Influence of metal properties on the effectiveness of zero valent iron nanoparticles for soil remediation

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Abstract

The advances in nanotechnology have induced an increase in the use of nanomaterials in every sector of society, ranging from enhanced drug delivery to new methods for the treatment of polluted soil and groundwater (nanoremediation). In recent years, the environmental application of nanoscale zero-valent iron (nZVI) has generated a great deal of attention due to its potential for cost reduction compared to other in situ treatments, higher reactivity and broader applications. Several recent studies provided valuable insights into key nZVI properties associated with the potential to transform chlorinated organic compounds, metal ions such as Cd, Ni, Zn, As, Cr, Ag, and Pb, as well as notorious inorganic anions like perchlorate and nitrate [1]. Although most studies have focused on using nZVI to remove metals and metalloids from water and groundwater, metal immobilization in soils using nZVI has recently attracted attention [2-3]. In the present work, the effectiveness of nZVI for reducing the availability of heavy metals (Cr, Pb and Zn) in soils was evaluated. The influence of the nZVI dose and the chemical characteristics of the metal was also determined.

The soil used in the present study was collected from the surface layer (0–30 cm depth), from an agricultural field at the East of Madrid Community. It was a loam soil, with acidic pH (5.3) and a low concentration of organic matter (0.61%) and nitrogen (0.03%). Samples of this soil were artificially polluted with $K_2Cr_2O_7$, $Pb(NO_3)_2$ and $ZnSO_4$, separately, around 200 mg/kg. The spiked soils were treated with different doses (1%, 5% and 10%) of commercial stabilized water dispersion of nZVI (NANOFER 25S, NANO IRON Rajhrad, Czech Republic). The mixtures were shaken for 72 hours. Control tests without nZVI were carried out in parallel. Three independent vials were used per treatment. Then, the relative metal availability in the soil was evaluated according the sequential extraction procedure developed by Tessier et al. [4]. Extractions with solutions of increasing strengths are sequentially added to the soil sample, and five fractions are obtained defined as exchangeable (EX), carbonate-bound (CB), Fe/Mn oxides-bound (OX), organic matter-bound (OM), and residual (RS) (in decreasing order of availability).

Figure 1 shows the sequential chemical distribution of Cr (A), Pb (B) and Zn (C) in the soil at the different nZVI doses. In general, the application of nZVI induced a significant decrease of metal concentration in the most available fraction (EX and CB), and an increase of the least available forms. Differences in the metals distribution in the soil fractions were observed, in function of the metal. In the case of Cr, the EX fraction decreased by 55% after the addition of commercial nZVI at 1%, and nearly 100% at the doses of 5% and 10%; accordingly, the OX fraction increased significantly but no differences were detected for OM and RS fractions between treated and untreated soil samples. The removal mechanism probably is reduction, Cr(VI) is reduced to Cr(III) and immobilized on the iron nanoparticle surface, into the iron oxyhydroxide shell [5]. In the case of Pb and Zn, the treatment with nZVI decreased the metal in the most available fractions (EX and CB) and increased their concentrations in RS and OX fractions; higher dose of nanoparticles showed better immobilization results. The treatment was more effective for Pb than for Zn, and this can be due to the different chemicals properties of these metals; the removal mechanism for Pb, slightly more positive than Fe, is sorption and reduction, while for Zn which has a standard potential more negative than Fe, the main mechanism is sorption or surface complex formation [2]. Thus, the use of nZVI to remediate soils polluted with Cr, Pb or Zn in soils is a promising *in situ* strategy; the proper nanoparticle dose and the effectiveness of the immobilization depend on the metal properties.

References

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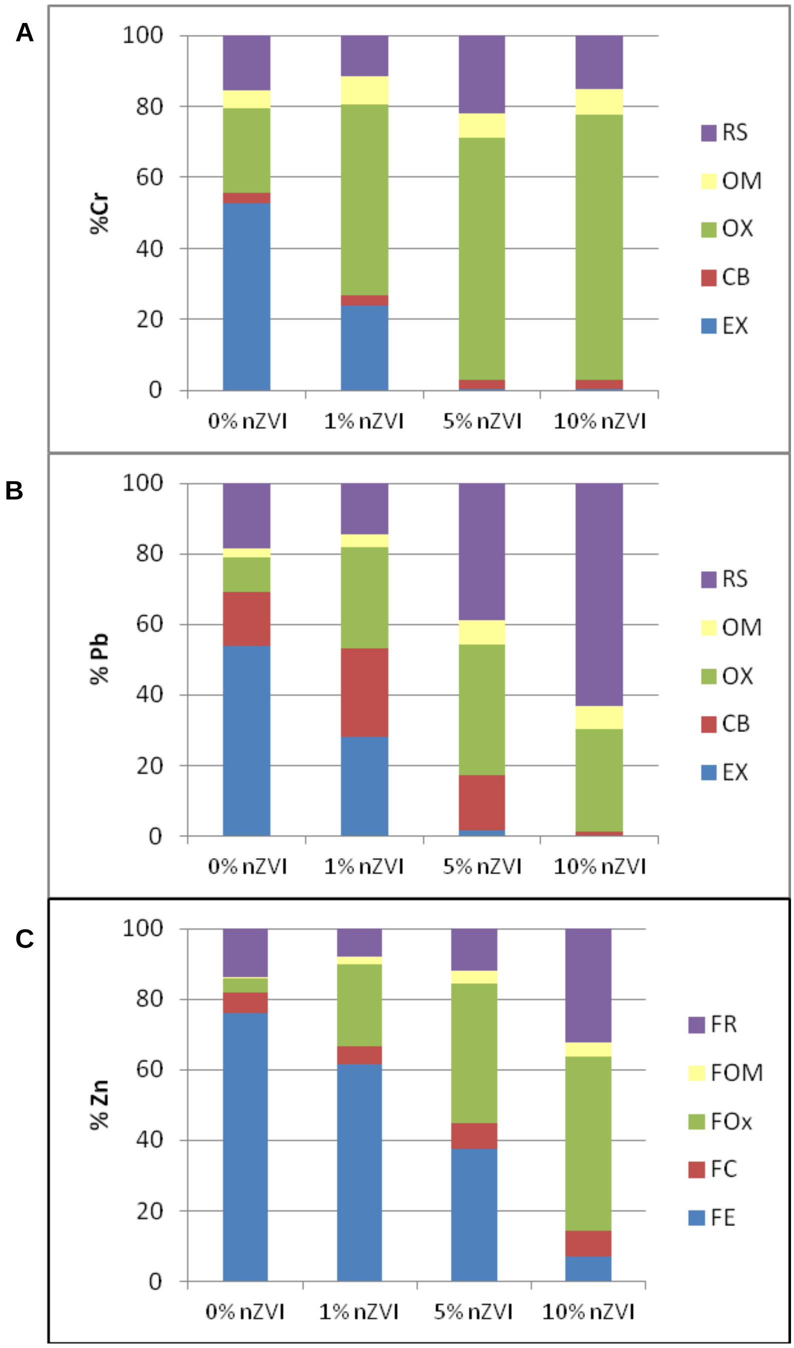
Figure 1. Sequential chemical distribution of Cr (A), Pb (B) and Zn (C) in the soil untreated and treated with nVZI (exchangeable, EX; carbonate-bound, CB; Fe/Mn oxides-bound, OX; organic matter-bound, OM; residual, RS).



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