THE PCA OF PHYTOMINING: PRINCIPLES, CHALLENGES AND ADVANCES

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There is a number of commercially valuable elements whose concentration in the crust of the earth is too low for an economic mining with traditional approaches. However, phytotechnologies which take advantage of the capacity of certain plant species to take up these elements from the soil solution and accumulate them to large amounts in their biomass can be used for an economic winning of various metals and metalloids. This specific use of phytoextraction which has already been as one technology in the phytoremediation of contaminated sites is called "phytomining".

The aim of phytomining is to accumulate the elements of interest in high concentrations in the aboveground biomass of plants, from which, after harvest, these elements can be extracted for purification. The whole process consists of a number of individual steps, each of them related to a different scientific discipline and requiring specific methods. The main steps are the following:

(1) Growth of plants: Here usually (second generation) energy crops with a high biomass yield and some tolerance to adverse soil conditions are used. The high biomass gain allows for a large amount of elements to be accumulated in the biomass and an easy harvest of the plants.

(2) Increase of bioavailability of target elements in the soil and root environment (rhizosphere): Availability of the valuable elements can be increased by either induced phytoextraction by adding chelating agents like EDTA, organic acids or ammonium sulphate to the soil, or by growing plants with a high capacity for modifying their rhizosphere via e.g. organic acids or siderophores.

(3) Digestion of plant material: After harvest, the dried plant material can either be burnt and the target elements recovered from ash, or the fresh plant material can be digested for producing biogas as a second economically valuable product.

(4) Extraction of target elements from digestates: After fermentation (or ashing followed by chemical leaching) of the biomass, or alternatively after chemical or enzymatical digestation, the target elements can be extracted from the liquid phase via solid-liquid or liquid-liquid-separation.

(5) Re-use of digestates as fertilizer for plant growth: The residues from the digestation process still contain valuable nutrients, mainly phosphorous, which can be used as fertilizers.

Experiments were performed with various (second generation) energy crops (grasses, forbs) grown in pots and in the field, investigating their potential for accumulation of germanium (Ge) and rare earth elements (RREs). Forbs turned out to accumulate REEs, whereas grass species accumulated predominantly Ge. Whereas forbs accumulated Ge mainly in belowground organs, accumulation of Ge in grasses was highest in stems and leaves. Co-cultivation of oats with lupines increased concentration of REEs in above-ground organs of oats. Mixed cultures of rapeseed and lupine increased the concentration of available Ge in the soil and the concentration of Ge in rapeseed plants. The concentration of Ge and REEs in residues after fermentation could be increased up to 10-fold compared to the plant biomass of reed canary grass (*Phalaris arundinacea*).

It is concluded that grassy energy crops are good accumulators for Germanium, whereas forbs accumulate mainly rare earth elements. The amount of available elements in the soil solution can be increased by chelating agents released from plants with very active rhizosphere processes such as lupines. Digestion of plant biomass does not only yield biogas, but also residues in which target elements are concentrated with respect to the plant biomass. Therefore the investigated plant species are good candidates for an efficient extraction of valuable metal(loid)s from the soil via phytomining.

Key words: Phytoextraction, Accumulation, Biomass, Chelatants, Digestion, Fermentation