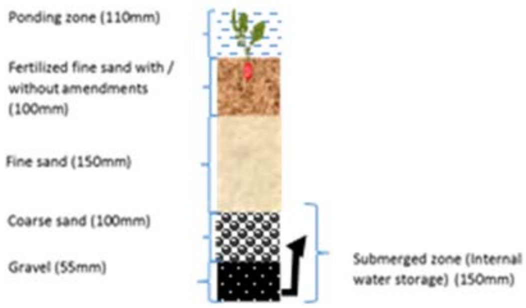

Figure 1. Set-up of biofilter columns

Water sampling was conducted twice throughout the three-month experimental period. Inflow and outflow samples were collected two and a half weeks after planting and when the experiment concluded, but before the plants were harvested. All water samples were analysed for total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), chromium (Cr), copper (Cu), nickel (Ni), Pb, zinc (Zn), manganese (Mn) and Cd. All plants were harvested at the end of the experiment and divided into edible, above-ground (leaves and stem) and roots. The plant parts were washed with deionised water to remove any attached pollutants and analysed for Pb and Cd. Filter media cores were taken at two depth intervals; 0-100mm and 101-350mm and tested for Pb and Cd. Data analysis was conducted using univariate and multivariate ANOVA. Metal concentration factor, calculated as the ration of metal concentration in the plant part to metal concentration in the filter media, was also used because it normalizes the plant metal concentrations by the soil metal concentration.

3 RESULTS AND DISCUSSION

The edible portion of radish was found to contain the highest Cd and Pb concentrations followed by kale and broad beans. Plants have been shown to take up metals at different rates, with leafy vegetables often being high accumulators of metals. However, this study found that a root vegetable, radish, had the highest metal concentration in the edible portion (Table 1). Intuitively, this is not entirely surprising since root vegetables are in direct contact with the top 100 mm of filter media, where metals, especially Pb, have been shown to primarily accumulate (Baker and Brooks, 1989, Marchiol et al., 2004). A comparison of the Cd and Pb concentration in the edible portions of each vegetable to World Health Organization (1996) guidelines demonstrated that Pb concentration in radish exceeded guideline values for all configurations except for mains water control configuration (Table 1). One potential explanation for this occurrence is that Pb is less easily translocated and hence accumulates in the part of the plant that is in contact with Pb, i.e. the roots (Baker and Brooks, 1989, Zimdahl and Koeppe, 1977). Cd concentrations in all configurations and Pb concentration in kale and broad bean configurations were below the guideline values.

Table 1. Mean metal concentrations in the edible portion of plants (standard deviation shown in parentheses) and World Health Organization (1996) guidelines. No results are reported for broad beans grown in zeolite-amended filter media because they did not fruit during the experimental period.

Plant type	**Filter media amendment**	**Water source**	**Cadmium (mg/kg)**		**Lead (mg/kg)**	
			Edible portion	**WHO**	**Edible portion**	**WHO**
Broad bean	Hydroxyapatite	Stormwater	0.010 (0.000)	0.1	0.02 (0.01)	0.1
	Lime	Stormwater	0.010 (0.000)		0.04 (0.05)	
	Zeolite	Stormwater	-		-	
	None	Stormwater	0.014 (0.005)		0.02 (0.02)	
	None	Mains Water	0.01 (0.00)		0.01 (0.00)	
Kale	Hydroxyapatite	Stormwater	0.026 (0.007)	0.2	0.020 (0.008)	0.3
	Lime	Stormwater	0.017 (0.004)		0.02 (0.01)	
	Zeolite	Stormwater	0.03 (0.02)		0.013 (0.002)	
	None	Stormwater	0.03 (0.01)		0.02 (0.02)	
	None	Mains Water	0.012 (0.004)		0.016 (0.008)	
Radish	Hydroxyapatite	Stormwater	0.05 (0.04)	0.1	0.2 (0.2)	0.1
	Lime	Stormwater	0.04 (0.03)		0.4 (0.8	
	Zeolite	Stormwater	0.04(0.02)		0.15 (0.07)	
	None	Stormwater	0.05 (0.02)		0.2 (0.1)	
	None	Mains Water	0.01 (0.00)		0.012 (0.004)	

The effectiveness of the various amendments were found to be dependent on the plant type, metal type and plant part. While there were no significant differences in metal concentrations in the edible portions of plants between amended configurations, Pb uptake was found to be lowest in hydroxyapatite-amended configurations. Although soil metal concentrations in hydroxyapatite-amended columns were second highest among all stormwater configurations, the metal concentration factor in the edible portion of broad beans cultivated in hydroxyapatite amended columns was the lowest

(0.02). This indicates that hydroxyapatite is able to trap Pb within the filter media and also reduce the amount of bioavailable Pb. As plant metal uptake does not only correspond to filter media metal concentration but is dependent on metal bioavailability, the ability of hydroxyapatite in reducing metal bioavailability is key in improving the safety of crops (Tom et al., 2014, Rattan et al., 2005). Similarly, lime was found to be effective in retaining Cd within the filter media and reducing Cd uptake in plants. Filter media Cd concentrations were found to be the highest in lime-amended configurations among all amended configurations which demonstrated that Cd was retained within the filter media. Nevertheless, Cd concentrations in broad bean pods in lime-amended configurations were below detection limit (<0.01 mg/kg).

The stormwater treatment function of the biofilters were found to be maintained with the use of vegetable crops as biofilter vegetation. Previous studies have demonstrated the importance of plant selection for pollutant removal, particularly nutrients (Bratieres et al., 2008). This results of this study indicate that the treatment efficiency of biofilters is not compromised by the use of vegetable crops. At the end of the experiment, TP concentration reductions averaged at 69% while TN concentration reduction averaged at 59%. In addition, the use of filter media amendments also has the potential to improve the metal treatment performance of the system, in that Pb concentrations in the outflow of lime-amended configurations were lower than all other design configurations.

4 CONCLUSION

The filter media amendments were found to reduce the concentration of metals in the edible portions of vegetables grown in stormwater biofilters. However, Pb concentrations in radishes still exceeded food safety guideline values, regardless of the design configurations (except for the mains water control). This suggests that root vegetables may not be suitable for stormwater-irrigated urban agricultural systems because the edible plant part is in direct contact with the contaminated filter media. Nevertheless, the filter media amendments were found to be a potential solution for improving crop safety in systems irrigated with stormwater and the water treatment function of the system was also maintained. Further studies will be required to understand how these systems will function over a longer term and the impacts of metal accumulation in biofilters on metal uptake in vegetables.

LIST OF REFERENCES

Australian government bureau of meteorology. 2016. *Climate statistics for australian locations* [online]. Available: http://www.bom.gov.au/climate/averages/tables/cw_086071.shtml [accessed 30 august 2016].

Baker, A. & Brooks, R. 1989. Terrestrial higher plants which hyperaccumulate metallic elements. A review of their distribution, ecology and phytochemistry. *Biorecovery.,* 1**,** 81-126.

Bratieres, K., Fletcher, T., Deletic, A., Alcazar, L., Le Coustumer, S. & McCarthy, D. Removal of nutrients, heavy metals and pathogens by stormwater biofilters. 11th International Conference On Urban Drainage, 2008.

Chlopecka, A. & Adriano, D. C. 1997. Influence of zeolite, apatite and Fe-oxide on Cd and Pb uptake by crops. *Science of the Total Environment,* 207**,** 195-206.

Cunningham, S. D., Berti, W. R. & Huang, J. W. 1995. Phytoremediation of contaminated soils. *Trends in Biotechnology,* 13**,** 393-397.

Food Standards Australia New Zealand. 2011. *Standard 1.3.2 maximum residue limits* [online]. Australia. Available: https://www.comlaw.gov.au/series/f2008b00619 [accessed 1 february 2016].

Marchiol, L., Assolari, S., Sacco, P. & Zerbi, G. 2004. Phytoextraction of heavy metals by canola (brassica napus) and radish (raphanus sativus) grown on multicontaminated soil. *Environmental Pollution,* 132**,** 21-27.

Ng, K., Herrero, P., Hatt, B., Farrelly, M. & McCarthy, D. 2018. Biofilters for urban agriculture: metal uptake of vegetables irrigated with stormwater. *Ecological Engineering,* 122**,** 177-186.

Payne, E. G. I., Hatt, B. E., Deletic, A., Dobbie, M. F., Mccarthy, D. T. & Chandrasena, G. I. 2015. Adoption guidelines for stormwater biofiltration systems-summary report: Cities as water supply catchments-sustainble technologies Melbourne, Australia: Coorperative Research Centre for Water Sensitive Cities.

Rattan, R., Datta, S., Chhonkar, P., Suribabu, K. & Singh, A. 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, Ecosystems & Environment,* 109**,** 310-322.

Tom, M., Fletcher, T. D. & McCarthy, D. T. 2014. Heavy metal contamination of vegetables irrigated by urban stormwater: A matter of time? *Plos One,* 9**,** e112441.

World Health Organization 1996. Trace elements in human nutrition and health.

Zimdahl, R. & Koeppe, D. 1977. Uptake by plants. *Lead in the Environment.(WR Boggess y BG Wixson, Eds.). Castle House Publications Ltd. Washington Dc, EUA***,** 99-104.