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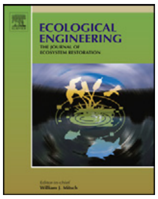

Short communication

Heavy metals in plants and substrate from simulated extensive green roofs

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ABSTRACT

Recycled brick could be used in green roofs but may pose environmental risk due to its heavy metal contents. In this study, concentrations of eight heavy metals (Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg) in three edible and medicinal plants (*Sedum lineare Thunb* (*SL*), *Sedum sarmentosum Bunge* (*SS*) *and Portulaca oleracea L.* (*PO*)), and in recycled brick substrate from simulated extensive green roofs, were investigated in Spring and Autumn. The results showed that most heavy metal concentrations in plants (aboveground parts) in April were significantly lower than those in October, and significantly increased year on year. None of the three species showed superiority or inferiority in all heavy metal concentrations at all the four samplings. Heavy metal concentrations in aboveground parts were all significantly lower than in roots, and significantly lower than in substrate except for Zn. The three species could not be used as food a year after they were sown; only PO collected in April can be harvested as medicine, mainly due to Pb concentrations exceeding the standard. Cd concentration in substrate increased and Ni decreased during the experiment, while the others kept unchanged. The substrate was polluted according to the standard due to its high Cd concentration which mainly came from recycled brick.

1. Introduction

The use of recycled brick in green roofs is appreciated not only for its low price but for its benefit of reducing solid waste locally (Molineux et al., 2009). Meanwhile, as some widely used green roof plants such as *Sedum lineare Thunb* (*SL*), *Sedum sarmentosum Bunge* (*SS*) and *Portulaca oleracea L.* (*PO*) in China have food and medicine value (Fu and Fu, 1984; CPC, 2010; Tang, 1996), the harvesting of them from green roofs will bring additional benefit. Therefore, the combined use of recycled brick and edible and medicinal plants in the cost-saving type of extensive green roofs will achieve optimal benefit–cost ratio, which is very important for the fast spread of green roofs in China.

However, recycled brick may pose environmental risk for its heavy metal contents (Emilsson, 2008; Molineux et al., 2009). And this risk will be enhanced by particulate matter introduced by dry and wet deposit (Landing et al., 2010). Since plants may absorb heavy metals from contaminated substrate and accumulate them in their tissues, their utilization as food or medicine will perhaps be harmful for human health. Therefore, if these edible and medicinal plants are to be harvested from green roofs with recycled brick substrate, heavy metal pollutions in plants and substrate should be examined in advance.

Very few studies, apart from Molineux et al. (2009), have concerned about heavy metals in green roof substrate. Moreover, so far no research has been reported on heavy metals in green roof plants. By investigating the concentrations of Cr, Ni, Cu, Zn, As, Cd, Pb, and Hg in three popular edible and medicinal species of plants (*SL*, *SS*, and *PO*) and in recycled brick substrate from simulated extensive green roofs established a year ago, we mainly addressed the following questions:(i) the variations of heavy metal concentrations in substrate and plants over time, and the causes for the variations; (ii) the sources of heavy metals in substrate; (iii) whether heavy metal concentrations in substrate and plants were influenced by plant species; (iv)whether substrate and plants were polluted by heavy metals according to relevant China standards.

2. Methods and materials

2.1. Establishment of simulated extensive green roof plots

Twelve same-sized simulated extensive green roof plots were established with a drainage slope of 1% on the rooftop of the No. 2 Teaching Building in the campus of Hubei University of Arts

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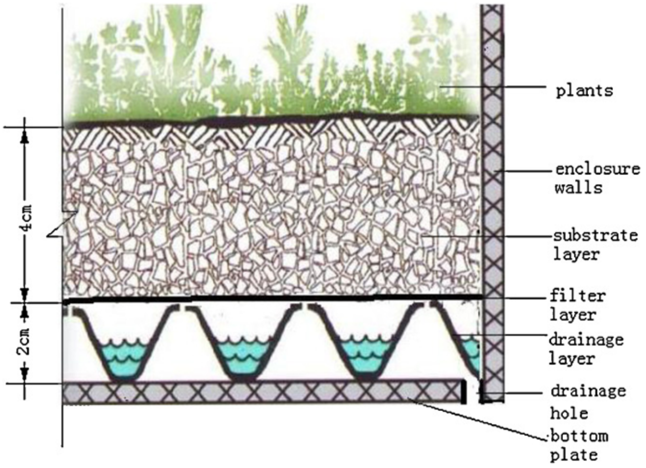

Fig. 1. The structure of simulated extensive green roof plot.

and Science on April 20, 2009. The plot, with a net interior area of 1.05 × 1.10 m^2 and a net containing height of 23.5 cm, had an open-box structure – a bottom plate and four enclosure walls all made of 10 mm thick PVC board (see Fig. 1). A drainage hole with a diameter of 20 mm was drilled in the middle of the lower edge of the bottom plate. From the bottom up, the green roof system comprised of a drainage layer made of HW-PSD20 (106) plate, a filter layer made of non-woven fabric, and a recycled brick substrate layer (Fig. 1). By referring to Villarreal and Bengtsson (2005) and FLL (2008), the substrate was mixed with (by mass) 7% crushed limestone, 75% recycled crushed brick, 5% distiller's grains, and 13% clay. In addition, for each plot, 10 g Lexishi CRF ((wt%) N: 15, P: 20, K: 10) was added. The brick was recycled from Xianshan dumping site – the main dumping site for construction waste in Xiangyang, where over 80% construction waste in Xiangyang was dumped. 105 Sampling points with an interval of 10 m were randomly selected around the whole dumping site, and 6 pieces of brick were collected at each point. According to FLL (2008), the particle size distribution of the substrate was prepared as (by volume): $\leq$0.075 mm, 7%; 0.075–1.18 mm, 34%; 1.18–2.36 mm, 28%; 2.36–9.50 mm, 21%; 9.50–10.50 mm, 10%. The substrate had field water capacity of 23%, dry apparent density of 1.26 g/cm^3, and porosity of 47%. For each *SL* or *SS* plot, 2.0 g seeds were sown, and for each *PO* plot, 10 g used. Three waterings (using deionized water) were done (without runoff occurred) every sunny day in the first 2 months, and shade nets were used for the first 3 months. To make the biomass in each plot comparable, seedlings were transplanted on June 25, 2009 resulting in an equal 100 seedlings with uniform distribution in each plot. Therefore, this experiment was arranged as a completely randomized block design with 3 treatments, 4 replicates.

2.2. Sampling and sample analyses

In the four samplings, a cutting ring with the diameter of 70 mm was used to position the sampling points in each plot by random. The aboveground parts of plants within the cutting ring were collected in all the four samplings, but the plant roots only collected in the last sampling.

The gathered plant roots were immersed in 0.01 mol/L EDTA for 5 min, then rinsed with deionized water for three times. The aboveground parts of plants and distillers' grains were also rinsed as roots. All the above cleaned materials were dried for 12 h at 70 °C, weighed and ground till fine particles (<0.15 mm) were obtained. Initial and final substrate, crushed brick, clay and limestone were sampled by 100 cm^3 respectively, and then dried and ground to particles smaller than 0.074 mm.

As and Hg were analyzed by atomic fluorescence spectrometry, and the other six elements by X series 2-ICP-MS (Thermo, USA).

2.3. Statistical analyses

Heavy metal concentrations in each species were analyzed by repeated measures ANOVA using sampling time as within-subject factor. Lack of sphericity was corrected by Greenhouse–Geisser correction. Paired comparisons were used to test the difference between the repeated data measured on different sampling occasions. For each sampling, one way AVONA was used to test for the difference of concentrations between species. Means were separated by Post Hoc LSD. Natural logarithm transformation was employed for the data that did not meet test of homogeneity of variance. Paired samples *T* tests were used to check the difference of concentrations between initial and final substrate, plant aboveground parts and roots, and plant aboveground parts and final substrate. The significance level was set to $P < 0.05$ unless otherwise stated. All statistical analyses were done with SPSS17.0.

3. Results

3.1. Heavy metal concentrations in substrate

Meteorological data during the experiment were shown in Fig. 2. The annual average daily temperature was 16.3 °C in 2010, and 16.1 °C in 2011. The annual precipitation was 884.3 mm in 2010 and 664.3 mm in 2011 respectively. Only Hg concentrations in final substrate had significant difference between species ($P = 0.017 < 0.05$), the other seven metal concentrations and pH value did not show significant difference between species (all $P > 0.05$).

Only concentrations of Ni and Cd in final substrate changed significantly as compared with those in initial substrate (all $P < 0.05$), the other six kept unchanged (Table 1). By the formula for complex quality index (P_n) in HJ332-2006 and Liu et al. (2011), P_n of initial and final substrate was calculated as 1.24 and 1.56 respectively, which meant they were polluted (According to HJ332-2006, P_n larger than 1.0 means being polluted). The pollution was caused by Cd concentrations above the standard of HJ332-2006. The decreases of substrate soil environmental quality during the experiment was also attributed to the increase of Cd concentration.

Heavy metals in initial substrate mainly came from recycled crushed brick which not only accounted for 75% volume of initial substrate, but also had the concentrations of 8 heavy metals close to those in the initial substrate (Table 1). Another heavy metals source for initial substrate was clay. The concentrations in clay, except for Cd, were close to those in initial substrate too (Table 1). The Cu and Zn concentrations in limestone were also close to those in initial substrate, but the others were much lower than in initial substrate. As heavy metal concentrations in distiller's grains and CRF were much lower than in initial substrate, they were the minor sources (Table 1).

3.2. Heavy metal concentrations in three species of plants

By the end of November of 2009, the plant coverage rate on *SL* or *SS* plots was about 45–50%, and on *PO* plots 40–45%. And by the end of November of 2010 and 2011, the coverage rate for *SL* or *SS* plots became 70–80, 85–95% respectively, and for *PO*, 65–70, 80–90% respectively. The average dry biomass (aboveground parts) of *SL* was recorded as 148.9, 347.4, 143.6, and 412.4 g/m^2 for the four samplings respectively. For *SS*, these values became 124.0, 299.8,