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Multifunctional infiltration swales - Optimized topsoil layer with substrate amendments for enhanced urban stormwater treatment

Rigoles d'infiltration multifonctionnelles - Développement d'une terre végétale optimisée avec des amendements de substrat pour un traitement amélioré des eaux pluviales urbaines

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RÉSUMÉ

Les rigoles d'infiltration avec une couche de sol végétalisée optimisée et une plantation indigène biodiversifiée peuvent avoir une contribution positive en tant qu'infrastructure bleue-verte multifonctionnelle dans les zones urbaines. L'objectif de ce projet de recherche est de développer un système d'infiltration amélioré en ce qui concerne la sécurité du drainage, la rétention des polluants et la création d'un habitat précieux pour les plantes et les animaux. L'objectif de cette étude est d'améliorer la rétention des polluants tels que les métaux lourds provenant des eaux de ruissellement des zones de circulation et les biocides provenant des eaux de ruissellement des façades et des toits verts dans la couche de sol végétalisée grâce à des amendements du substrat. Dans les expériences en laboratoire et à l'échelle semi-technique, une bonne efficacité d'élimination a pu être déterminée pour les métaux lourds particuliers et dissous ainsi que pour les matières en suspension totales et fines. Les biocides ont été retenus dans les expériences en laboratoire et à l'échelle semi-technique dans l'ordre suivant : Terbutryn, Diuron >> Mecoprop. En particulier pour le Mecoprop, une forte dépendance entre la rétention et le taux d'afflux a pu être évaluée.

ABSTRACT

Infiltration swales with an optimized vegetated soil layer and biodiverse native planting can have a positive contribution as multifunctional blue-green infrastructure in urban areas. The aim of this research project is to develop an improved infiltration system regarding drainage safety, pollutant retention and additionally create a valuable plant- and animal-habitat. The improved retention of pollutants such as heavy metals from traffic area runoff and biocides from facade/green roof runoff in the vegetated soil layer by substrate amendments is in the focus of this study. In laboratory and semi-technical scale experiments good removal efficiency could be determined for particulate and dissolved heavy metals as well as for total and fine suspended solids. Biocides were retained in the lab-scale and semi technical scale experiments in the following order: Terbutryn, Diuron >> Mecoprop. Especially for Mecoprop a strong dependence between retention and inflow rate could be observed.

KEYWORDS

biocides, heavy metals, infiltration swales, pollution-retention, traffic area runoff

1 INTRODUCTION

In addition to the change in the local water balance, the increasing sealing of surfaces due to the rapid progress of urbanization leads to pollution of stormwater runoff in environmentally relevant concentrations. Heavy metals from traffic areas and metal roofs as well as biocides from construction materials are particularly relevant (Galster and Helmreich, 2022; Huber et al., 2016; Wicke et al., 2022). Biocides originate primarily from facade surfaces as well as bituminous sheeting of e.g. green roofs. Biocide concentrations of several milligrams per liter can be detected in direct runoff from new facade surfaces (Vega-Garcia, 2020). However, recent studies point out that classic infiltration swales are not a decent sink for biocides from stormwater (Bork et al., 2021). In contrast, the vegetated soil of infiltration swales is known to retain particulate and also dissolved heavy metals from stormwater runoff, while equally supporting the Blue-Green Infrastructure in urban areas (Fardel et al., 2019; Kluge et al., 2018). The prerequisites for a sufficient pollutant retention are good planning and regular maintenance.

Until now the main functions of infiltration swales are to ensure drainage safety and a sufficient pollutant retention. Therefore, they are often planted with grass in order to achieve a quick surface coverage and to keep the maintenance effort low. This restricts the ecological and aesthetic design options. Thus, the need for multifunctionality - i.e., drainage safety, optimized retention of pollutants, and improved ecological diversity with native plants adapted to the climate - has increased.

The Aim of this research project is to develop and evaluate a multifunctional infiltration swale with an adapted vegetated topsoil layer for urban areas (cf. Fig. 1), together with the University of Applied Sciences Weihenstephan-Triesdorf (HSWT) and the Prügl Soil Institute. At the Technical University of Munich, the focus of the research is on the development of a suitable and optimized topsoil with different substrate amendments. The optimizations are aiming to improve the pollutant retention and water storage capacity for the plants. The research for an adapted and suitable native planting is carried out by the partner HSWT and is not part of this article.

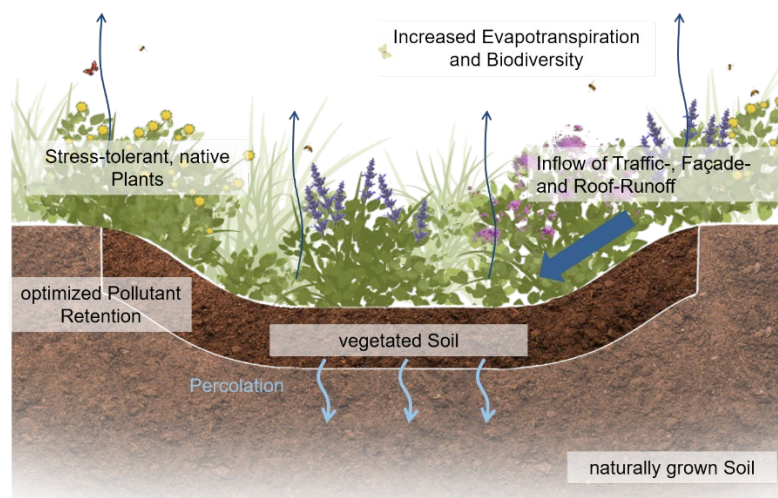


Fig. 1 Schematic structure and effect of a multifunctional infiltration swale for urban areas

2 MATERIALS & METHODS

The development of a suitable substrate was carried out within a 3-step process from laboratory experiments to semi-technical and technical scale. In the first step, laboratory tests were carried out to evaluate the retention of zinc and copper and the three biocides Terbutryn, Diuron and Mecoprop for different substrates. Based on the results, planted, semi-technical experiments were set up in mid-2021 and are still in operation. Two application scenarios were chosen, either treating traffic area runoff or facade/green roof runoff. For each application, a suitable substrate mixture was developed based on natural topsoil (topsoil mixture) and on quartz sand (subsoil mixture). All substrate mixtures have the same percent amendment of brick sand to increase the water storage capacity. Further amendments were e.g. granular activated carbon (GAC) if biocides were in the feed solution. The soil substrates meet the criteria of German guideline DWA-A 138-1 (2020), i.e. they are adjusted with compost to a humus content of 2-3 %, a water permeability of $\sim 5 \cdot 10^{-5}$ m/s and a fine soil content

of max. 15 %.

The feed solution for the semi technical swales were:

- Traffic area: real traffic area runoff from a highly trafficked street in Munich (24,000 vehicles per day).
- Facade/green roof: Synthetic stormwater with Terbutryn, Diuron, Mecoprop (10 µg/L each).

In total, a minimum of 20 runoff simulation experiments will be conducted over two years with three different inflow rates from low to high. So far for every runoff experiment the following parameters were analyzed:

- Traffic area runoff: suspended solids (TSS) and fine suspended solids ($\geq 0.45 \mu\text{m}$ and $< 64 \mu\text{m}$; SS63), Copper (Cu), Zinc (Zn), Vanadium (V) and dissolved organic carbon (DOC)
- Facade/green roof runoff: Terbutryn(TB), Diuron (DR), Mecoprop (MCP)

Possible negative effects such as leaching of pollutants (e.g. V from brick sand) or nutrients (e.g. DOC from compost) from the substrate amendments were also investigated.

In April 2022, a pilot-scale plant of a multifunctional infiltration swale on a heavily trafficked road in Munich was implemented. For this purpose, two swales of 8 m² each were equipped with measurement technology in order to investigate the pollutant retention of the traffic area runoff and the operational stability under real conditions. This represents a unique opportunity to compare the different findings of the in-situ sampling and the semi-technical tests.

3 RESULTS AND DISCUSSION

The laboratory tests showed an overall low and differentiated biocide retention in the topsoil mix amended with GAC in the following order: Terbutryn > Diuron >> Mecoprop. For this reason, activated carbon (10 Vol.%) was added to the topsoil and subsoil mixture for the semi-technical experiments in order to improve the adsorption of biocides in the substrate in addition to the expected biodegradation in the longer field trials.

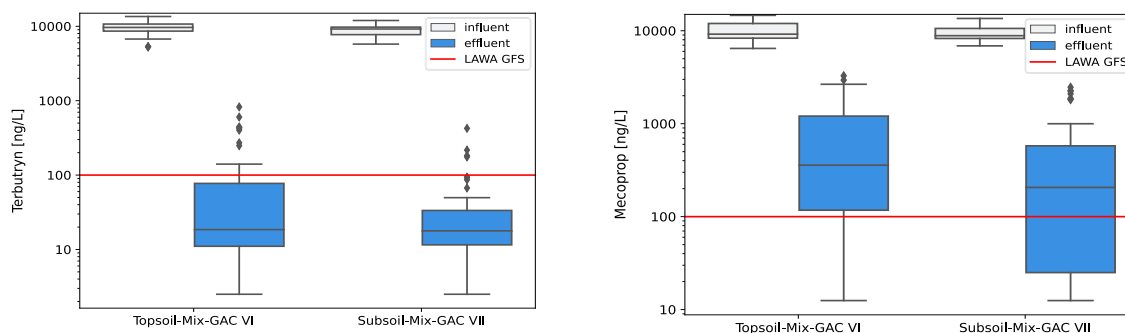


Fig. 2 Retention of Terbutryn (left) and Mecoprop (right) in the semi-technical experiments with the topsoil and subsoil mixtures with synthetic façade/green roof runoff as influent (n = 16); log y-axis

For the first five synthetic runoff simulation experiments, a clear effect of the GAC amendment could be determined. After 16 evaluated experiments so far, the reduction of the influent concentrations is on average over 90 %. Nevertheless, effluent concentrations in the semi-technical tests for Terbutryn and Mecoprop over the insignificance threshold values (In German: Geringfügigkeitsschwellenwerte GFS) (2017) were already analyzed (see Fig. 2). Especially for Mecoprop, a correlation to the inflow rate could mainly be shown, which is in good agreement with results of other studies. High Mecoprop effluent concentrations were observed in a study of the German Environment Agency, only during heavy rainfall events (UBA, 2016). The poor sorption of Mecoprop, which adsorbs mainly on organic matter, can be explained by its polarity and negative charge (Buss et al., 2006). The retention of diuron, similar to Terbutryn, is still very high in both substrate mixtures also during the high inflow rate - except for single outliers.

First results from the semi-technical experiments with real traffic area runoff show promising removal of main concerning pollutants (cf. Fig. 3). The concentration of the two heavy metals Cu and Zn were beside few outliers under the German threshold for the pathway soil-groundwater with 50 µg/L and 600 µg/L, respectively

(Mantelverordnung, 2023). The concentration of TSS and the more critical SS63 in the effluent was in the median slightly higher for the reference in comparison to the developed substrate mixtures.

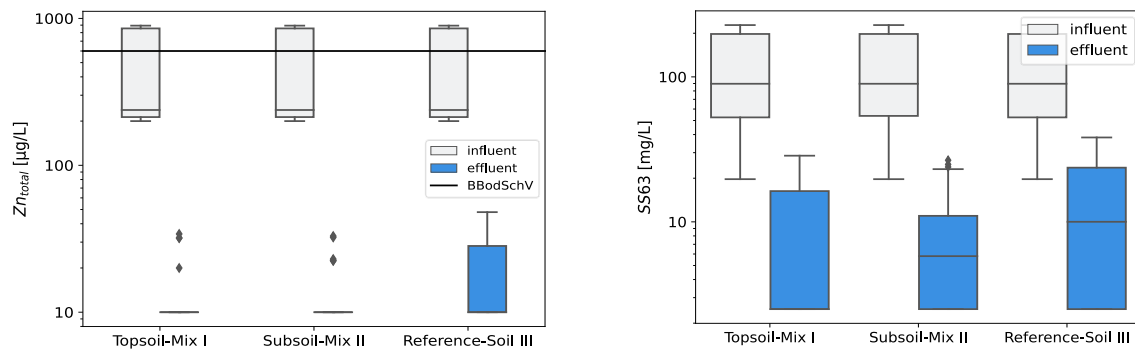


Fig. 3 Retention of total Zinc (left, $n = 7$) and fine suspended solids (right, $n = 11$) in the semi-technical experiments with the topsoil, subsoil mixtures and reference soil with real traffic area runoff as influent, log y axis

4 CONCLUSION

The preliminary results of the laboratory and semi-technical experiments show good retention performance for Cu, Zn and SS63 from traffic area runoff. The retention of biocides from facade or green roof runoff are dependent on the loading rate but are still over 90 %. However, with Mecoprop, poor biocide retention was detected at higher infiltration rates. Based on the results obtained so far, additional infiltration swales on pilot-scale have been constructed and the sampling is ongoing.

This research project forms the basis for a future guidance for operators and planners, from which the ecological and economic advantages, as well as the effort for maintenance, will become apparent.

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