Exploring plant-fungal symbioses for bioremediation of radioactively contaminated soils from nuclear sites in Germany

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Over the past decades, significant quantities of solid radioactive waste have accumulated during the operation and decommissioning of nuclear facilities in Germany. In particular, this is related to radioactively contaminated soil at the Helmholtz-Zentrum Dresden-Rossendorf nuclear research reactor site and the Rheinsberg NPP site in Brandenburg. These soils, containing typical radionuclide vectors of nuclear installations operation, are categorized as low to intermediate-level radioactive waste. Their removal and treatment for the intermediate or final disposal entails high costs and significant efforts. Bioremediation represents a promising alternative for reducing the radioactive waste volume, particularly through biogenic processes aimed at radionuclide uptake or immobilization. Of special interest are plant-fungal symbioses, particularly involving arbuscular mycorrhizal (AM) fungi, which can significantly alter the chemical behavior and mobility of radionuclides in the rhizosphere, and enhance radionuclide availability for plant uptake.

This study investigates how specific plant-fungal associations could facilitate the removal of radionuclides from contaminated soils, potentially lowering their concentrations below regulatory limits. The plants selected for this experiment – *Medicago sativa* (lucerne) and *Helianthus annuus* (sunflower) – are known accumulators of soil radionuclides.

The three batches of plant seedlings were inoculated correspondingly with the commercial AM fungal mixture "Tyroler Glückspilze Mykorrhiza Granulat", a saprotrophic basidiomycete *Schizophyllum commune* with proven radionuclide bioaccumulation capacity and activated charcoal (1.5 $g \cdot kg^{-1}$) known to enhance cation exchange capacity and nutrient retention, thereby potentially promoting radionuclide uptake.

The experiment was conducted in growth chambers, using 3 kg soil from Rossendorf site per pot, over three months. The growth conditions included 20 °C temperature, a 16/8 h light/dark cycle, 55% relative humidity, and periodic watering with Hoagland nutrient solution. After cultivation, plant shoots and roots were harvested separately, dried at 105 °C, ashed at 400 °C for 24 hours, digested in 8M HNO_3, and analyzed using HP-Ge gamma spectrometry.

The initial results demonstrated that AM inoculation of *M. sativa* grown on soil from Rossendorf site led to a moderate increase in ^{60}Co and ^{137}Cs activity concentration in aboveground biomass. Charcoal addition significantly boosted ^{60}Co uptake by plant shoots (~ 80%) but had minimal impact on ^{137}Cs accumulation in plants. In turn, the presence of *S.commune* caused 60 % increase of ^{137}Cs activity concentration in plant shoots.

For *H.annuus*, the colonization both with AM fungi and *S.commune* resulted in up to 40-50 % increase in ^{137}Cs and ^{60}Co activity concentrations in their shoots, although plant biomass was slightly reduced compared to control plants. Charcoal-treated sunflowers showed only a slight increase in ^{137}Cs activity concentration in root and shoot tissues.

Overall, ^{137}Cs and ^{60}Co were mainly retained in the root system of the studied plants, and their root-shoot translocation was limited. *S.commune* had the strongest positive impact on the radionuclide accumulation by both plant species, while AM fungi demonstrated a moderate impact. Ongoing experiments with plant cultivation on highly radioactive soil from Rheinsberg NPP site will provide a more comprehensive understanding of the uptake patterns for gamma-emitting radionuclides and help assess whether plant-fungal remediation can reduce soil contamination to levels below the threshold for radioactive waste classification and allow clearance of the material.