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Understanding rhizosphere processes to enhance phytoextraction of germanium and rare earth elements

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Germanium (Ge) and rare earth elements (REEs) are economically valuable raw materials that are not actually rare in terms of concentrations in soils but they are hardly available for plant uptake due to interactions with organic matter (SOM), secondary soil constituents such as Fe/Mn oxides and P bearing soil fractions. Processes in the rhizosphere might influence availability of Ge and REEs in the soil-plant system, since lowering of the pH and presence of carboxylates and siderophores (small molecules that strongly chelate Fe and other elements) strongly influences the chemical speciation of Ge and REEs in soil and consequently this comprehensive knowledge helps us to improve phytomining.

In a series of field and greenhouse experiments 16 plant species from the functional groups of grasses, herbs and legumes were tested with regard to their accumulation efficiency of Ge and REEs in shoots. Subsequently, we conducted mixed culture experiments in which inefficient species (e.g. cereals like Avena sativa, Hordeum vulgare, Panicum miliaceum) were cultivated in mixed cultures with efficient species (Lupinus albus, Lupinus angustifolius). Based on the plant concentrations a principal component analysis (PCA) was performed to identify significant factors that explain the accumulation behavior of different plant species with regard to Ge, REEs, Si, Fe and Mn. In this analysis Mn was used to identify plant species with efficient mechanisms to access sparingly available P-resources in soils. Particularly in nonmycorrhizal species concentrations of Mn in leaves often indicate a carboxylate based P-mobilising strategy.

Herbaceous plant species accumulated significantly higher amounts of REEs while grasses accumulated significantly higher amounts of Ge. Concentrations of Ge in shoots of grasses correlated significantly positive with Si, but negatively with concentrations of Mn. Indeed, the results of the PCA clearly show that plants with high Mn concentrations tend to have lower contents of both Ge and REEs. However, intercropping of Avena sativa and Hordeum vulgare with Lupinus albus significantly enhanced uptake of REEs in Avena sativa and Hordeum vulgare but not the uptake of Ge. These results suggest that rhizosphere processes play an integral part during mobilization of Ge and REEs in soil and uptake in plants. The availability of Ge to grasses closely follows a "Si-nutrition strategy", while plants that deploy a P-mobilizing strategy based on the release of carboxylates seem to be able to mobilize REEs as well, but they are unable to accumulate the mobilized REEs in the shoots.

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