Identifying substrates for greywater treatment in a novel green wall system based on trickling filters

M.G.P. Grau*, N. Krähenbühl*, N. Antenen*

* Institute of Natural Resource Sciences, Zurich University of Applied Sciences, Grüentalstrasse 14, 8820 Wädenswil, Switzerland (E-mail: *maximiliangerdphilipp.grau@zhaw.ch)*

Abstract
Green walls with greywater treatment capabilities can play a key role to close water cycles in growing cities worldwide. Most green wall systems for greywater treatment apply a similar process as in constructed wetlands, where the substrate acts as plant substrate and to treat the polluted water. A novel green wall system is in development that separates the plant layer from the greywater treatment, by introducing a setup similar to a trickling filter. In a first step, various commercial substrates were tested for their suitability in terms of treatment performance at two different hydraulic loading rates over a 10-week period, using synthetic greywater. Measured parameters for determining pollutant removal were turbidity, chemical oxygen demand (COD), and others over a treatment time of seven days, measuring concentrations at the beginning, after three days and at seven days. The first substrate, expanded shale, performed best, achieving removal rates up to 60% for COD, closely followed by the other two substrates, plastic Hel-x and foam carriers. Generally, most pollutants were removed within the first three days of treatment. Even though plastic Hel-x carriers were not as efficient in pollutant removal as expanded clay, the carrier will be used for planned pilot trials of the novel green wall system due to their lower weight.

Keywords
Green walls; greywater treatment; substrate tests; trickling filter; water re-use

INTRODUCTION

The urbanization of the world's population is steadily increasing. 68% of people are projected to live in urban areas by 2050 (United Nations 2019), which will increase the pressure on water supply and sanitation. It is essential that water resources are managed sustainably, and also the use of alternative water sources must be considered (Bahri 2012). Greywater has shown great potential for re-use, however treatment technologies on household level need to be developed (Ghaitidak and Yadav 2013). In recent years, nature-based solutions have emerged as potential treatment options for greywater treatment in urban settings, especially green roofs and green walls, demonstrating high removal efficiencies of up to 80% for organic matter (Boano et al. 2020). Additionally, green walls have the potential to address other pressing issues of growing cities, such as the heat island effect (Pucher et al. 2022). Most green wall systems with integrated greywater treatment are designed similarly to constructed wetlands, where the substrate in pot-based, vertical systems acts as the substrate for the plants and also for greywater treatment, optimized for pollutant removal (Masi et al. 2016; Prodanovic et al. 2017). Also other processes such as trickling filters have been demonstrated to be suitable for greywater treatment (Ghaitidak and Yadav 2013; Gross, Kaplan, and Baker 2007). However, trickling filters have hardly been developed in the form of a green wall. In this study, a novel, layered green wall system, that separates the greywater treatment from the plant section is being developed. A filter system operates like a trickling filter on the back of the module, with a separate plant part in the front layer. The focus of this study was to test various commercially available substrates for their application as filter media for the green wall system in development.

MATERIALS AND METHODS

In order to find the most suitable substrate for the back layer of the green wall, the pollutant removal efficiency of three commercially available substrates (i.e., expanded shale, plastic Hel-x carriers, and foam carriers) were investigated in a column experiment over a period of 10 weeks under controlled climate conditions (25 °C and 60 % rH). Each column contained 2 L of a single substrate and was operated as a trickling filter under either a fast (34 l m-2 h-1) or slow (8 l m-2 h-1) hydraulic loading rate (HLR). Each column had a separate bucket for the greywater that was continuously recirculated through the columns with an aquarium pump. Each substrate and hydraulic loading regime was performed in triplicate, resulting in a combined setup of 18 columns. Prior to the experiment, each substrate was inoculated by being submerged in real greywater for 1 month. Every week each replicate was dosed with 15 ml of synthetic greywater and tap water was added to maintain a starting volume of 20 litres. The greywater addition was approximated to contain 300 mg/l chemical oxygen demand (COD), 14 mg/l total nitrogen (TN) and 3.5 mg/l total phosphorus (TP). This addition was maintained throughout the trial regardless of the concentrations remaining from the previous week. To determine the pollutant removal efficiency of the substrate and general conditions several parameters relevant to water quality were measured 2 hours (Day 0), 3 and 7 days after synthetic greywater addition. Removal rates were calculated compared to day 0 measurements. Measured parameters were pH, dissolved oxygen, temperature and conductivity, turbidity, COD, TP, total organic carbon (TOC) and TN.

RESULTS AND DISCUSSION

Expanded shale consistently exhibited the highest removal across all examined parameters, followed by Hel-x carriers, reaching removal efficiencies for COD up to 60% (Figure 1). Foam carriers generally performed either similar or worse than the Hel-x counterparts. A slower HLR showed partially better treatment performance compared to the faster HLR, while still preventing excessive biofilm formation that could clog the trickling filter. Particularly changes in TP highlighted the benefit of utilising complex materials containing natural adsorption sites, such as expanded shale for phosphorus removal. Apart from TOC most of the removal for various pollutants occurred within the first 3 days after greywater addition (up to: 80% for turbidity, 60% for TN, 40% for TP). This highlights the importance of biofilm establishment and adaptation to the pollutants present in greywater when in operation. Even though expanded shale demonstrated the best treatment performance, plastic Hel-x will be considered for the use in a pilot installation of the novel green wall system, mainly due to its lower weight of the material, thus achieving a lighter weight per m^2 green wall installed.

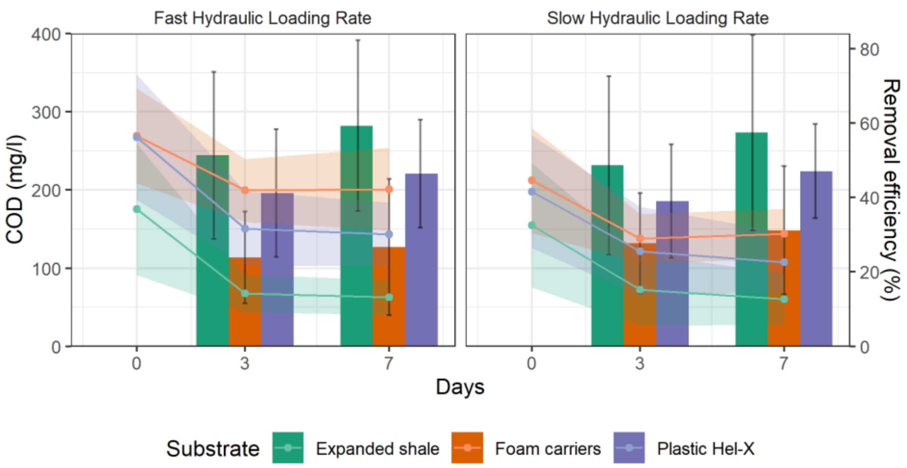

Figure 1. Treatment efficiency for COD of the three substrates; Average COD concentrations plotted as lines at the beginning and after 3 and 7 days over a 10-week period on the left axis. Average COD removal efficiency % plotted as bar graphs on the right axis.

REFERENCES

Bahri, Akiça. 2012. 'Integrated Urban Water Management'. Stockholm: Global Water Partnership (GWP). http://dx.doi.org/10.13140/RG.2.1.4187.0160.

Boano, Fulvio, Alice Caruso, Elisa Costamagna, Luca Ridolfi, Silvia Fiore, Francesca Demichelis, Ana Galvão, Joana Pisoeiro, Anacleto Rizzo, and Fabio Masi. 2020. 'A Review of Nature-Based Solutions for Greywater Treatment: Applications, Hydraulic Design, and Environmental Benefits'. *Science of The Total Environment* 711 (April): 134731. https://doi.org/10.1016/j.scitotenv.2019.134731.

Ghaitidak, Dilip M., and Kunwar D. Yadav. 2013. 'Characteristics and Treatment of Greywater—a Review'. *Environmental Science and Pollution Research* 20 (5): 2795–2809. https://doi.org/10.1007/s11356-013-1533-0.

Gross, Amit, Drora Kaplan, and Katherine Baker. 2007. 'Removal of Chemical and Microbiological Contaminants from Domestic Greywater Using a Recycled Vertical Flow Bioreactor (RVFB)'. *Ecological Engineering* 31 (2): 107–14. https://doi.org/10.1016/j.ecoleng.2007.06.006.

Masi, F., R. Bresciani, A. Rizzo, A. Edathoot, N. Patwardhan, D. Panse, and G. Langergraber. 2016. 'Green Walls for Greywater Treatment and Recycling in Dense Urban Areas: A Case-Study in Pune'. *Journal of Water, Sanitation and Hygiene for Development* 6 (2): 342–47. https://doi.org/10.2166/washdev.2016.019.

Prodanovic, Veljko, Belinda Hatt, David McCarthy, Kefeng Zhang, and Ana Deletic. 2017. 'Green Walls for Greywater Reuse: Understanding the Role of Media on Pollutant Removal'. *Ecological Engineering* 102 (May): 625–35. https://doi.org/10.1016/j.ecoleng.2017.02.045.

Pucher, Bernhard, Irene Zluwa, Philipp Spörl, Ulrike Pitha, and Günter Langergraber. 2022. 'Evaluation of the Multifunctionality of a Vertical Greening System Using Different Irrigation Strategies on Cooling, Plant Development and Greywater Use'. *Science of The Total Environment* 849 (November): 157842. https://doi.org/10.1016/j.scitotenv.2022.157842.

United Nations. 2019. 'World Urbanization Prospects The 2018 Revision (ST/ESA/SER.A/420)'. New York: United Nations.