Reclamation Of Heavy Metal Contaminated Soil By Using Biochar As Soil Conditioner

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Abstract: Increasing population density and scarce funds available for environmental restoration gearing to explore and speed-up the low-cost and ecologically sustainable remedial options to restore contaminated lands so as to reduce the associated risks, make the water and land resources available for agricultural production, enhance food security and scale down the land tenure problems. Biochar is a carbon negative, charcoal based, soil amendment that can be designed to help reclaim and improve marginal soils by increasing soil water holding capacity and enhancing fertility, while also generating high-value renewable energy co-products during its production. In this study, the soil samples collected form a field which is assumed to be contaminated with various heavy metals (esp: Cd and Pb) was conducted to reclaim by using biochar from difference raw material sources (coconut shell, peanut shell, wheat straw, rice husk and biogas byproduct) with the same dosages. Biochar from coconut shell was used in three difference particle sizes 30-60 mesh, 60-80 mesh and 80-200 mesh. The experiment was carried out in pot trial under nursery house with four replicas. Soil organic matter analysis, pH, cation exchange capacity of soil, N, P, K assimilation and incorporated heavy metal concentration from both soil and plant samples were tested in order to know the effect of amended biochar. The purpose of this research is to evaluate the effectiveness of biochar from difference raw material sources to reduce levels of heavy metal in the soil through the analysis of their status and sorption behavior on biochar. The research was conducted at Guangdong Academy of Agricultural Science, Guangzhou, China.

Keywords: Biochar; Sustainable; Raw materials; Contaminated; Sorption

1. Introduction

Nowadays, according to industrialization, civilization and anthropogenic activities, excessive loss of arable soil pace a way to handle the soil contamination as a common global challenging problem. Soils are the major sink for heavy metals released into the environment by human activities and most metals can't undergo microbial or chemical degradation and their total concentration in soils persists for a long time after their introduction [1]. Although heavy metal can be found in the soil naturally from the pedogenetic processes of weathering of parent materials at levels that are regarded as trace (<1000mgkg−1), and not reaches to toxic level [2]. The primary culprits of agricultural and urban soil contamination are mining, manufacturing, and the use of synthetic products (e.g. pesticides, paints, batteries, industrial waste, and land application of industrial or domestic sludge). Risks associated with polluted soils can imply underground water pollution, the bioavailability of toxic elements (i.e. ability to enter the different compartments of the food chain) and primarily to the phytoavailability (i.e. availability to plants). Plants are fundamental components of natural ecosystem and agroecosystems, and also the basic compartments of the terrestrial food chain [3]. The Itai-Itai disease that affected on farmers is the best example for long-term diet of cadmium-contaminated rice [4]. On the other hands, due to the high level of toxic elements in their tissue, plants may also lost their nutritional value, dramatic reduce in growth and crop yields that may lead to further economic damage of farmers, as can be observed near metal smelters or mine spoils. Even though it will be toxic and negative effects at high concentrations, some essential elements still need to be present in the plants tissues as their deficiency can induce loss of biomass production and physiological disorder is plants [3]. Irrespective of their sources in the soil, accumulation of heavy metals can degrade soil quality, reduce crop yield and the quality of agricultural products, and thus negatively impact the health of human, animals, and the ecosystem [5]. In recent years, the environmental pollution caused by heavy metals has become increasingly prominent around the world and there is an urgent need to properly resolve these complex environmental problems. In order to support ecologically and socially sustainable development, it is necessary to coordinate the activities of the governments and markets to control the discharges of heavy metals as well as exploring new strategies for remediation of the polluted environment. Biomass pyrolysis derived charred, so called Biochar, has been attracted significant research interests due to its carbon storage and climate change mitigation potential [4]. Addition of these carbonaceous materials to the soil may not only lastingly store CO_2 captured from the atmosphere in the terrestrial environment [6] but also its amendment to the contaminated soil [7] offers benefits for the in-situ sequestration of hydrophobic organic compounds (HOCs) [8]. Biochar can help to reclaim and improve marginal soils by increasing soil water holding capacity and enhancing fertility, while also generating high-value renewable energy co-products during its production [10]. Biochar has been considered as a possible solution to various environmental problems, including soil contamination with potentially toxic elements. It provides a unique opportunity to improve soil fertility and nutrient-use efficiency using locally available and renewable materials in a sustainable way [3]. In addition, biochar darkens the colour of soil, so that it warms more quickly in spring. The effects of biochar on the mobility of metals in soils are, however, poorly understood as their interactions are complex and several sorption mechanisms have been proposed for divalent metals such as lead, copper, cadmium, zinc and nickel (Pb, Cu, Cd, Zn and Ni), including electrostatic attraction with negatively charged biochar surfaces [11]. One of the concerns regarding the use of biochar for soil remediation is its long-term impact on the persistence of biodegradable pollutants [12]. Biochar may also increase beneficial microbial activity in the soil, which can contribute to higher crop yields. Moreover, adding biochar usually darkens the color of the soil, and since dark soils absorb more solar energy they may, depending on water content and plant cover, result in higher soil temperatures. This will affect rate processes, such as the nutrient cycling, and potentially prolong the growing season in seasonal environments. For example, in Japan it is a customary farming practice to apply charcoal to speed up snow melt [13]. Not all biochar is the same; the properties of the biochar will vary according to the type feedstock used (wood, animal waste, etc) and the temperature and duration of pyrolysis through which it is produced. This gives biochar the potential to be engineered for specific properties that would meet specific needs in different types of soil. All of the fertility benefits of biochar will also vary depending on original soil properties, type of crop, local climate and geography [14].

2. Material and Methods

Bioremediation is an effective and widely accepted method of treating heavy metal polluted soils. In this research, the agricultural soil samples which have high level of heavy metal incorporating were collected from the field of Renhua, Shaoguan City, Guangdong Province. The possible sources of pollutants in that soil samples might be accumulation from the environment as the place is surrounded by numerous mining industries. The potential contaminants are Pb and Cd whereas other type of metals may also be possible. The ex-situ remediation treatment of was conducted by difference biochar and soil conditioner in small pots at the nursery house of Guangdong Academy of Agricultural Science, Guangzhou. During soil preparation for mustard cultivation, eight difference pots (including control one) with four replicas were prepared by amending the soil with biochar of seven different types: biochar from coconut shell in three difference particle sizes (30-60 meshs, 60-80 meshs, 80-200 meshs), biochar from peanut shell, biochar wheat straw, biochar from rice husk and biochar from biogas byproducts. Beside these amended biochar, the soil was also nourished by adding N, P, K in appropriate ratio. The vegetable mustard was cultivated in each pot for eight weeks and then collected the plants and soil samples for further analysis in laboratory. The soluble concentration of N, P, K, Zn, Ca, Pb, Cd, enzymes, pH and cation exchange capacity (CEC) were measured from the collected soil whereas the total concentrations of those incorporated metals and other parameters were also found-out in plant samples.

3. Result and Discussion

The properties of biochar solely depend on the type and particle size of raw material used, temperature and process of pyrolysis. Difference biochar possess difference capacity and some particular materials might be more suitable than others to remediate different heavy metals. So, it is very important to consider not only soil type and characteristics but also the key biochar properties such as raw material source, surface area, pH, ash and carbon content which can be affected by post-treatments in order to promote biochars' ability to immobilize heavy metals [15]. According to experimental result biochar from difference sources play a difference role in plant growth. In the case of macronutrient uptake by plants, those all treatments are slightly less than the control one. In the case of heavy metal uptake by plant, those all the analyzed results showed that the amount detected in the biochar treatment were far less than the control one. The most significant treatments were the pots with coconut shell (80-200 mesh) derived biochar and pots with biogas byproduct derived biochar. In the heavily contaminated soil with biogas byproduct derived biochar added to it, the result measured about 20 percent uptake reduction of the heavy metal cadmium and lead whereas 16 percent of chromium uptake in comparison to those of the vegetable that grew in the same soil with no biochar. The treatment with coconut shell biochar (60-200 mesh) stands at the second less uptake of heavy metal into the plant. Amongst all the treatment, biochar from coconut 30-60 mesh and 60-80 mesh amended pots revealed far least effectiveness compare to other pots but they still can reduce heavy metal uptake by plants. Table 1 and 2 showed all the experimental results of the plant samples for N, P, K and other contaminants. The plants' uptake of heavy metals was substantially reduced in soil which contained biochar. Biochar could also be used as a soil conditioner prior to plant colonisation in acidic, polluted mine tailings. The results of Hartley et al. (2009) show that biochar can be used in combination with Miscanthus for phyto-stabilisation. More recent research has proved that biochar can have an added environmental benefit, improving the greenhouse gas balance of other bioenergy crops such as Miscanthus [16].

Table 1: *N, P, K assimilation in plant samples (mg/kg)*

Treatment	Total N	Total K	Total P
Control	55.4	81.5	4.8
Coconut Shell 30-60 mesh	54.2	90.5	4.82
Coconut Shell 60-80 mesh	50.3	91.5	4.8
Coconut Shell 80-200 mesh	47.9	88.25	5.37
Peanut Shell	54.6	105.25	5.03
Wheat Straw	52.8	117.25	4.72
Rice Hush	44.8	94.25	4.29
Biogas Byproduct	44.3	72.25	4.19

Table 2: *Incorporated heavy metal concentration in plant samples (mg/kg)*

Treatment	Pb	Cd	Cr	Cu	Zn	As	Hg
Control	102	17.1	15	23.6	1667	3.56	0.019
Coconut Shell 30-60 mesh	50	15.1	9.9	21.1	1727	1.49	0.01
Coconut Shell 60-80 mesh	37	13	5.9	18.2	1447	1.09	0.006
Coconut Shell 80-200 mesh	19	8.6	2	15.9	989	0.797	0.003
Peanut Shell	26	9.6	1.9	17.1	779	0.619	0.005
Wheat Straw	33	16.6	4	16.5	1196	0.92	0.007
Rice Hush	23	9.6	1.6	14.8	1044	0.779	0.005
Biogas Byproduct	21	3.5	2.5	9.3	188	0.98	0.006

Biochar is incorporated in soil with organic or inorganic fertilizer as a soil ameliorant to enhance certain soil properties such as pH, CEC and microbial proliferation. As deliberate soil amendment, biochar is, in most cases, incorporated within the soil, rather than just being added on the surface where wind or water erosion can transport biochar particles [17]. Biochar has some unique properties that make it particularly susceptible to movement in the soil [4]. Uptake and accumulation of trace elements by plants are affected by several soil factors, including pH, Eh, clay content, organic matter content, cation exchange capacity, nutrient balance, concentration of other trace elements in soil, and soil moisture and temperature. Many findings confirm that the solubility of heavy metals in soil is directly correlated with the redox potential [18]. H. S. Helmisaari et al. (2007) showed that under same pH values, metal solubility increases as redox potential decreases. As redox potential decreases, trace elements become less available. The experiments for determination of pH, total N, P, K assimilation and available concentration of phosphorus, Pb, Cd, Cu and Zn in soil samples were also carried out. The long lasting benefits of biochar include the soil's increased retention of nutrients and water, which enhances crop growth. The most significant improvement is increase in soil pH from 5.95 up to 7.4 and it can provide short-term benefits by contributing nutrients and offering a liming effect for soils. The available concentrations of Pb, Cd, Cu, Zn and P were also increased compare with non-biochar treated one. Biochar can have an unusually high cation exchange capacity, but also appears able to adsorb phosphate and an anion. All the experimental results for soil samples analysis were shown in Table 3 and Table 4. It is likely that that one of the best approaches to combine biochar and phyto-extractors would be in multicontaminated soils, where both can target at different elements.

Table 3: *Chemical assimilation in soil samples (mg/kg)*

Treatment	pH	OM	Total N	Total P	Total K	Hydrol ytic N
Control	5.95	0.078	0.126	0.105	0.623	29.21
Coconut Shell 30-60 mesh	6.06	0.189	0.029	0.148	1.03	16.98
Coconut Shell 60-80 mesh	5.94	0.168	0.048	0.12	0.118	39.23
Coconut Shell 80-200 mesh	6.12	0.078	0.0647	0.135	0.207	22.49
Peanut Shell	6.37	0.196	0.073	0.152	1.095	36.43
Wheat Straw	6.18	0.159	0.039	0.229	0.515	20.46
Rice Hush	6.14	0.191	0.047	0.098	0.778	25.84
Biogas Byproduct	7.4	0.117	0.046	0.099	0.623	11.37

Table 4: *Chemical assimilation in soil samples (mg/kg)*

Treatment	As	Available Pb	Available Cd	Available Cu	Available Zn	Available P
Control	1.928	3.074	0.076	0.064	5.989	6.923
Coconut Shell 30-60 mesh	1.028	7.771	0.048	0.196	5.788	3.242
Coconut Shell 60-80 mesh	1.303	11.635	0.082	0.022	4.359	5.19
Coconut Shell 80-200 mesh	0.799	7.972	0.014	0.134	2.173	7.663
Peanut Shell	0.435	9.264	0.078	0.118	4.863	1.861
Wheat Straw	0.747	7.972	0.092	0.047	4.825	9.894
Rice Hush	1.886	9.264	0.039	0.198	1.871	5.242
Biogas Byproduct	1.722	7.15	0.013	0.152	12.351	3.839

4. Conclusion

In China, the environmental pollution caused by heavy metals has become increasingly prominent and is the most challenging problem. There is an urgent need to find better and environmentally sound approaches that can properly effective to reclaim the pollution . In order to support ecologically and socially sustainable development, it is necessary to coordinate the activities of the governments, researchers and farmers for best fit soil and environment management practices. The relative contribution of the different mechanisms to heavy metal immobilization by different biochar remains unknown, although some authors postulate that it is mostly a pH effect. The changes that biochar can undergo also depend upon its production conditions. These conditions are of great importance to achieve long-term soil enhancement – for example, its sorption properties are initially strongly influenced by the production temperature [4] and atmosphere, which determine the surface area of the particles. Less leaching of nutrients (such as calcium, potassium, magnesium, and nitrogen) means that more nutrients are available for plant uptake. Therefore adding biochar to soil will result in greater fertilizer efficiency: the crop can use a greater amount of the fertilizer added. Although biochar is not a fertilizer itself, it improves the overall health and quality of the soil [20]. According to this experiment, it is clear that biochar from biogas by-product is the most effective one amongst all other treatment. They may be due to the use of integrated biomass for its production. Coconut shell derived biochar of 80-200 mesh also show promising result and effectiveness whereas the rest two coconut shell derived biochar, 30-60 mesh and 60-80 mesh, have the least improvement. Further investigation for relationship between particle size and sorption behavior was needed. Increasing the efficiency of crop-bearing soil could be one of the greatest breakthroughs to food provision around the world and this may help to reduce such fluctuations of the most important supplies that human beings rely upon for survival.

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Acknowledgements

This study was financially supported by the National key research and development program（SQ2017YFNC060046 National Natural Science Foundation of China (41571313, 41401353), Guangdong Natural Science Foundation (2015A030313570, 2016A030313772), Department of Science and Technology of Guangdong Province (2016A020210034, 2016B070701009), Pearl River S&T Nova Program of Guangzhou, China (201610010131), and President Foundation of Guangdong Academy of Agricultural Sciences, China (201716). The author would like to express her gratitude to Ministry of Education, Myanmar, Guangdong Academy of Agricultural Science, P.R China and Ministry of Science and Technology, P.R China for this research.