ASSESSING SOIL AND PLANT PARAMETERS AFFECTING URANIUM AVAILABILITY AND PLANT UPTAKE

Background

In the assessment of the potential impact of contaminants in soils and the requirement for the implementation of corrective actions, it is important to determine the contaminant's mobility and bioavailability and to identify the processes and parameters ruling it. Mobility and bioavailability of contaminants are among others affected by the physicochemical characteristics of the environment itself and plant properties. This is also the case for uranium (U), reported to be the most frequent radionuclide contaminant in ground and surface water and soils. The actual failure of the available transfer factor (TF) data and their broad relation to soil type to be an appropriate measure for food chain transfer in assessment models, calls for a more mechanistic understanding of the individual processes affecting bioavailability.

Objectives

- Test if Diffusive Gradient in Thin film (DGT) measured concentrations adequately assess U bioavailability;
- Evaluate if differences in U uptake by plants can be explained by variation in root-mediated changes in selected soil properties and assess the role of organic acids in this process.

Principal results

DGT derived concentrations is no universal bioavailability index for U

In recent experiments, we aimed to quantify the influence of soil parameters on U uptake by ryegrass from 18 soils with distinct soil properties, spiked with ^{238}U (Vandenhove et al., 2007a). We did not find a significant relation between the U-TF and the U concentration in the soil solution (C_{sol}). This could indicate that U in the soil solution is not the only pool from which uranium can be sequestered. There was, however, neither a significant relationship between the TF and the uranium recovered in several selective soil extracts tested, nor with any of the other soil parameters screened. We, therefore, wanted to test if the DGT approach, developed to assess metal bioavailability in soils, could be proposed as a tool to predict U bioavailability. The DGT device contains an ion-exchange resin which acts as a sink, inducing a flux of ions from the soil to the resin (through a diffusion layer and a membrane in contact with the soil) which mimics the action of a plant root (Fig. 1a). The approach was tested for the 18 spiked soils and for 6 soils with distinct soil properties and U contamination history (2 aged spiked soils, 2 soils impacted by the P-industry and 1 impacted by U milling activities, 1 soil with high natural background levels of U).

Only when there was an important difference in U bioavailability, as was the case for the soils with different contamination history, a significant relationship between DGT-measured concentrations and uptake by ryegrass was found (Fig. 1b) but soil solution U concentrations predicted uptake even slightly better (R^2=0.90). For the spiked soils C_{DGT} did not explain the uptake observed (Fig 1c). The DGT method can hence not be put forward as a universal method to assess U uptake.

In both experiments the importance of U speciation (forms of U) on uptake was featured. Improved correlations were obtained (R^2=0.92) for soils with different contamination history when relating the U TF with the summed calculated soil solution concentrations of following species: free uranyl, uranyl carbonate complexes and $UO_2PO_4^-$. This observation highlights the complexity of U behaviour.

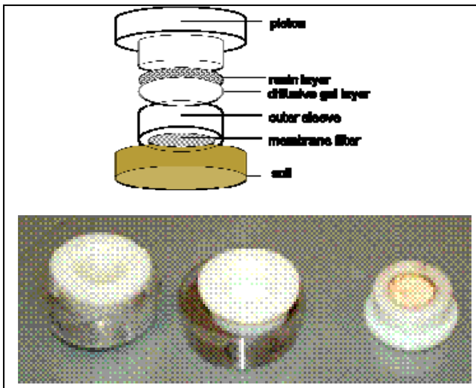

Fig. 1a: The DGT device is pushed gently into the surface of a 1.5 cm depth of moist soil

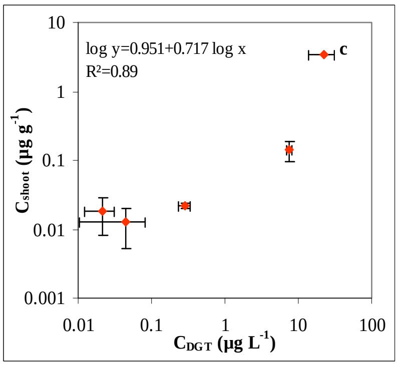

Fig. 1b: Relation between C_{DGT} and U concentrations in ryegrass shoots for soils with different contamination history

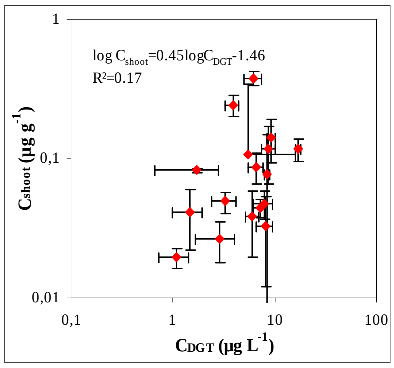

Fig. 1c: Relation between C_{DGT} and U concentrations in ryegrass shoots for U-spiked soils

Plant-induced changes in root environment could not explain differences in uptake between plants

The transfer factor (TF) of five plant species (maize, ryegrass, Indian mustard, wheat and pea) differing in their reported U uptake characteristics and uptake strategy in case of trace elements deficiencies was screened to elucidate the effect of plant-induced changes in the soil environment on the U TF. The experiment was performed in greenhouse using ^{238}U-spiked alkaline and acid soil. U uptake was always higher on the alkaline soil than on the acid soil but differences in U uptake between the two soils and the five plants was only partially explained by the difference in U concentrations in soil solution (C_{sol}) or differences in soil properties. The major plant induced change in the soil environment was the significant increase in C_{sol} but induced differences in C_{sol} or exchangeable U could not explain the difference in U uptake between plants for a given soil. Only for the acid soil, and this when excluding the data for mustard, a significant correlation was obtained between C_{sol} and the U uptake by shoots. Organic acids are known to increase availability of many heavy metals, including U, but differences in organic acid concentration in the root environment could neither explain difference in the transfer observed. The results obtained on the acid soil point to the importance of plant physiological characteristics in governing observed shoot TFs. C_{sol} of the acid soil varied 7-fold after growth of the 5 plants, their root U concentrations, however, only varied 2-fold, while the shoot concentrations 42-fold. This indicates that the physiological mechanisms by which root-to-shoot U transfer is inhibited or promoted seemed at least as important as the plant-induced changes in soil characteristics in determining soil-to-shoot transfer of U.

Additionally, hydroponics experiments also elucidated the lack of relationship between concentrations of root exudates (organic acids) or (root mediated changes in) culture conditions on uptake by roots or shoots. Indian mustard, showing the highest uptake produced most organic acids and was the only plant liberating malate and succinate, which can act as metal transporters in plants. We wanted to find out if U distribution in the roots could elucidate differences in root-shoot transport observed by XRF analysis of roots of maize and Indian mustard. Results showed that U is more or less equally distributed along the root of Indian mustard. For maize most U is concentrated in the first few mm from the root tip onwards and then decreases importantly. At the level of the root-stem interface, U was still detectable for Indian mustard but not for maize. U translocation to the upper plant parts (including the rest of the root) is hence strongly prohibited for maize but not for Indian mustard.

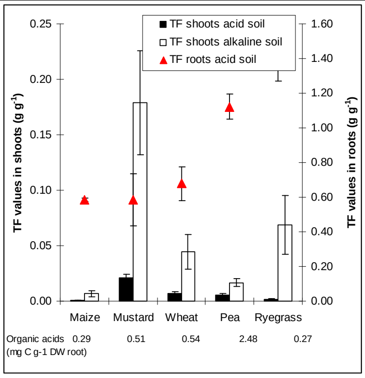

Fig. 2a: U soil-to-plant transfer factors for shoots and roots (acid soil only) of maize (M), Indian mustard (I), wheat (W), pea (P), ryegrass (R) and total concentration of organic acids in the rhizosphere of acid soil

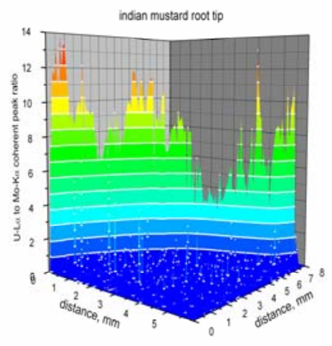

Fig. 2b: XRF area scan of root of Indian mustard where U is found all along the root

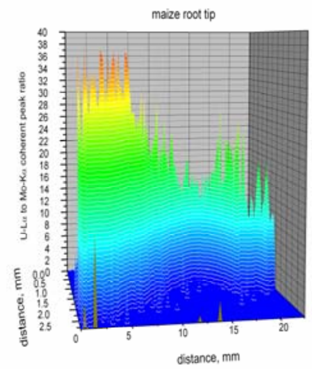

Fig. 2c: XRF area scan of root of maize. All U is concentrated at the height of the root tip

Future work

Future work will concentrate on further elucidation of factors affecting U uptake and compartmentalisation. This information is important for assessing how plant mechanisms may affect global transfer to the shoots, which is relevant for food chain modelling. Information on U distribution within the plant and the influence of environmental conditions on U distribution is also important for the study of biological effects induced by U and elucidate differences observed between different plant compartments.

Future work will also deal with application of soil amendments to alter U (bio)availability and screening of plants to search for optimal phytomanagement approaches for multiple contaminated sites.

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Main references

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