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Can plants uptake pure nanoscale zero-valent iron used for remediation proposals?

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Nanoscale zero–valent iron (nZVI) is widely used for site remediation, yet its impacts within the soil-plant system remain poorly understood. In this study, we developed a methodology to assess whether plants can uptake the pure nZVI—or at least the iron (Fe) coming from it through dissolution and redox processes—and subsequently translocate it to their aerial tissues. To achieve this, nZVI was synthesized using a ^{57}Fe spike as the Fe source and applied in a hydroponic experiment with tomato plants (*Solanum lycopersicum*), a well–established model for Fe-related studies. Initially, plants were cultivated for three weeks in a modified Hoagland solution containing Fe coming from a ^{56}Fe spike. Subsequently, the ^{57}Fe spike nZVI was introduced into the solution for an additional three days, with a parallel control conducted without nZVI. At the end of the experiment, treated plants exhibited a marked increase in ^{57}Fe content relative to control, indicating that plants can uptake and translocate nZVI or Fe derived from nZVI.

To elucidate Fe speciation within plant tissues, ^{57}Fe Mössbauer spectroscopy was conducted (ID18 - ESRF synchrotron). Although low Fe concentrations in aerial tissues precluded reliable spectral acquisition, bulk root analysis revealed the presence of both nZVI (Fe^0) and oxidized Fe (Fe^{3+}). Scanning electron microscopy confirmed the presence of nZVI aggregates adhered to root surfaces, suggesting that while some Fe is released, a considerable fraction remains as nZVI within the root system. Further investigation using XRF, XAS (ID21 - ESRF synchrotron) and LA-ICP-MS clarified the mechanisms behind the Fe uptake and accumulation. These techniques showed that nZVI-aggregates accumulate on the root epidermis, where Fe oxidation occurs, releasing Fe^{3+} from newly nZVI by-products. This Fe^{3+} is subsequently uptake and then reduced to Fe^{2+} before translocation to aerial tissues. The significantly higher concentration of ^{57}Fe compared to ^{56}Fe confirmed that the observed Fe originated from the applied nZVI. In conclusion, although plants do not directly uptake nZVI, the environmental application of nZVI can lead to the uptake and translocation of Fe released from these nanoparticles. These findings provide valuable insights into the potential environmental implications of nZVI-based remediation strategies on plant systems.