European Commission

FARMING PRACTICE
SOIL AMENDMENT WITH BIOCHAR

IMPACT: HEAVY METALS POLLUTION

Reference 1

Albert, HA; Li, X; Jeyakumar, P; Wei, L; Huang, LX; Huang, Q; Kamran, M; Shaheen, SM; Hou, DY; Rinklebe, J; Liu, ZZ; Wang, HL 2021 Influence of biochar and soil properties on soil and plant tissue concentrations of Cd and Pb: A meta-analysis Sci Total Environ. 755:142582. 10.1016/j.scitotenv.2020.142582

Background and objective

The application of biochar to soils contaminated with potentially toxic elements (PTEs) has received particular attention due to its ability to reduce PTE uptake by the plants. Examine and quantify the effects of biochar and soil properties, and processing factors on soil PTEs with the specific concern on Cd and Pb uptake by plant. We hypothesized that 1) biochar would increase soil organic carbon (SOC), pH, CEC, and EC, which can in turn reduce soil Cd and Pb mobility and plant uptake, 2) biochar derived from different feedstocks would have different effects on shoot and root Cd and Pb concentration, and 3) the toxic Cd and Pb concentrations in shoot and root would depend on biochar physical and chemical properties and plant types.

Search strategy and selection criteria

Relevant peer-reviewed scientific journal articles were collected using the search terms such as "biochar and contaminated soil", "soil + potentially toxic metal and biochar", "soil + heavy metal and biochar", and "shoot/root potentially toxic metal concentration and biochar" on Web of Sciences, ScienceDirect, Elsevier, SpringerLink, and Google Scholar. The study mainly targeted on the term "biochar and soil potentially toxic metal or soil heavy metal concentration" was selected. Furthermore, the search was limited to the studies conducted either in the pot or field experiment. However, the studies conducted on soils artificially amended with potentially toxic metals were excluded from this study.

Data and analysis

OpenMEE (Wallace et al., 2017) software for meta-analysis in ecology and evolutionary biology was used to conduct this study. The natural log of response ratio (equation R) was used as the effect size induced by biochar treatment compared to control. The mean effect-sizes and 95% confidence intervals (CI) were generated by building random-effect models with maximum likelihood (RMML) in OpenMEE software (Windows 8 64-bit OpenMEE Windows). The response ratio R was transformed into a percentage. The biochar treatment group was significantly different from the control group if 95% CI generated building RMML in OpenMEE software of change did not overlap with zero in each figure, otherwise, no significant difference between biochar treatment group and control. The significant difference among covariate levels was computed through meta-regression analysis using random effects, maximum likelihood estimator, and mixed-effects models. For a covariate, the total heterogeneity was computed using mixed-effects models.

Number of papers	Population	Intervention	Comparator	Outcome	Quality score
65	Vegetables, grass, legume, maize, wheat, rice, and bamboo.	Soil amendment with biochar	No amendment	Metric: Shoot and root Cd and Pb concentration; Effect size: Logarithm of ratio of the considered metrics in the intervention to the considered metrics in the control	0.75

Results

- Biochar significantly reduced soil available Cd and Pb compared to control, by 42.1% and 47.1%, respectively.
- The overall significant ($P < 0.01$) reduction in shoot Cd and Pb concentration induced by biochar treatment compared to control was estimated at 40.1% for Cd and 39.4% for Pb and the corresponding values for root was estimated at 27.7% (Cd) and 37.1% (Pb).
- The reduction in shoot Pb concentration increased with an increase in pyrolysis temperature ranging from 300 °C to 600 °C; then it decreased when the pyrolysis was higher than 600 °C. Furthermore, the biochar produced at pyrolysis temperature ranging from 401 °C to 600 °C significantly ($P < 0.01$) induced high reduction in root Cd concentration; whereas the lowest and no significant ($P < 0.01$) reduction in root Cd concentration was recorded under biochar produced at pyrolysis temperature higher than 600 °C. In addition, the biochar with pyrolysis temperature ranging from 401 to 600 °C significantly ($P < 0.01$) had a high reduction in root Pb concentration compared to biochar with pyrolysis temperature ranged from 600 °C to 900 °C.
- High decrease in Cd and Pb concentration of shoot and root was generally obtained when biochar pH ranged from 10 to 11.3 compared to biochar pH ranged from 6.6 to 10.
- Except for root Pb concentration, there was a significant difference among effect sizes induced by biochar application rates of ≤0.5%, 0.5–2%, and ≥2% on shoot ($P < 0.01$) and root ($P < 0.01$) Cd and shoot Pb ($P < 0.05$) concentrations. Furthermore, the reduction in root and shoot Cd and Pb concentration compared to the control increased with the increase in biochar application rate.

Factors influencing effect sizes

- Crop type : The reduction of Cd and Pb concentrations in shoot and root induced by biochar significantly ($P < 0.01$) varied with the plant type subgroups classified as vegetables, grass, legume, maize, wheat, rice, and bamboo.
- Particle size : The biochar with lower particle size (<2 mm) significantly ($P < 0.01$) reduced Cd concentration by 50.4% in shoot and 31.8% in root, which was higher than 41.0% in shoot and 25.6% in root recorded under biochar with large size (>2 mm). For Pb concentration, the reduction was significantly higher and was estimated at 41.5% in shoot and 47.4% in root when biochar size was <2 mm compared to 25.3% in shoot and 40.9% in root with biochar size > 2 mm.
- Soil organic carbon : A significant reduction in shoot and root Cd concentration was recorded with increasing SOC concentrations of ≤15, 15–30, and >30 SOC g kg^{-1}. For shoot and root Pb concentration, it was observed that there was no significant difference among reductions in root and shoot metal concentration induced by ≤15, 15–30, and >30 g kg^{-1} of SOC concentrations.

- Soil texture : Sandy loam soil induced the highest reduction (33.8%) in root Cd concentration compared to sand, sandy clay, and clay soil
- Soil pH : The highest reduction in Cd concentration was recorded in neutral soil (54.9% in shoot, 42.7% in root) followed by that in acid soil (41.8% in shoot, 25.9% in root; with a significant difference ($P < 0.01$) among reductions in shoot and root Cd concentration induced by soil pH subgroups (acid, neutral, and alkaline soils). For root Pb concentration, it was observed that the highest reduction in root Pb concentration (40.0%) was recorded in the acid soil followed by that recorded in neutral soil (29.2%) with a significant difference among the reduction induced by soil pH subgroups.

Conclusion

Addition of biochar to metal contaminated soil significantly reduced Cd and Pb phytoavailability and concentrations in plant shoots and roots, through enhancing soil chemical properties and immobilizing Cd and Pb in soil.