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Field Studies on Effects of Bioaugmentation on Phytoextraction of Germanium, Rare Earth Elements and Potentially Toxic Elements

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Soil inoculation with plant growth promoting rhizobacteria (PGPR) promises benefits for agriculture as well as phytoremediation and phytomining of potentially toxic elements (PTEs) and critical raw materials (CRMs) in soil. Thus, we investigated on a field scale the effects of soil inoculation on biomass production as well as on phytoextraction of germanium (Ge), sum total of rare earth elements (REET), copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), cobalt (Co), nickel (Ni), Iron (Fe), calcium (Ca) and phosphorus (P). *Zea mays* (ZM) and *Helianthus annuus* (HA) were used as test plants and the commercially available PGPR RhizoVital®42 containing *Bacillus amyloliquefaciens* FZB42 as source of inoculum. Post-harvest, biomass/m^2, shoot element content/m^2, root concentration and water-soluble soil element fraction of root soils were compared for plants grown on inoculated versus uninoculated reference soil. Results indicated increase of 24 % and 26 % for ZM and HA grown on inoculated soils respectively, albeit insignificant at $p \leq 0.05$. Inoculation with PGPR enhanced the ZM shoot content of P, K, Co, Cd and Ge by percentages between 20 and 80 % (significant only for Ge) and decreased shoot content of Pb, REET and Cu by 35 %, 28 % and 59 % respectively. For HA grown on inoculated soil, shoot content of Ca, Ni, Cu, Zn, Ge, REET and Pb increased by over 28 % with negligible decrease observed for Cd. Water soluble element concentrations revealed increased concentrations of more than 15 % for K, Fe, Zn, Cd, Pb, Ge and REET in inoculated post-harvest root soils of ZM with negligible changes of less than ≤ 5% observed for P, Ca, Co, Ni and Cu. For HA , increase of ≥ 28 % for water soluble element concentrations occurred only for P and Ca, with concentrations of Ni, Cu, Zn, Cd, Pb and REET decreasing by percentages between 11 and 41 %. Also, increased root concentrations of ≥ 22 % for ZM growing on inoculated soils occurred only for P, Ca, Cu and Cd while decreased concentration of ≥ 12 % occurred only for Fe, Co, Ni, Pb and REET. Summarily, results suggest that bioaugmentation with commercially available PGPR RhizoVital®42, containing *Bacillus amyloliquefaciens* FZB42 has the potential to enhance biomass production as well as enhance or inhibit phytoextraction of some elements. Also, effects of PGPR on phytomining and phytoremediation is plant specific for some elements, depending mostly on plant physiological characteristics.