Immobilization of potentially toxic metals in acid and alkaline soil using charcoal, activated carbon and biochar

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Introduction

Charcoal (lignite), activated carbon and biochar, are three forms of carbon that have a lot of common properties, with very similar composition and methods of production (Břendová et al, 2016). Biochar is a carbon-rich solid that is particularly derived from organic matter (from plants) that is heated in an absence of oxygen environment. It is intended for agricultural use, and is typically applied as a soil ameliorative. Charcoal (lignite) is also a carbon-rich solid that is derived from biomass in a similar manner (Pentari et al, 2009). Activated carbon is a carbon-rich solid that is derived from biomass or other carbonaceous substances, using pyrolysis. A carbon material is also "activated" by processes that greatly increase the surface area of the material, allowing it to adsorb a larger quantity of molecules.

Important physicochemical properties of charcoal (lignite), activated carbon and biochar such as favourable pH, high water holding capacity, low bulk density, and in the most cases, the presence of substantial plant nutrients makes them potential soil ameliorant for immobilizing metals in contaminated soils (Klucakova & Pavlikova 2017).

Figure 1: Charcoal

Figure 2: Activated Carbon

Figure 3: Biochar

Freundlich and Langmuir models were used to fit the sorption isotherms. The Langmuir isotherm model assumes that the adsorption process is monolayer. The Langmuir model is expressed as:

$$qe = \frac{Q_{max} b c_e}{1 + b c_e}$$

where Q_{max} ($mg*g^{-1}$) is the maximum adsorption capacity, q_e ($mg*g^{-1}$) is the amount of metals adsorbed at equilibrium, b ($L*g^{-1}$) is the constant associated with the affinity, c_e ($mg*L^{-1}$) is the equilibrium metals concentration in solution.

The dimensionless separation parameter R_L can be calculated according to the following equation, which can be used to determine the favorability of heavy metal ion sorption onto BCs.

$$R_L = \frac{1}{1 + b_{c0}}$$

where c_0 ($mg*L^{-1}$) is the concentration of metals in solution at initial time.

The Freundlich isotherm model assumes that the adsorption process is multilayer; there is no limit to the amount of adsorbate that can be adsorbed. The Freundlich isotherm model is given by:

$$q_e = K_f c_e^{1/n}$$

where K_f ($mg*g^{-1}$) is the adsorption capacity, n is the Freundlich constant associated with the surface heterogeneity, q_e ($mg*g^{-1}$) is the amount of metals adsorbed at equilibrium, c_e ($mg*L^{-1}$) is the equilibrium metals concentration in solution.

Results & Discussion

In the following Figures 4 & 5 the concentrations of Cu, Cr, Zn and Ni in control soil and in the soil- amendments mixtures used, in acid (Figure 4) and alkaline (Figure 5) are presented

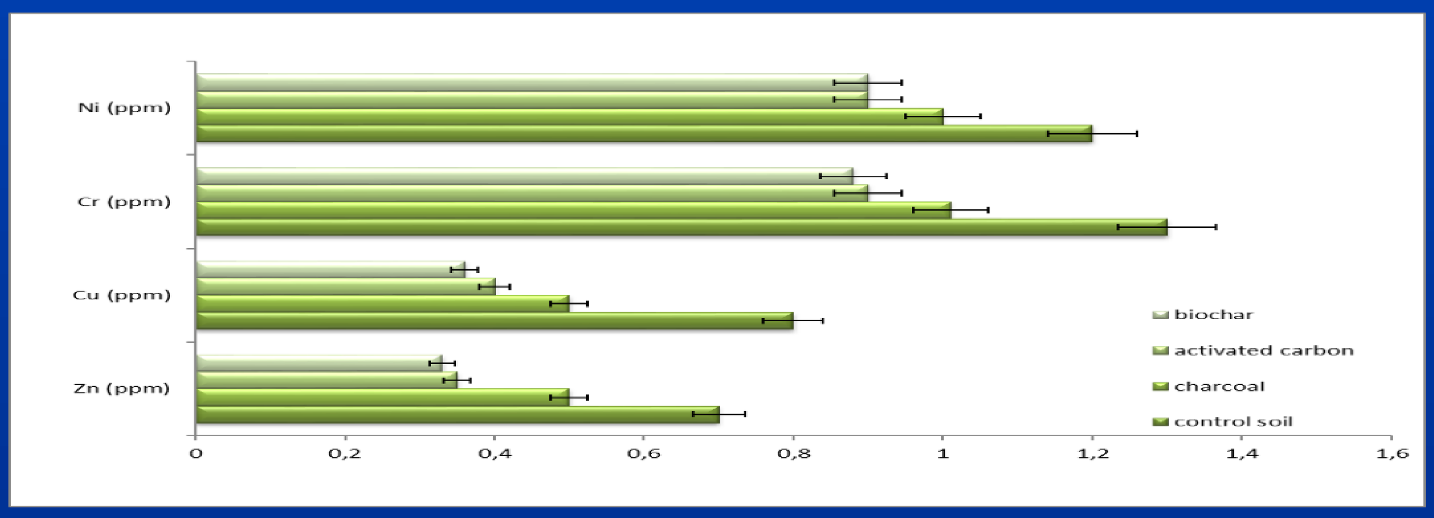

Figure 4: Available (DTPA extractable) metals concentrations (mg/kg dry soil) in an acid soil

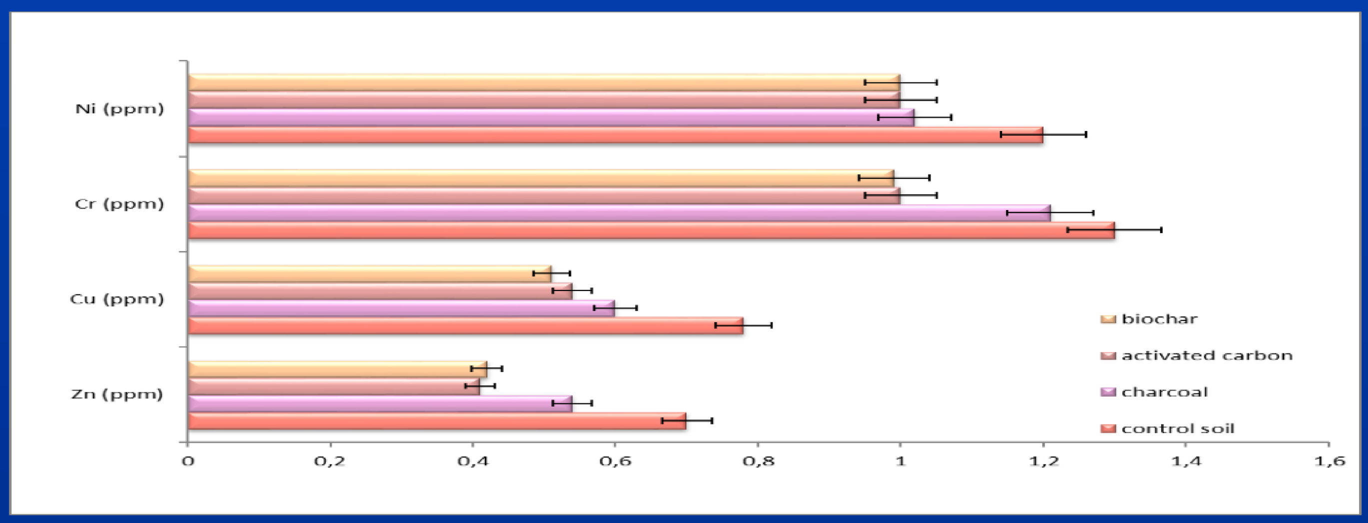

Figure 5: Available (DTPA extractable) metals concentrations (mg/kg dry soil) in an alkaline soil

The addition of activated carbon and biochar have been shown to reveal a very high affinity and capacity for sorbing mostly Cu and Zn, both in acid and alkaline soils (O'Connor et al, 2018) Active charcoal has proven to be effective at reducing high concentrations of soluble Cu in contaminated soils. The formation of a different complex in the carbon phase can be hypothesized. Also, the formation of a metal hydroxide at the surface of carbon can be assumed. The high efficiency of biochar in reducing the solubility of Cu, Cr and Zn might be caused by its relatively high alkalinity and high organic matter content (Hagemann et al, 2018).

DTPA extractable metals concentration was decreased by Cr (32,3% and 23,8%), Cu (55% and 34,6%), Ni (25% and 16,6%) and Zn (52,8% and 40%) when biochar was applied in acid and alkaline soils respectively. The same reduction (not significant p<0.01) was also observed when activated carbon was used in the soil samples. In figures 1&2 a significant reduction of metals content was observed in the rate Cu>Zn>Cr>Ni, when the three amelioratives were studied. Biochar caused the greater reduction, along with activated carbon following by lignite application.

In acidic soil the changes were much more pronounced than in alkaline. This is probably due to the fact that the addition of solids caused an increase in soil reaction (Anwar et al, 2009). This results in reduced mobility and therefore the availability of minerals more in acidic and less in alkaline soils (Simmler et al, 2013).

In dead, the pot experiment conducted in the present study demonstrated that applying charcoal (lignite) significantly reduced available Cr (22,3%), Cu (37,5%), Ni (16,6 %) and Zn (28,5%), in contaminated acid soil, primarily through increased soil pH. The capacity of lignite and lignite-soil mixtures to sorb metals at various soil pH and metals loadings showed that over a pH range of 6 - 8, metals sorption by lignite was 1 - 2 orders of magnitude greater than in the control soil. This may be due to preferential binding of metals to organic sulphur in lignite along with their content in humic and fulvic acids (Pekar & Klucakova, 2008).

Conclusions

Therefore, biochar and activated carbon can both be considered as an efficient strategy to ameliorate the hazardous effects and to enhance the toxic results of the mobile metals. So they can be recommended for reducing the adverse environmental effects of heavy metals in moderately contaminated Greek soils.

References

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- O'Connor D., Peng T., Zhang J., Tsang D.C.W., Alessi D. S., Shen Z., Bolan N. S., Houa D. 2018. Biochar application for the remediation of heavy metal polluted land: A review of in situ field trials. Science of the Total Environment 619–620, 815–826