FARMING PRACTICE
SOIL AMENDMENT WITH BIOCHAR

IMPACT: HEAVY METALS POLLUTION

Reference 24

Chen, D; Liu, XY; Bian, RJ; Cheng, K; Zhang, XH; Zheng, JF; Joseph, S; Crowley, D; Pan, GX; Li, LQ 2018 Effects of biochar on availability and plant uptake of heavy metals - A meta-analysis Agric For Meteorol. 278:107625. 10.1016/j.jenvman.2018.05.004

Background and objective

Biochar can be an effective amendment for immobilizing heavy metals in contaminated soils but has variable effects depending on its chemical and physical properties and those of the treated soil. Quantitatively and systematically examine the range of biochar's effects on soil heavy metal availability and plant uptake.

Search strategy and selection criteria

Relevant scientific articles were collected using the search terms "biochar" or "bio-char" to search for articles in the databases at the Web of Science, Elsevier, Springerlink, Wiley online, and Google Scholar. The search included all relevant articles up until March 1, 2016. Although the terms "char", "black carbon" and "charcoal" have commonly been included in some former meta-analysis, here we mainly focused on "biochar" as this term intentionally denotes its use for agricultural and environmental applications, as opposed to studies on naturally occurring black carbon. The definition of "biochar" was formally established in 2006, therefore, the studies including "biochar" were published mainly after that year. The title and abstract of each article were examined and the articles relevant to heavy metal uptake by plant in soils treated with and without biochar were selected.

Data and analysis

The Q statistic was used to measure the heterogeneity of effect sizes among studies (Zhou et al., 2016). The total heterogeneity (Qt) of R among studies consists of within-group (Qw) and between-group (Qb) heterogeneity (Wang et al., 2016). A Qb larger than a critical value indicates significant difference between groups ($Pb < 0.05$). Mean effect sizes and 95% confidence intervals (CI) were calculated using MetaWin (version 2.1).

Number of papers	Population	Intervention	Comparator	Outcome	Quality score
74	Pot and field experiments with herbaceous crops (rice, wheat, maize, vegetables, grass, hyper accumulating plants)	Soil amendment with biochar	No amendment	Metric: Heavy metals (Cd, Cu, Pb,Zn) soil bioavailability and plant uptake; Effect size: Logarithm of ratio of the considered metrics in the intervention to the considered metrics in the control	0.75

Results

- The decreases in plant heavy metal concentrations corresponded with concomitant decreases in metal bioavailability as measured using various extraction methods and soil extractants (e.g. $CaCl_2$, NH_4NO_3, DTPA). The average concentrations of available Cd, Pb, Cu, and Zn in soil were reduced by 52, 46, 29, and 36%, respectively, following biochar application.
- Biochar consistently reduced the average concentrations of heavy metals in plant tissue as compared to plants grown in soils without biochar. Across all studies, the mean concentrations of Cd, Pb, Cu and Zn in plant tissues decreased by 38, 39, 25, and 17%, respectively, when the plants were grown in soils amended with biochar. Average concentrations of Cd, Pb, and Zn in plant tissues were reduced in both pot trials and field studies following biochar application.
- Biochars produced at 450–500°C are preferred for effectively reducing plant uptake of Cd, Pb, Cu, and Zn
- Biochar reduced Cd concentrations in rice (40%), wheat (42%), maize (36%), vegetables (41%), grass (40%), and hyper accumulating plants (42%), respectively. The reduction in Cd concentrations in legumes was the least (21%) compared to other types of plants. Pb concentrations were reduced in crops in each of the eight categories, with the effect size ranging between 14 and 75%. The greatest decrease in Pb concentration occurred in maize, followed by vegetables, while the smallest decrease was in wheat.
- Cu concentrations were reduced by biochar in rice (32%), wheat (46%), maize (24%), vegetables (26%), and grass (15%). As for changes in plant Zn concentrations, biochar use led to declines only for vegetable crops, legumes, and hyper-accumulating plants, while it had no effects in reducing Zn concentrations in rice, wheat, maize and grasses.

Factors influencing effect sizes

- Experimental conditions : Plant Cu concentrations were reduced only in pot experiments, without significant effects in field studies overall. The effects of biochar on plant Pb concentrations were greater in pot experiments than under field conditions.
- Soil pH : The effect of biochar on Pb uptake was highly dependent on soil pH, with an average decrease of 40, 44, and 20% in acid, neutral, and alkaline soils, respectively. In contrast, plant uptake of Cu in biochar amended soils was inversely related to pH, and was greatest in alkaline soil (39%) as compared to neutral (23%) and acid soils (20%). Plant Zn concentration showed the greatest decrease in response to biochar in neutral pH soils (34%), as compared to acid soils (8%), but was not decreased in alkaline soils.
- Soil texture : There were greater reductions in plant Cd concentrations in medium textured soil than in fine textured soil. Plant Pb concentrations underwent greater reductions in coarse textured soil than in medium or fine textured soil amended with biochar.
- Soil organic carbon content : There were greater decreases of plant heavy metal concentrations in soils containing higher levels of SOC than in soils with low SOC. With respect to Cd, the effects of biochar on reduction in plant tissue Cd concentrations were greater in soils having medium SOC levels (15–30 g kg−1) than in soils with low SOC levels (<15 g kg−1). Plant Pb concentrations were reduced by 30 and 54%, respectively in soils with low SOC content

and high SOC content (>30 g kg−1). Plant Zn concentrations were not affected by a biochar amendment in soils with low SOC content, but were reduced in soils with medium and high SOC levels.

- Biochar feedstock : The application of manure biochar resulted in the greatest reduction of plant Cd concentration (73%), which is superior to the other types of biochars evaluated. Agricultural residue biochar, wood biochar, and green waste biochar were also effective for decreasing plant Cd uptake (32–41%). In contrast, there was no significant change in plant Cd concentrations grown in sewage sludge biochar amended soils. Animal manure derived biochar reduced plant Pb concentration by 65%, wood biochar reduced Pb concentrations by 30%, whereas, the effects of other biochars were intermediate (39–41%). Cu concentrations in plants were reduced by the application of agricultural residue biochar (33%), wood biochar (19%), manure biochar (35%), green waste biochar (33%), and sewage sludge biochar (13%), respectively, as compared to un-amended soil. Plant Zn concentrations were only reduced by agricultural residue biochar (30%) and green waste biochar (33%).

Conclusion

Biochar additions to soil resulted in decreases in bioavailable metal concentrations in soils of 52, 46, 29, and 36%. Biochar additions to soil resulted in overall reductions in average concentrations of Cd, Pb, Cu, and Zn in plant tissues by 38, 39, 25, and 17%, respectively.