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by Ossyda Priyadarshini, Amir Hamzah, A Astuti

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Research Article

Growth performance and biomass production of *Eleusine indica* and *Rorippa sylvestris* on heavy metal contaminated soil after biochar application

Rossyda Priyadarshini[1], Amir Hamzah[2*], Astuti[2]

[1] University of Pembangunan Nasional Veteran Jawa Timur, Jl Raya Rungkut Madya Gunung Anyar, Surabaya 60294, East Java, Indonesia.

[2] University of Tribhuwana Tunggadewi. Jl Telaga Warna, Tlogomas, Malang 65144, East Java, Indonesia.

*corresponding author: amir.hamzah@unitri.ac.id

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Abstract: Heavy metal contamination was an environmental and human health problem all over the world. Cadmium is the most hazardous heavy metals due to its high mobility and toxicity at low concentrations. Lead (Pb) also belongs to the hazard element caused by its prolonged persistence in the soil. This study aimed to develop the remediation techniques on polluted soil, i.e. a combination of biochars and indigenous plants. This experiment was conducted at the farmland of Sumber Brantas, Malang, East Java. Rice husk and tobacco waste biochars, metal accumulator plants (*Eleusine indica* L.Gaertn and *Rorippa sylvestris* L. Bess) were used in this study. The results showed that rice husk biochar had a significant effect on pH value and potassium content of the soil. On the contrary, nitrogen content, organic-C content, and cation exchange capacity of the soil with tobacco waste biochar application were higher than those in the soil with rice husk biochar application. The improvement of soil characteristics increased the growth of *Eleusine indica* and *Rorippa sylvestris,* as indicated by the plant height and biomass. The addition of biochar promoted the growth of metal accumulator plants and enhanced the accumulation of Pb and Cd in the plants. The application of rice husk biochar and tobacco waste biochar mixtures caused *Eleusine indica* absorbed heavy metals more than *Rorippa sylvestris, Eleusine indica* absorbed Pb and Cd higher than *Rorippa sylvestris* as indicated by Pb and Cd contents in the soil.

Keywords: *biochar, heavy metal contaminated soil, phytoremediation*

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Introduction

Heavy metal contamination has become a common environmental and human health problem all over the world, due to biomagnification and their difficulties to degrade. Industrialization and technology advances have led to an increase in anthropogenic activities that are responsible for heavy metals input into the soil such as smelting, mining, use of fertilizers, pesticides, and sludge. The addition of fertilizer and sewage sludge in agricultural practices can increase heavy metals, especially Cd and Pb, contamination in the soil. Application of phosphate fertilizer that is rich in Cd will lead to Cd contamination. Cadmium is categorized as the most common heavy metal in the environment. One of the agricultural areas in East Java that has been intensively using inorganic fertilizers containing cadmium and lead to maintain soil productivity and crop production is Sumber Brantas Village, Bumiaji Sub District, Batu. Results of a study previously conducted by Hamzah et al. (2016) showed that Cd and Pb contents in the soil of the area were above the threshold value of Cd and Pb in soils according to Ministry of Environment of Finland (2007).

According to Devi and Bhattacharrya (2018), Cd is the most mobile and high risk for the environment. Lead (Pb) also belongs to the hazard element caused by its prolonged persistence in the soil (Wani et al., 2012). Some technologies included conventional methods has been used for decades to remediate the hazardous heavy metals (Khalid et al., 2017). Unfortunately, conventional remediation methods are expensive and environmentally damaged. One of the innovative, eco-friendly and low-cost alternative technologies is phytoremediation. This technique uses heavy metal tolerant plants to clean up the contaminants by absorbing, accumulating and detoxifying pollutants from the site through their metabolic processes (Bhat et al., 2016).

Phytoremediation is a low-cost, non-destructive, and aesthetically sound. It has caused an increasing interest to exploit the ability of plants to remediate pollutants from contaminated soil. The efficiency of phytoremediation is dependent on soil physical and chemical properties, metal bioavailability to plant, and plant capacity to uptake, accumulate and detoxify metals. The effectiveness of phytoremediation mechanisms depends on the plant biomass, heavy metal level in the plant tissues, and the availability of the heavy metals in the soil (Garba et al., 2013). The plant capability in absorbing heavy metals depends on the ability of the plant in producing biomass (Conesa et al., 2012). Many studies showed that grasses are the most common preferable plants for phytoremediation because of their capability to grow rapidly, produce a large amount of biomass, and adapt stress in the environment (Elakes, 2014). Brassicaceae family also contains a high number of species which can hyper accumulate heavy metals (Babula et al., 2012; Dar et al., 2014). Hyperaccumulator plant that belongs to grass species is *Eleusine indica* (L.) Gaertn and that from Brassicaceae family is *Rorippa sp.* Anarado et al. (2018) showed that *Eleusine indica* (L.) Gaertn is the best hyperaccumulator plant for zinc and cobalt; while *Rorippa sylvestris* (L.) Bess has significant potential in accumulating uranium on its shoot (Cordeiro et al., 2016). Hamzah et al. (2017) reported that *Eleusine indica* L. Gaertn and *Rorippa sylvestris* L. Bess are indigenous plant species that grew well on agricultural soil of Batu-East Java contaminated by heavy metals due to intensive use of inorganic fertilizers. Plant growth is an indicator of their potential as a metal accumulator plant (Ahammad, 2018).

Generally, heavy metals will cause oxidative stress by formatting free radicals which will cause a reduction in plant growth and biomass (Panda and Patra, 2016); it is thus essential to enhance the plant resistance against heavy metal stress. One of the techniques is using organic amendments, such as biochar. According to Chirakkara and Reddy (2015), the biomass of plants can be improved by adding biochar and compost amendments. By adding biochar, metals will be immobilized so that the essential nutrients can be released; soil water holding capacity, porosity and soil structure will be improved, and finally, it promotes plant growth. Biochar application on contaminated soils also allows the plant to sequester C then storing it into their part of the biomass. However, the results of a study previously conducted by Hamzah et al. (2017) showed that application of biochar alone was not sufficient to immobilize heavy metal in the heavy metal-contaminated soils. According to Nejad and Jung (2017), a combination of metal accumulator plants and amendment such as biochar can be more effective in the remediation process.v However, studies on phytoremediation of heavy metal-contaminated soil combined with biochar amendment are still limited. The objective of this study was to explore how biochar can affect indigenous metal accumulator plants and heavy metal uptake from heavy metal contaminated soils.

Materials and Methods

Study site and materials used

The study site is located at Sumber Brantas village, Bumiaji Sub District, Batu, East Java. The village is one of the horticulture areas located in Batu, East Java. As reported by Hamzah et al. (2016; 2017), Cd and Pb contents in the soil of the study area exceeded the threshold value. Materials used in this study were biochars (tobacco waste and rice husk biochars), and metal accumulator plants (*Eleusine indica* L. Gaertn and *Rorippa sylvestris* L. Bess). The biochars were prepared by burning tobacco waste and rice husk through a slow pyrolysis process at 300-550^{0}C for 3-5 hours, and residence time between 5-90 minutes (Gezae and Chandraratne, 2018), The chemical composition of the biochars is presented in Table 1. The selection of the two plant species was based on the results of previous studies that *Eleusine indica* L. Gaertn and *Rorippa sylvestris* L. Bess are indigenous plant species that can grow well on the study area of Sumber Brantas village, Bumiaji Sub District, Batu, East Java (Hamzah et al., 2016; 2017).

Experimental design

The experimental design used for this study was a completely randomized block design comprised two factors with three replications. The first factor was biochar types, i.e. tobacco waste biochar (TWB) and rice husk biochar (RHB). The second factor was metal accumulator plants, i.e. *Eleusine* *indica* and *Rorippa sylvestris.* There were four treatment combinations, i.e. B0 = no biochar addition; B1 = RHB (rice husk biochar); B2 = TWB (tobacco waste biochar), and (3) B3 = 50% of RHB + 50% of TBW, and two metal accumulator plants, i.e. *Eleusine indica* (T1) and *Rorippa sylvestris* (T3). A control treatment (no biochar addition) was also included in this study. The plot size used in this study was 3 m x 4 m. The biochar dosage used in this research was 20 kg/ha.

Table 1. The characteristics of the biochar used in this study.

Type of Biochars	pH (H_2O)	C (%)	N (%)	P (%)	K (%)	Cation Exchange Capacity (cmol/kg)
Rice Husk Biochar (RHB)	8.44	34.57	1.10	1.19	1.61	19.64
Tobacco Waste Biochar (TWB)	8.26	38.15	1.59	0.68	1.06	51.89

The biochar was applied one week before planting by mixing it thoroughly on the 20 cm of the topsoil. The accumulator plants were planted with a distance of 20 cm x 25 cm. During this experiment, the plant growth and soil parameters were measured. Plant height was measured every week, while plant biomass (root weight, shoot, and leaf, dry weight), and root length were recorded at harvest time (90 days after planting).

Plant sampling and analysis

At harvest, plant shoots, roots, and leaves were separated by cutting the plant 5 cm above the soil surface. All harvested materials were collected in the morning to maintain the freshness of the plant samples. The shoots, roots and leaves were washed separately with tap water and rinsed with distilled water. The samples were oven-dried at 60ºC for 72 hours and ground into the powdered for heavy metal content analysis. Cd and Pb concentration in the plant shoots and roots were determined using an atomic absorption spectrometer by extracting the 250 mg of plant material with 10 mL of HNO_3 and $HClO_4$ acid.

Soil sampling and analysis

Soil samples were randomly collected two times from the experimental plots at the early stage of the experiment (before planting), and the end of the experiment (after plant harvest). Soil samples were air-dried at 60ºC for 72 hours, ground, and sieved to pass through a 2 mm sieve, and then analyzed their soil physical and chemical characteristics. Soil physical characteristic analysis included texture, aggregate stability, bulk density, and soil water content. Soil chemical characteristic analysis included pH (H_2O), organic-C, total nitrogen, total phosphorus, total potassium, and cation exchange capacity. For the analysis of heavy metals (Cd and Pb) contents, two grams of soil sample was extracted in a mixture of 10 mL of HNO_3 and $HClO_4$. The extract was then heated until 2 mL of liquid left. This solution then was mixed with distilled water step by step and heated until the solution became clear. The C and Pb contents in the extract were determined using an atomic absorption spectrophotometer.

Translocation and bio-concentration factors

Translocation Factor (TF) is a ratio of ketal concentration in plant shoots and metal concentration in plant roots. Bio-Concentration Factor (BCF) is a ratio of metal concentration in plant roots and metal concentration in soils (Mellem et al., 2009). TF indicates the rate of transfer of heavy metals from plant roots to plant shoots, while BCF determines the plant ability in absorbing heavy metals. TF and BCF were calculated using the following equations,

$$TF = \frac{\text{concentration of heavy metals in stems}}{\text{concentration of heavy metals in roots}}$$

$$BCF = \frac{\text{concentration of heavy metals in stems}}{\text{concentration of heavy metals in soils}}$$

Statistical analysis

The data obtained were subjected to analysis of variance followed by Least Significance Difference (LSD) test at 5% significance level (α = 0.05). Specific parameters that could not be analyzed statistically were presented descriptively.

Results and Discussion

Soil characteristics

The addition of biochar affected soil characteristics (Table 2). The effect depended on the source and types of biochar. The magnitude of the effects biochar types on the soil properties determined by soil types, biochar types, and incorporation rate (Dai et al., 2014), whereas swine manure biochar > pineapple peel biochar > rape straw biochar > reed straw biochar. Overall, the results of this study showed that the application of biochar induced changes in soil chemical characteristics, in terms of

N, organic-C, K, and CEC. The soil pH value, potassium content and soil organic-C content before and after application of rice husk biochar were not different ($p = 0.25$; $p = 0.15$; $p = 0.34$). For the total Nitrogen and CEC, biochar application had a significant effect ($p = 0.003$; $p = 0.003$), which was shown by the increase of their contents in the soil due to biochar application. The same phenomenon also happened in tobacco waste biochar addition (Table 3). Application of tobacco waste biochar did not influence the value of pH and organic C ($p = 0.099$; $p = 0.17$), however, the application affected the nitrogen and potassium contents and also the soil CEC ($p = 0.011$; $p = 0.041$; $p = 0.001$). Most of the studies showed that biochar increases soil pH, but our results showed the opposite. Biochar amendment may decrease or increase the soil pH, depending on the pyrolysis processes, biochar type, and incorporation rate (Dai et al., 2014). Microorganisms can decrease the soil pH by producing organic acid, SO_2, and release ammonia content, while bacterial hydrolysis of protein which releases the NH_4^+ will increase soil pH. The different effects of biochar were attributed to the nature of biochar, and how is the biochar is produced (Obia et al., 2015).

Table 2. Effects of rice husk biochar on soil characteristics.

Biochar Application	pH	N (%)	K (mmol/k)	Organic-C (%)	CEC (mmol/kg)
Before	7.40±0.231	0.33±0.006	13.8±0.033	34.25±0.149	305.6±0.097
After	7.42±0.012	1.11±0.041	16.0±0.007	35.12±2.944	395.8±0.041

Note: Values represent the mean ± standard error (n=3), CEC = cation exchange capacity.

Table 3. Effects of tobacco waste biochar on soil characteristics.

Biochar Application	pH	N (%)	K (mmol/kg)	Organic-C (%)	CEC (mmol/kg)
Before	6.00±0.058	0.30±0.023	21.1±0.076	31.81±5.423	281.3±0.151
After	6.28±0.012	1.52±0.051	10.7±0.024	48.13±0.033	518.7±0.025

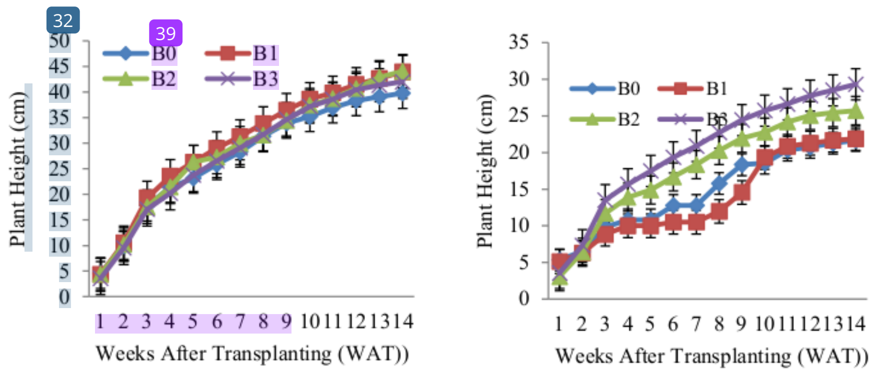
Note: Values represent the mean ± standard error (n=3), CEC = cation exchange capacity.

The nature of biochar will show the different effect on soil pH. Generally, biochar application improved soil characteristics (Tables 1 and 2) and affected all soil parameters measured. But the statistical analysis showed different effect between rice husk biochar and tobacco waste biochar on related soil properties. Rice husk biochar had a significant effect on pH value and potassium content ($p = 0.0001$; $p = 0.0004$). On the contrary, the addition of tobacco waste biochar served more available of soil nitrogen, soil organic-C, and cation exchange capacity ($p = 0.03$; $p = 0.00001$; $p = 0.00001$) than rice husk biochar. This difference was attributed to the alkalinity of biochar which is determined by the pyrolysis process and the soil types. Biochar alkalinity has a large contribution to the soil pH changes by changing the soil pH buffering (Dai et al., 2014). Rice husk biochar and tobacco waster biochar differed in alkalinity. Biochar amendment will increase the soil pH on acidic soil, just as already shown by Zhang et al. (2019). Obia et al. (2015) showed the difference effect of rice husk biochar and cacao shell biochar. Their study showed that rice husk biochar addition resulted in only 0.2 soil pH increase, whereas the cocoa shell will increase the soil pH by 2.3 units. It shows the alkalizing effect of biochar.

Growth and biomass of accumulator plants

In general, the results of this study showed that both *Eleusine indica* and *Rorippa sylvestris* are potential metal tolerant-plants because they could grow well on the contaminated soil. The addition of the biochar amendment had a significant effect on plant growth, as shown by increasing plant height (Figures 1a and 1b). Biochar has a positive effect on plant growth, due to improvement in soil physical, chemical, and biological properties (Cornelissen et al., 2013; Ding et al., 2016; Jalal et al., 2020), as also shown in Tables 2 and 3. The beneficial effects of biochar addition for the availability of C, N, Ca, Mg, P, and K are largely due to biochar capability in absorbing and releasing the nutrients (Rawat et al., 2019). The improved soil physical characteristic is caused by the porous structure of biochar, and also the presence of functional groups in the organic compounds of biochar. These soil characteristics indicate the sorption properties, included the sorption water capacity; then it will enhance the sorption on the nutrient. Biochar will also affect the activities and population of soil microorganisms, fungi and bacteria; and soil chemical properties, by creating a favourable environment for the microorganism, so it increases the soil fertility and productivity. Biochar addition improved soil fertility, especially soil C and N (Jalal et al., 2020), sufficient amount of nitrogen availability will lead to increase in plant growth (Akhtar et al., 2018).

The beneficial effects of biochar addition for the availability of nutrients are largely due to the higher content of potassium, phosphorus, and zinc availability, and to a lesser extent, calcium and copper (Lehmann et al., 2003).



(a) (b)

Figure 1. The influence of biochar on the height of *Eleusine indica* (a), and *Rorippa sylvestris* (b).

Biochar application will improve soil physicochemical characteristics such as water holding capacity and bulk density. According to Kätterera et al. (2019) biochar addition significantly decreased soil bulk density, increased WHC, increased available P, and also available K (Wang et al., 2018; Prawito, 2019). Biochar has a high surface area with high porosity (Jien and Wang, 2013), variable charges, cation exchange capacity (19.21 cmolc/kg), and surface sorption area (Sun et al., 2018). Biochar also contains more labile compounds of organic matter that support carbon for microbes activities. Microbial biomass was attributed to biochar mineralization, and responsible for organic matter content which is essential in serving available substrates for soil microbes. Ghorbani et al. (2019) showed that biochar added will affect the soil microbial abundance and community composition, then improve the soil organic content. The ratio of soil carbon and nitrogen will also change; thus, the nitrogen mineralization will increase. Saletnik et al. (2018) stated that biochar addition increases other biogenic compounds such as phosphorus, potassium, magnesium, and nitrogen. The role of biochar as a soil agent in improving soil properties could provide benefits for plant growth and development. Generally, the results of this study showed that *Eleusine indica* and *Rorippa sylvestris* are potential metal tolerant plants because they could grow well on the contaminated soil. The addition of the biochar amendment had a significant effect on plant growth, as shown by the increase of plant height (Figures 1a and 1b). Biochar application affected the metal accumulator plant growth. For all treatment, the plant growth increased polynomially from 3 weeks after transplanting (WAT) until 14 WAT. The addition of biochar could promote the metal accumulator plant growth at the early growth stage. This phenomenon can be associated with the biochar characteristics, which categorizes as slow-release material. There were no significant differences between all of the biochar types added to the *Eleusine indica* height (Figure 1a). However, a different pattern occurred on the growth of the *Rorippa sylvestris* plant. Figure 1b shows that the mixture of tobacco and rice husk biochars (B3) had the highest rate of *Rorippa sylvestris* height. Overall, the average height of *Eleusine indica* was higher than *Rorippa sylvestris*. *Eleusine indica* has greater adaptability on the contaminated soil, which can be seen from the tillers and leaves amount. Results of this study showed that the addition of tobacco waste biochar (B2), as well as the mixture of tobacco waste with rice husk biochar (B3), gave a higher number of tillers and leaves compared with no biochar (B0) and rice husk biochar (B1) treatments. It seemed that the addition of a mixture of rice husk biochar and tobacco waste biochar was more effective in affecting the plant metal accumulator growth compared with the rice husk biochar (B3)and tobacco waste biochar (B2). The total dry weight of leaf and root biomass increased due to the addition of biochar compared with no biochar treatment. Addition of biochar affected the dry weight of leaves and root biomass (p<0.1). Videgain-Marco et al. (2020) reported the increase of the dry weight of plant root biomass and grain weight due to biochar addition. Physico-chemical parameters changes caused by biochar addition can affect the plant biomass (Lehmann et al., 2011). Biochar affects the bulk density and soil porosity so that the roots can grow more easily. Biochar releases nutrients slowly and enhances the activities of soil microorganisms; therefore, the soil nutrients available will be longer, and the plant growth will improve. In this study, biochar types had no significant effect on the dry biomass weight ($p < 0.05$), either the below-ground biomass (root) or above-ground biomass (leaves).

Effect of the biochar on plant growth is strongly dependent on biomass feedstock derived biochar, pyrolysis method, and soil types (particle size, soil texture, mineralogy) (Videgain-Marco et al., 2020). The influence of biochar is more clearly shown on acidic sandy texture soils (Liu et al., 2013; Bi et al., 2019). Soil nutrient contents such as hydrogen, nitrogen, and oxygen decrease with increasing pyrolysis temperature. The specific area and pore volume also increases with rising pyrolysis temperature. Biochar produced at low temperature also leads to higher biological yield.

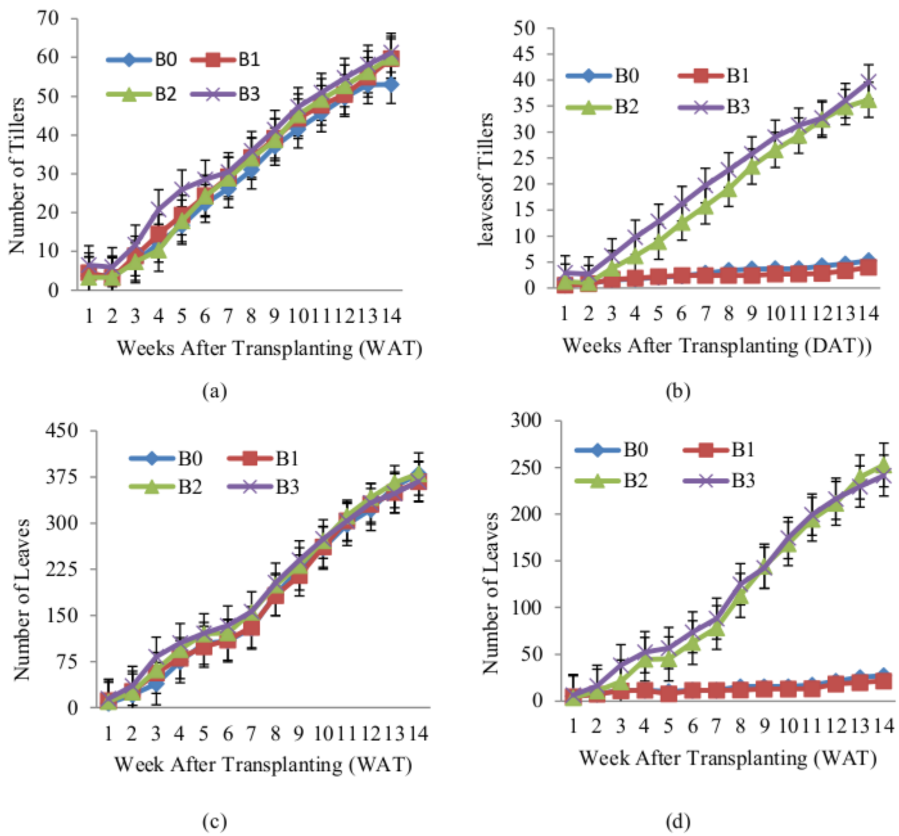


Figure 2. The influence of biochar on tiller and leaves of *Eleusine indica* (a), and *Rorippa sylvestris* (b).

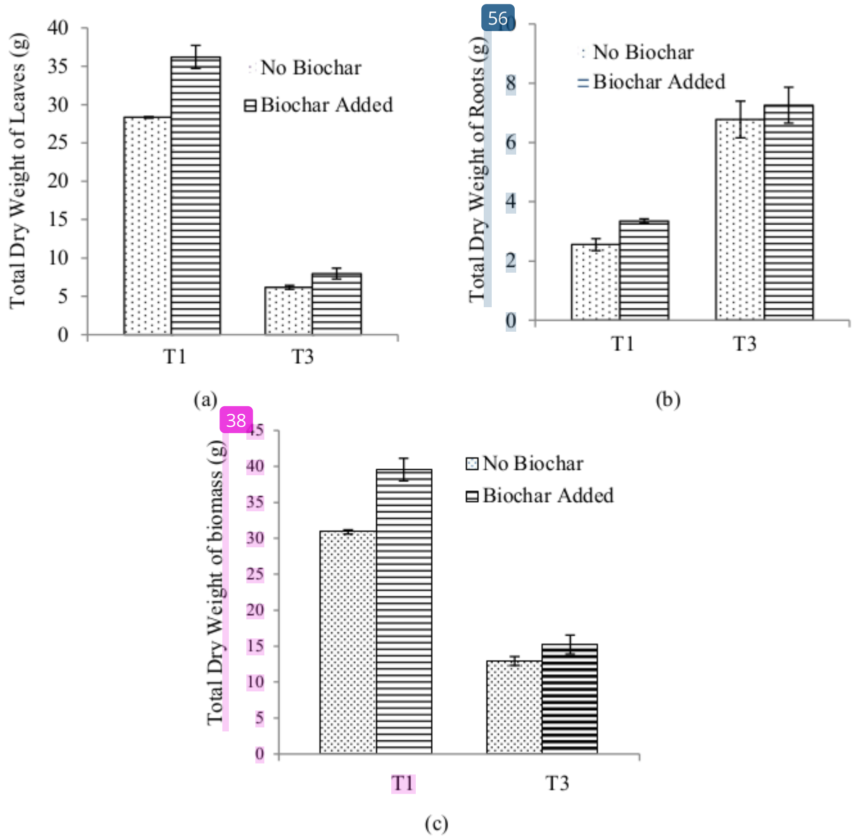


Figure 3. The dry weight of (a) leaves, (b) roots, and (c) biomass of *Eleusine indica* (T1), and *Rorippa sylvestris* (T3) due to the application of biochar.

Extracted Pb and Cd in soil

Pb and Cd contents in the soil due to the phytoremediation process by *Eleusine indica* was different from *Rorippa sylvestris* for all the types of biochar addition (Figure 4). Overall, *Eleusine indica* seemed to be more effective in absorbing heavy metals; the availability of soil Pb content was lower than that of *Rorippa sylvestris*. Figure 4 also shows that combining *Eleusine indica* with tobacco waste biochar mix with rice biochar (B3) was more effective than rice husk biochar (B1) or tobacco waste biochar (B2). Heavy metal phytoremediation by *Eleusine indica* and *Rorippa sylvestris* on polluted agricultural soil significantly improved the soil characteristics. The reduction of soil heavy metals content is an indicator of the succeeds of soil characteristics improvement. The diminishing of soil heavy metal content by each plant is presented in Figure 4. The combination of two types of metal accumulator plants and biochar seemed effective in reducing heavy metals as shown in the B3 treatment (a mixture of rice husk biochar and tobacco waste). The application of rice husk biochar or tobacco waste biochar alone was less significant in reducing soil Pb and Cd content, but the combination of two kinds of biochar and metal accumulator plants was more effective in absorbing heavy metal (Figure 4). This indicates that combining *Eleusine indica* and *Rorippa sylvestris* with the mixture of rice husk biochar and tobacco waste can diminish Pb and Cd heavy metals in polluted soils. Different types of biochar have a different effect on heavy metal extractability and enzymes activity. Rice straw biochar is more potential in increasing the urease and catalase activity (Yang et al., 2016), which is essential in soil productivity. Biochar has high reactivity of organic compounds that are formed during the pyrolysis process. The pyrolysis process resulted in the forming of surface functional groups.

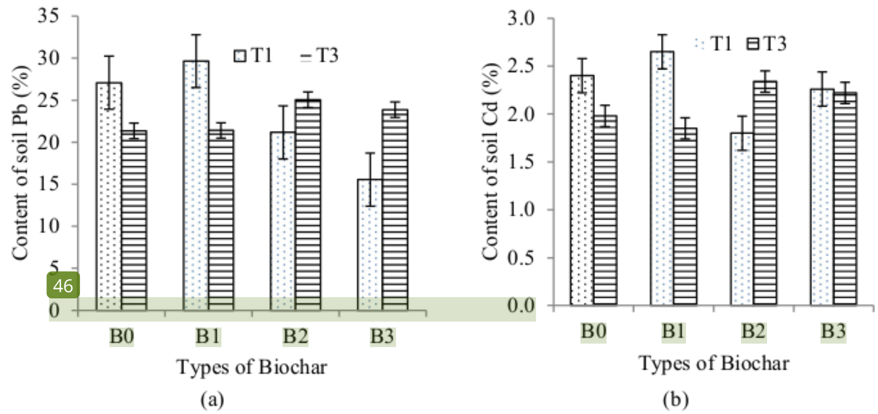


Figure 4. Soil Cd content on different types of biochar (B0 = without biochar; B1 = rice husk biochar; B2 = tobacco waste biochar; B3= mixture of B1 and B3) on *Eleusine indica* (T1) and *Rorippa sylvestris* (T3).

Thus it has potency in improving degraded soil, especially soil contaminated heavy metals. An organic acid is a polymer, an end product of a plant or living organism decomposition. Organic acids have the potential to enhance metal mobility in soil profiles by reducing soil pH and forming complexes with heavy metals. The high affinity and functionality of soil organic acids bind heavy metals that are related to their molecular weight will diminish heavy metals availability by chelating mechanism (Ahmed et al., 2019). The organic acids will form complexes with heavy metals organometallic or chelate complexes with their functional group (Adeleke et al., 2017). Biochar characteristics i.e. porous structure, high charge surface area, and surface functional groups (carboxyl, hydroxyl, phenolic hydroxyl, and carbonyl groups) were important factors that affect the bioavailability of soil contaminant (Nartey and Zhao, 2014). The functional group at the biochar surface determined the heavy metals immobilization; thus, the availability of the heavy metals will be decreased (Chibuike and Obiora, 2014).

The addition of soil amendment such as biochar is important in heavy metals immobilization on polluted soils (Liu et al., 2020). Biochar will enhance the absorption of heavy metals that, in turn, improve soil physical, chemical and biological properties. According to Atkinson et al. (2010), biochar application will improve soil characteristics by (1) increasing nutrient availability, nutrient retention, and water retention, and (2) creating suitable habitat for symbiotic microorganisms. Besides their positive effect on soil properties, biochar application in acid soils increases crop productivity (Jeffery et al. 2011; Spokas et al. 2011). Gaskin et al. (2010) revealed that no significant effect of biochar application on soils with neutral pH in Mid-West USA. The use of biochar on agricultural soil reduces the rate of CO_2 and N_2O emissions. It contributes to increasing carbon stocks (52.8%), meaning that biochar can store carbon in among time and large enough quantities (Chen et al., 2015).

Heavy metal content in plant shoots and roots

Figure 5 illustrates the effects of different types of biochar on the accumulation of heavy metals in the shoots (leaves) and roots of two metal accumulator plants. The metal concentration of heavy metal was higher on roots than shoots. This result coincided with Huang et al. (2018), they showed that biochar increased the root Pb, Zn, Cu, Cd, and As concentration, but no significant differences of the shoot of plants. Among the biochar types treatment, both *Eleusine indica* and *Rorippa sylvestris* have the same capability in heavy metal accumulation. However, Cd accumulation was lower than Pb accumulation. In this study, the rice husk biochar and tobacco waste biochar improved soil characteristics. Soil improvement would enhance the growth of the metal accumulator plant, so the accumulation of Pb and Cd (Figure 5) would increase that in turn, affected the growth of *Eleusine indica* and *Rorippa sylvestris*. The plants would accumulate the heavy metals in their biomass, and soil heavy metals availability would be diminished and recovering the polluted soils. Planting the food crops in the next season by measuring the accumulation of heavy metal in their plant tissue will make sure whether this technique succeeded or not.

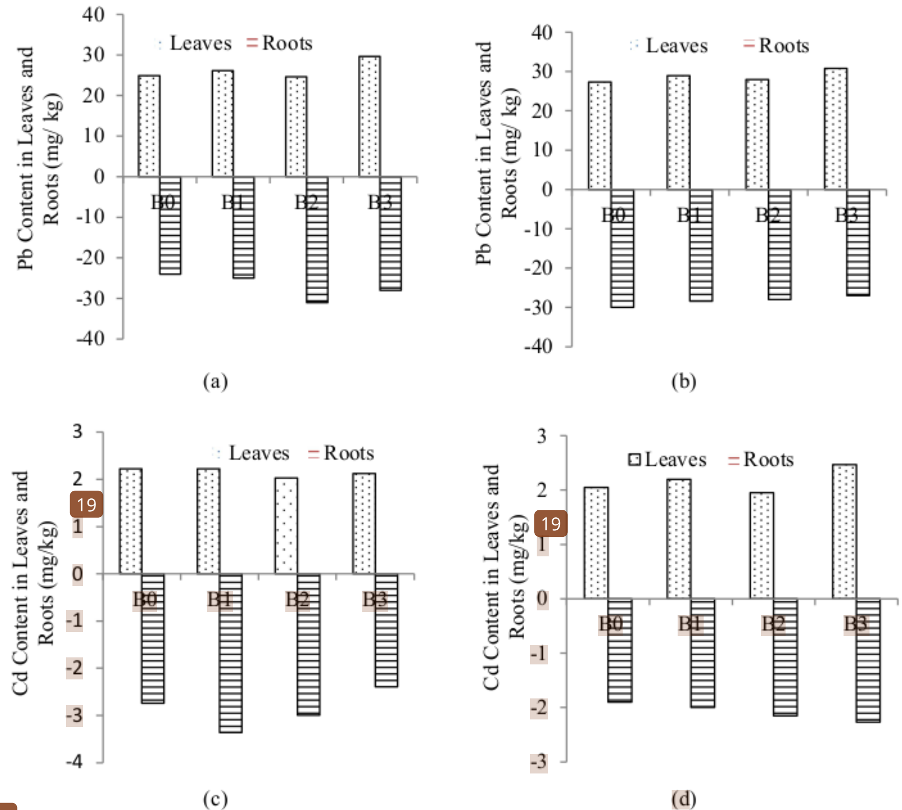


Figure 5. Effects of biochar types on Pb content in leaves and roots of (a) *Eleusine indica* and (b) *Rorippa sylvestris*; and Cd content in leaves and roots of (c) *Eleusine indica* and (d) *Rorippa sylvestris*.

The results showed that both *Eleusine indica* and *Rorippa sylvestris* were able to reduce heavy metals in the soil until 75%. *Eleusine indica* combined with rice husk biochar was able to reduce Pb until 78.36%, while tobacco waste combined with biochar could reduce Pb up to 84.15%. *Rorippa sylvestris* plant combined with rice husk biochar could reduce up to 82.49%, and the combination of rice husk biochar and tobacco waste biochar could reduce up to 82.74%. Results of this study showed that the combination of *Eleusine indica* (and tobacco waste biochar was the highest (85%) in absorbing heavy metals Cd, and the lowest was the combination of rice husk and tobacco waste biochar (79.03%). A different pattern was found with the uses of *Rorippa sylvestris*. Tobacco waste biochar with *Rorippa sylvestris* combination had the lowest heavy metals accumulation. A combination of rice husk biochar and tobacco waste biochar reduced Cd by 81.57% and 80.40%, respectively, while tobacco waste biochar alone reduced Cd by 76.12%. Overall, the application of both types of metal accumulator plants and rice husk and tobacco waste biochar was able to reduce Pb and Cd up to > 80%. This occurred because both plant species well adapted on polluted soil.

This study showed that *Rorippa sylvestris* had a higher capacity on Cd or Pb absorption than *Eleusine indica* as shown by their TF and BCF values for Cd and Pb. Both plant species had TF and BCF values for Cd and Pb higher than 1. This means that those plants can be categorized as Cd and Pb hyperaccumulators. The translocation factor value ranged for Cd and Pb from 1.91 until 2.14 for *Eleusine indica* and 1.79 until 2.06 for *Rorippa sylvestris* (Figure 6). Bioconcentration factor (BCF) represents the content of heavy metal in an organism and their potency to remove from the soil.

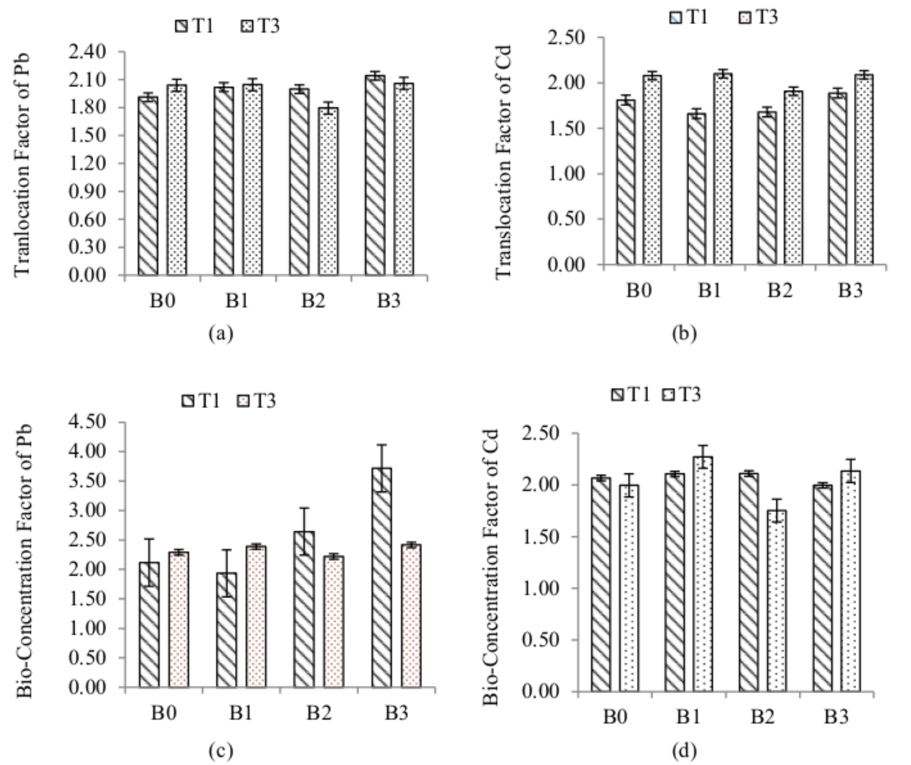


Figure 6. Translocation Factor (TF) of *Rorippa sylvestris* (T1) and *Eleusine indica* (T3) for Pb (a) and (b) Cd (b), and Bio-Concentration Factor (BCF) of *Rorippa sylvestris* (T1) and *Eleusine indica* (T3) for Pb (c) and Cd (b).

The translocation factor (TF) refers to the ability of heavy metals to be translocated from roots to shoots or stems. These value refers to the plant ability to translocate heavy metals (Takarina and Pin, 2017). Each plant has different ways of storing heavy metals in stems, roots, or leaves (Ndeda and Manohar, 2014). Bio-Concentration Factor (BCF) is a common index usually used in determining and evaluating the ability of a plant to extract heavy metals. Plants with the BCF value higher than 1 are categorized as hyperaccumulators, while plants with BCF value lower than 1 are considered as accumulators (Mellem et al., 2009; 2012). The metal accumulator plants have different ways of storing heavy metals in their body. Some plants store heavy metals in its roots, but others translocate heavy metals into their shoot and or leaves. The translocation factor (TF) value is commonly used to evaluate the heavy metals storage in plant tissue. TF>1 indicates that the plants are effective in translocating heavy metals from roots to shoot (Fayiga and Ma, 2006; Rezvani and Zaefarian, 2011). This result is in line with Cordeiro et al. (2016) who reported that *Rorippa sylvestris* showed significantly higher concentration of heavy metals in their upper parts of their body. The translocation factor value above 1 suggests better partitioning in the aerial parts, as also has been shown in Figure 5.

Conclusion

Eleusine indica (L.) Gaertn and *Rorippa sylvestris* (L.) Bess are potential metal accumulator plants in Cd and Pb polluted soil based on their growth and high Pb and Cd accumulation in leaves. The application of biochar increased growth of the plants and decreased the accumulation of heavy metals in leaves. The application of the mixture of rice husk biochar and tobacco waste biochar showed the best improvement on plant growth, dry biomass of leaves and roots, plant height, and tiller numbers. The biochar application also increased soil pH, C, N, K, and cation exchange capacity.

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References

Adeleke, R., Nwangburuka, C. and Oboirien, B. 2017. Origins, roles and fate of organic acids in soils: A review South *African Journal of Botany* 108:393–406, doi: 10.1016/j.sajb.2016.09.002.

Ahammad, S.J., Sumithra, S., Jameer, S. and Senthilkumar, P. 2018. Mercury uptake and translocation by indigenous plants. *Rasayan Journal of Chemistry* 11(1):1-12, doi: 10.7324/RJC.2018.1111726.

Ahmed, I.M., Helal, A., Aly., El Aziz, N.A., Gamal, R., Shaker, N.O. and Helal, A.A. 2019. Influence of some organic ligands on the adsorption of lead by agricultural soil. *Arabian Journal of Chemistry* 12:2540–2547, doi: 10.1016/j.arabjc.2015.03.012.

Akhtar, K., Wang, W., Khan, A., Ren, G., Zaheer, S., Sial, T.A., Feng, Y. and Yang, G. 2018. Heat straw mulching with fertilizer nitrogen: an approach for improving soil water storage and maize crop productivity. *Plant, Soil and Environment* 64: 330–337, doi: 10.17221/96/2018-PSE.

Anarado, C.E., Mmeka, O.P., Anarado, C.J.O. and Umedum, N.L. 2018. Phytoremediation potentials of *Dieffenbachia bownanii* and *Eleusine* indica (L.) Gaertn for cadmium, lead, zinc and cobalt. *IOSR Journal of Applied Chemistry* 11(7) Ver. II : 68-71, doi: 10.9790/5736-1107026871.

Atkinson, C.J., Fitzgerald, J.D. and Hipps, N.A. 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and Soil* 337:1–18, doi:10.1007/s11104-010-0464-5.

Babula, P. Adam, V., Havel, L. and Kizek, R. 2012. Cadmium accumulation by plants of Brassicaceae family and its connection with their primary and secondary metabolism. Chapter 3 *In The Plant Family Brassicaceae*: *Contribution Towards Phytoremediation*, Environmental Pollution 21. N.A. Anjum et al. (eds.) . Springer Science+Business Media Dordrecht, doi: 10.1007/978-94-007-3913-0_3.

Bhat S.A., Bhatti S.S., Singh, J., Sambyal, V., Nagpal, A. and Vig, A.P. 2016. Vermiremediation and phytoremediation: eco approaches for soil stabilization. *Austin Environmental Sciences* 1(2): 1006.

Bi, Y., Cai, S., Wang, Y., Xia, Y., Zhao, X., Wang, S. and Xing, G. 2019. Assessing the viability of soil successive straw biochar amendment based on a five-year column trial with six different soils: Views from crop production, carbon sequestration and net ecosystem economic benefits. *Journal of Environmental Management* 245:173–186, doi: 10.1016/j.jenvman.2019.03.051.

Chen, J., Kim, H. and Yoo, G. 2015. Effects of biochar addition on CO_2 and N_2O emissions following fertilizer application to a cultivated grassland soil. *PLoS ONE* 10(5): e0126841, doi: 10.1371/journal.pone.0126841.

Chibuike, G.U. and Obiora, S.C. 2014. Heavy metal polluted soils: effect on plants and bioremediation methods. *Applied and Environmental Soil Science* Volume 2014, Article ID 752708, doi: 10.1155/2014/752708.

Chirakkara, R.A. and Reddy, K.R. 2015. Biomass and chemical amendments for enhanced phytoremediation of mixed contaminated soils. *Journal of Ecological Engineering* 85 : 265-274, doi: 10.1016/j.ecoleng.2015.09.029.

Conesa, H.M., Evangelou, M.W.H., Robinson, B.H. and Schulin, R. 2012. A critical view of current state of phytotechnologies to remediate soils: still a promising tool?. *The Scientific World Journal* Volume 2012. Article ID. 173829, doi:10.1100/2012/173829.

Cordeiro, C., Favas, P.J.C., Pratas, J., Sarkar, S.K. and Venkatachalam, P. 2016. Uranium accumulation in aquatic macrophytes in a uraniferous region: Relevance to natural attenuation. *Chemosphere* 156:76-87, doi: 10.1016 /j.chemosphere.2016.04.105.

Cornelissen, G., Martinsen, V., Shitumbanuma, V., Alling, V., Breedveld, G.D., Rutherford, D.W., Sparrevik, M., Hale, S.E., Obia, A. and Mulder, J. 2013. Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia. *Agronomy* 3: 256–274, doi:10.3390/agronomy3020256.

Dai, Z., Wang, Y., Muhammad, N., Yu, X., Xiao, K., Meng, J., Liu, J., and Brookes, P.C. 2015. Effects and mechanisms of soil acidity changes, following incorporation of biochars in three soils differing in initial pH. *Soil Science Society of America Journal* 78(5):1606, doi: 10.2136/sssaj2013.08.0340.

Dar, M.I., Khan, F.A., Rehman, F., Masoodi, A., Ansari, A.A., Varshney, D., Naushin, F. and Naikoo, M.I. 2014. Roles of Brassicaceae in Phytoremediation of Metals and Metalloids. A.A. Chapter 14 *In* Phytoremediation: Management of Environmental Contaminants, Volume 1, 201. Ansari et al. (eds.). © Springer International Publishing Switzerland 2015. DOI 10.1007/978-3-319-10395-2_14.

Devi, U. and Bhattacharyya, K.G. 2018. Mobility and bioavailability of Cd, Co, Cr, Cu, Mn and Zn in surface runoff sediments in the urban catchment area of Guwahati, India. *Applied Water Science* 8, article number**:** 18, doi: 10.1007/s13201-018-0651-8.

Ding, Y., Liu, Y., Liu, S., Li, Z., Tan, X., Huang, X., Zeng, G., Zhou, L. and Zheng, B. 2016. Biochar to improve soil fertility: a review. *Agronomy for Sustainable Development* 36, article number: 36, doi: 10.1007/s13593-016-0372-z.

Elakes, C.C. 2014. Eco-technological solutions for the remediation of polluted soil and heavy metal recovery. In: Hernández-Soriano, M.C., Ed., *Environmental Risk Assessment of Soil Contamination*, InTech, Rijeka, 309-335. http://dx.doi.org/10.5772/57314.

Fayiga, A.Q. and Ma L.Q. 2006. Using phosphate rock to immobilize metals in soils and increase arsenic uptake in *Pteris vittata*. *Science of the Total Environment* 359:17-25, doi: 10.1016/j.scitotenv.2005.06.001.

Garba, S.T., Kolo, B.G., Samali, A. and Nkfaminya, I. I. 2013. Phytoremediation: Enhanced phytoextraction ability of *E. Indica* at different level applied EDTA. *International Journal of Science and Nature* 4(1): 72-78, doi:10.1080/15320383.2014.815153.

Gaskin, J., Steiner, C., Harris, K., Das, K., Dewey Lee, R., Morris, L. and Fisher, D.S. 2010. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrients status, and yield. *Agronomy Journal* 102(2): 622-633, doi: 10.2134/agronj2009.0083.

Gezae, A. and Chandraratne, M. 2018. Biochar production from biomass waste-derived material. In *Reference Module in Materials Science and Materials Engineering*, doi: 10.1016/B978-0-12-803581-8.11249-4.

Ghorbani, M., Asadi, H. and Abrishamkesh, S. 2019. Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. *International Soil and Water Conservation Research* 7:258-265, doi:10.1016/ j.iswcr.2019.05.005.

Hamzah, A., Hapsari, R.I. and Priyadarshini, R. 2017. The potential of wild vegetation species of *Eleusine indica* L., and *Sonchus arvensis* L. for phytoremediation of Cd-contaminated soil. *Journal of Degraded and Mining Lands Management* 4(3): 805-813.

Hamzah, A., Hapsari, R.I. and Wisnubroto, E.I. 2016. Phytoremediation of cadmium-contaminated agricultural land using indigenous plants. *International Journal of Environmental & Agriculture Research* 2(1): 8-14.

Huang, L., Li, Y., Man Zhao, Chao. Y, Qiu, R. Yang, Y. and Wang, S. 2018. Potential of *Cassia alata* L. coupled with biochar for heavy metal stabilization in multi-metal mine tailings. *International Journal of Environmental Research and Public Health* 15(3): E494, doi:10.3390/ijerph15030494.

Jalal, F., Arif, M., Akhtar, K., Khan, A., Naz, M., Said, F., Zaheer, S., Hussain, S., Imtiaz, M., Khan, M.A., Ali, M. and Wei, F. 2020. Biochar integration with legume crops in summer gape synergizes nitrogen use efficiency and enhance maize yield. *Agronomy* 10, article number: 58, doi:10.3390/agronomy10010058.

Jeffery, S., van der Velde, M., Verheijen, F.G.A. and Bastos, A. C. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture Ecosystems & Environment* 144(1):175-187, doi: 10.1016/j.agee.2011.08.015.

Kätterera, T., Roobroeck, D., Andrénc, O., Kimutaib, G., Karltund, E., Kirchmannd, H., Nyberge, G., Vanlauweb, B. and de Nowina, K.R. 2019. Biochar addition persistently increased soil fertility and yields in maize soybean rotations over 10 years in sub-humid regions of Kenya. *Field Crops Research* 235:18–26, doi:org/10.1016/j.fcr.2019.02.015.

Khalid, S., Muhammad, S., Nabeel K.N., Behzad M., Irshad, B. and Camille, D. 2017. A comparison of technologies for remediation of heavy metal contaminated soils. *Journal of Geochemical Exploration* 182:247-268, doi: 10.1016/j.gexplo.2016.11.021.

Lehmann J., Rillig M.C., Thies J., Masiello C.A., Hockaday W.C. and Crowley D. 2011. Biochar effects on soil biota: a review. *Soil Biology and Biochemistry* 43: 1812-1836, doi: 10.1016/j.soilbio.2011.04.022.

Lehmann, J., da Silva, J.P. Jr., Steiner, C., Nehls, T., Zech, W. and Glaser, B. 2003. Nutrient availability and leaching in an archaeological anthrosol and a ferrasol of the Central Amazon basin: fertilizer, manure, and charcoal amendments. *Plant and Soil* 249:343-357, doi:10.1023/A:10228331161.

Liu, W., Li, Y., Feng, Y. and Qiao, J. 2020. The effectiveness of nano biochar for reducing phytotoxicity and improving soil remediation in cadmium-contaminated soil. *Scientific Reports* 10**:** 858, doi: 10.1038/s41598-020-57954-3.

Liu, X., Zhang, A., Ji, C., Joseph, S., Bian, R., Li, L., Pan, G. and Paz-Ferreiro, J. 2013. Biochar's effect on crop productivity and the dependence on experimental conditions -A meta-analysis of literature data. *Plant and Soil* 373(1-2):583–594, doi: 10.1007/s11104-013-1806-x.

Mellem, J., Baijanth, H. and Odhav, B. 2009. Translocation and accumulation of Cr, Hg, As, Pb, Cu and Ni by *Amaranthus dubius* (Amaranthaceae) from contaminated sites. *Journal of Environmental Science and Health* 44:568-575, doi:10.1080/10934520902784583.

Mellem, J.J., Baijnath, H. and Odhav, B. 2012. Bioaccumulation of Cr, Hg, As, Pb, Cu and Ni with the ability for hyperaccumulation by *Amaranthus dubius*. *African Journal of Agricultural Research* 7(4): 591-596, doi: 10.5897/AJAR11.1486.

Ministry of the Environment, Finland. 2007. Government Decree on the Assessment of Soil Contamination and Remediation Needs (214/2007, March 1, 2007).

Nartey, O.D. and Zhao, B. 2014. Characterization and evaluation of biochars derived from agricultural waste biomass from Gansu, China Conference Paper. *The World Congress on Advances in Civil Environmental and Materials Research* 14. https:// www. researchgate.net/publication/320371719.

Ndeda, L.A. and Manohar, S. 2014. Bioconcentration factor and translocation ability of heavy metals within different habitats of hydrophytes in Nairobi, Dam, Kenya. *IOSR Journal of Environmental Science, Toxicology and Food Technology* 8(5) Ver. IV: 42-45.

Nejad, Z. D. and Jung, M.C. 2017. The effects of biochar and inorganic amendments on soil remediation in the presence of hyperaccumulator plant. *International Journal of Energy and Environmental Engineering* 8: 317–329, doi: 10.1007/s40095-017-0250-8.

Obia, A., Cornelissen, G., Mulder, J. and Dörsch, P. 2015. Effect of soil pH Increase by biochar on NO, N_2O and N_2 production during denitrification in acid soils. *Plos One* 10(9): e0138781, doi:10.1371/ journal.pone.0138781.

Panda, S.K. and Patra, H.K. 2016. Heavy-Metal-Induced Oxidative Stress in Plants: Physiological and

Molecular Perspectives. In: *Abiotic Stress in Plants*, Publisher: John Wiley & Sons, doi: 10.1002/9783527694570.ch11.

Prawito, P. 2019. Effect short–term biochar application on Ultisol of Bengkulu, Indonesia. *The UGM Annual Scientific Conference Life Sciences* 2016, KnE Life Sciences, pages 245–254. Doi: 10.18502/kls.v4i11.3870.

Rawat, J., Saxena, J. and Sanwal, P. 2019. Biochar: a sustainable approach for improving plant growth and soil properties. Biochar - an imperative amendment for soil and the environment. Intech Open. doi: 10.5772/intechopen.82151.

Rezvani, M. and Zaefarian, F. 2011. Bioaccumulation and translocation factors of Cadmium and Lead in *Aeluropus littoralis*. *Australian Journal of Agricultural Engineering* 2(4): 114-119.

Saletnik, B., Zagula, G., Bajcar, M., Czernicka, M. and Puchalsk, C. 2018. Biochar and biomass ash as a soil ameliorant: the effect on selected soil properties and yield of giant Miscanthus (*Miscanthus x giganteus*). *Energies* 11:25-35, doi: 10.3390 / en11102535.

Spokas, K.A., Cantrell K.B. and Novak J.M., Archer, D.W., Ippolito, J.A., Collins, H.P., Boateng, A.A., Lima, I.M., Lamb, M.C., McAloon, A.J., Lentz, R.D. and Nichols, K.A. 2011. Biochar: a synthesis of its agronomic impact beyond carbon sequestration. *Journal of Environmental Quality* 41: 973–989, doi: 10.2134/jeq2011.0069.

Sun, W., Zhang, S. and Su, C. 2018. Impact of biochar on the bioremediation and phytoremediation of heavy metal(loid)s in soil. In *Advances in Bioremediation and Phytoremediation* Chapter 9, doi: 10.5772/intechopen.70349.

Takarina, N.D. and Pin, T.G. 2017. Bioconcentration Factor (BCF) and Translocation Factor (TF) of heavy metals in in mangrove trees of Blanakan fish fees farm. *Makara Journal of Science* 21(2): 77-81, doi: 10.7454/mss.v21i2.7308.

Videgain-Marco, M., Marco-Montori, P., Martí-Dalmau, C., del Carmen Jaizme-Vega, M., Manyà-Cervelló, J.J. and García-Ramos, F.J . 2020. Effects of biochar application in a sorghum crop under greenhouse conditions: growth parameters and physicochemical fertility. *Agronomy* 10, article number:104, doi:10.3390/agronomy10010104.

Wang, Li., Xue, Cheng., Nie, Xinxing., Liu, Yi. and Chen, Fang. 2018. Effects of biochar application on soil potassium dynamics and crop uptake. *Journal of Plant Nutrition and Soil Science* 181(50: 635-643, doi: 10.1002/jpln.201700528.

Wani, S.H., Sanghera, G.S., Athokpam, H., Nongmaithem, J., Nongthongbam, R., Naorem, B.S. and Athokpam, H.S. 2012. Phytoremediation: curing soil problems with crops. *African Journal of Agricultural Research* 7(28): 3991-4001, doi:10.5897/AJAR12.1061.

Yang, X., Liu, J., McGrouther, K., Huang, H., Lu, K., Guo, X., He., L., Lin, X., Che, L., Ye, Z. and Wang, H. 2016. Effect of biochar on the extractability of heavy metals (Cd, Cu, Pb, and Zn) and enzyme activity in soil. *Environ Science and Pollution Research* 23: 974–984, doi: 10.1007/s11356-015-4233-0.

Zhang, M., Riaz, M., Zhang, L., El-desouki, Z and Jiang, C. 2019. Biochar induces changes to basic soil properties and bacterial communities of different soils to varying degrees at 25 mm rainfall: more effective on acidic soils. *Frontiers in Microbiology* 10:1321, doi: 10.3389/fmicb.2019.01321.

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---

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---

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