Effect of biochar and leaching on concentrations of available lead in two soils

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Abstract

Biochar is an environmentally friendly and cost-effective adsorbent made from plant and animal materials. The ability of biochar to reduce pollutants is attributed to its physicochemical unique properties. To study the efficiency of biochar for reducing mobility and bioavailability of lead element in two contaminated soils, incubation experiments including pot and column leaching experiments were conducted. The results showed that adding lead concentrations (75, 150, and 300 mg.kg-1) had a significant effect by increasing the concentrations of available lead in the soils. As for the effect of adding levels of biochar (7.5, 15, and 30 gm.kg-1), it was noted that there was a significant decrease in the values of available lead with increasing levels of added biochar in the two soils which leached with distilled and salt water. The highest concentrations of available lead were recorded in clayey soil leached with salt water, which was 47.84 mg.kg-1, while sandy soil gave the lowest concentration, which amounted to 34.82 mg.kg-1.

.Introduction

Lead is a heavy element that cannot be degraded in the soil. It shows long-term resistance in the environment and becomes toxic to humans, plants, and animals [1,2]. Lead is considered a toxic element, even in low concentrations, to humans, animals, and plants. It is not essential for plant growth, and its content varies according to the type and part of the plant [3]. This element is able to move in the soil solution or along the soil surface. And leaching into groundwater due to its dissolution of soil minerals through acidic water or through industrial discharge, mining waste, and landfills [4,5.[

Thus, to reduce its mobility and bioavailability, and thus stabilize it in the soil and in the environment, sorbents and sedimentation agents are usually used to achieve these goals [1,6,5]. As an adsorbent, biochar has the ability to stabilize heavy metals in the soil and the environment [7]. Biochar is an environmentally friendly and cost-effective adsorbent made from plant and animal materials [8]. The ability of biochar to reduce organic and inorganic compounds is attributed to its physicochemical properties, which include porous structure, active functional groups, extended specific surface area, cations exchange capacity (CEC) and high organic carbon content [8,9.[

Various studies have revealed that the stabilization of heavy metals in soil is attributed to the field application of biochar, which helps in reducing bioavailability and leaching through adsorption and chemical transformation, which helps control the toxicity of these heavy metals in the soil and in the environment [11,10], Physical properties Biochar chemistry and heavy metal adsorption and generally, increasing the pyrolysis temperature increases the surface area of biochar, which carries a large negative charge and shows strong affinity for metal cations. Thus, biochar reduces the concentration of elements in soil solutions. Increasing pyrolysis temperatures to 300-500 °C increases the pH of the resulting biochar, due to the conversion and release of essential

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alkaloid elements such as Ca2+, Mg2+ and K+ from the feedstock [12, 13, 14]. Therefore, the application of biochar to soil increases soil pH and heavy metal sorption for both biochar and soil due to deprotonation from pH-dependent cation exchange sites on soil and biochar surfaces [15.[

Materials and methods :

The research aimed to study the effect of different concentrations of lead and levels of biochar under leaching with distilled and salt (0.4 , 4.7 dS.m-) water on the element availability in sandy and clayey soils. The two soils were air-dried, ground, passed through a sieve with a diameter of 2 mm, and mixed well. The two soils were air-dried, ground, passed through a sieve with a diameter of 2 mm, and mixed well. The properties (table 1) were measured according to [16], The soils were contaminated with lead nitrate [Pb(NO3)2] at levels of 75, 150, and 300 mg.kg- and incubated for 30 days. After that, levels of biochar(0,7.5,15 and 30 g.kg-1) were added and the samples were incubated for another 30 days in plastic pots at field capacity, and at room temperature (25 ± 2 degrees Celsius). The pH, electrical conductivity, and cation exchange capacity (table 2) of the biochar were measured according to [17,18]. Column leaching experiments were conducted according to [19] with little modification: 1000 g of soil (dry mass) with three replicates per treatment. Soil samples contaminated with different concentrations of lead and levels of biochar were placed in columns (5 cm in diameter and 25 cm length). A wild-mouth bottle (500 mL) was placed under each column. The treatments were arranged in an CRD. In the beginning, 100 mL of distilled and salt water were added to each column at an interval of 7 days. This process was repeated four times. Available Pb in the soil samples were analysed after leaching processes [11] and measured using flame Atomic Absorption Spectrophotometer-Shimadzu AA-7000.

Table (1) Properties of studied soils.

parameter	**Unit**	**Sandy soil**	**Clayey soil**
pH	-	7.2	7.6
EC	$dS.m^{-1}$	1.19	2.51
$CaCO_3$	%	7.96	17.62
O.M	%	0.2	0.8
Clay	%	4.8	60
Silt	%	1.4	30
Sand	%	93.8	10

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Table (2) Chemical properties of biochar.

parameter	**Unit**	value
pH	-	8.6
EC	$dS.m^{-1}$	4.28
CEC	$Cmol.Kg^{-1}$	30.5

Results and Discussion

Available lead after leaching with distilled water

It is clear from table (3) that the type of soil has a significant effect on the concentration of available lead in the soil washed with distilled water. The highest concentration was in the clay soil, which was 42.21 mg.kg-, while the sandy soil gave the lowest concentration (39.67 mg.kg-. The low concentration of element in sandy soil may be due to the sandy soil's lack of clay minerals, organic matter, and calcium carbonate. These components work to adsorb the element, and thus the sandy soil facilitates the washing of heavy elements to reach the groundwater. It was also observed that the addition of lead concentrations (75, 150, and 300) mg.kg- had a significant effect by increasing the available lead concentrations in the studied soils. Regarding the effect of the levels of added biochar, it may be noted from the results that there is a significant decrease effects in the values of available lead for soils leached with distilled water with increasing levels of added biochar. This was significant for all levels of added biochar (7.5, 15, and 30 g.kg-), and the values were 42.22, 37.93, and 42.22, 37.93, and 34.06 mg.kg- respectively compared with control value (49.54) mg.kg

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Table (3) Effect of lead concentrations and levels of biochar on available element phase in studied soils leached with distilled water

Soil	Lead(Pb) (mg kg^{-})	Biochar(C) levels (g kg^{-1})				S x Pb	Soil Mean
		0	7.5	15	30		
Sandy	0	0.46	0.27	0.22	0.11	0.26	39.66
	75	49.21	42.47	44.29	35.99	42.99	
	150	64.20	55.77	46.33	42.67	52.24	
	300	82.75	67.34	54.20	48.29	63.15	
Clayey	0	0.89	0.87	0.56	0.50	0.71	42.21
	75	43.01	37.26	35.95	32.02	37.06	
	150	68.60	62.10	51.62	47.53	57.46	
	300	87.18	71.67	70.21	65.37	73.61	
LSD 0.05		LSD S x Pb x C = 0.5099				LSD S x Pb =0.235	LSD S =0.1275
S x C							
Sandy S1		31.76	36.26	41.46	49.16	S X C=0.2550	
Clayey S2		36.35	39.59	42.98	49.92		
Biochar level		C × Pb Interference					
		0	7.5	15	30	Lead rate	
Lead concentration	0	0.67	0.57	0.39	0.30	0.48	
	75	46.11	39.87	40.12	34.00	40.03	
	150	66.40	58.94	48.97	45.10	54.85	
	300	84.97	69.50	62.21	56.83	68.38	
LSD 0.05		LSD Pb x C =0.3324				LSD Pb =0.1803	
Biochar rate		49.54	42.22	37.93	34.06	LSD C= 0.1803	

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Available lead after Leaching
with salt water

Table (4) showed a significant effect of the type of soil leached with salt water on available lead in the studied soil. The highest concentrations of available lead were recorded in clayey soil, which was 47.84 mg.kg-1, while sandy soil gave the lowest concentration, which amounted to 34.819 mg.kg-1. The increase in available lead concentration in clayey soil leaching with salt water is due to their high specific area and organic matter content, in addition to the background of lead content.Also the results showed that adding lead concentrations (75, 150, and 300 mg.kg-1) had a significant effect by increasing the concentrations of available lead in the soils. As for the effect of adding levels of biochar (7.5, 15, and 30) gm.kg-1, it is noted from the results that there is a significant decrease in the values of available lead with increasing levels of added biochar. This was significant for all levels of added biochar and the values were 43.28 , 37.40 and 34.395 mg.kg-1 respectively compared with control value (50.22 mg.kg-1). Sorption mechanisms for metal contaminated soils by biochar could be dependent on the type of soils and the cations present in both soils and biochar, and thus implications for metal remediation in contaminated soils could vary [20.[

Generally, the decrease in available lead concentrations in soils leached with distilled and salt water with increasing levels of added adsorbent material (biochar) is attributed to its unique physicochemical properties, such as high specific surface area associated with porous structure of fine particles which possessing charged surface functional groups on its large outer and inner surfaces that strongly attract heavy element in the soils by adsorption, complexation and precipitation reactions[21]. When
interacting with biochar, some metal ions undergo reduction and oxidation reactions,
precipitation, and co-precipitation[22] which reduces the effectiveness of the extraction material (DTPA) that used to remove available Pb element bound on outer and inner surfaces of biochar with strong forces during incubation period, with the exception of the ions of the element ions that are associated with relatively, weak forces on the outer surfaces of the biochar particles, which is called exchangeable phase of element. Because biochar is usually alkaline, the application of biochar to soil can improve the pH value of soil, thus affecting the mobility and bioavailability of heavy metal through ion exchange, precipitation or surface complexation [23]. In the same context, [24] proposed various mechanisms for Pb2+ sorption by biochar that could include (1) heavy metal exchange with Ca2+, Mg2+, and other cations associated with biochar, attributing to co-precipitation and inner-sphere complexation with complexed humic matter and mineral oxides of biochar; (2) the surface complexation of heavy metals with different functional groups, and inner-sphere complexation with the free hydroxyl of mineral oxides and other surface precipitation; and (3) the physical adsorption and surface precipitation that contribute to the stabilization of Pb2.+

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Table (4) Effect of lead concentrations and levels of biochar on available element phase in studied soils leached with salt water

<table>
<tr><td rowspan="2">Soil</td><td rowspan="2">Lead(Pb) (mg kg-1)</td><td colspan="4">Biochar(C) levels (gm.kg-1)</td><td rowspan="2">S x Pb</td><td rowspan="2">Soil rate</td></tr>
<tr><td>0</td><td>7.5</td><td>15</td><td>30</td></tr>
<tr><td rowspan="4">Sandy</td><td>0</td><td>0.45</td><td>0.44</td><td>0.10</td><td>0.01</td><td>0.25</td><td rowspan="4">34.82</td></tr>
<tr><td>75</td><td>41.51</td><td>38.35</td><td>35.54</td><td>29.30</td><td>36.18</td></tr>
<tr><td>150</td><td>56.88</td><td>50.11</td><td>41.11</td><td>37.83</td><td>46.48</td></tr>
<tr><td>300</td><td>77.73</td><td>62.10</td><td>43.80</td><td>41.78</td><td>56.35</td></tr>
<tr><td rowspan="4">Clayey</td><td>0</td><td>0.73</td><td>0.73</td><td>0.54</td><td>0.55</td><td>0.64</td><td rowspan="4">47.84</td></tr>
<tr><td>75</td><td>49.64</td><td>44.25</td><td>42.63</td><td>39.48</td><td>44.00</td></tr>
<tr><td>150</td><td>78.83</td><td>69.83</td><td>59.72</td><td>55.54</td><td>65.98</td></tr>
<tr><td>300</td><td>96.01</td><td>80.46</td><td>75.74</td><td>70.65</td><td>80.71</td></tr>
<tr><td>LSD 0.05</td><td></td><td colspan="4">LSD S x Pb x C = 0.4701</td><td>LSD S x Pb =0.2471</td><td>LSD S =0.1236</td></tr>
<tr><td colspan="2">S x C</td><td colspan="6"></td></tr>
<tr><td colspan="2">Sandy S1</td><td>44.14</td><td>37.75</td><td>30.14</td><td>27.23</td><td colspan="2" rowspan="2">S X C=0.2471</td></tr>
<tr><td colspan="2">Clayey S2</td><td>56.31</td><td>48.82</td><td>44.66</td><td>41.55</td></tr>
<tr><td colspan="2" rowspan="2">Biochar level</td><td colspan="6">C × Pb Interference</td></tr>
<tr><td>0</td><td>7.5</td><td>15</td><td>30</td><td colspan="2">Lead rate</td></tr>
<tr><td rowspan="4">Lead concentration</td><td>0</td><td>0.59</td><td>0.59</td><td>0.32</td><td>0.28</td><td colspan="2">0.44</td></tr>
<tr><td>75</td><td>45.58</td><td>41.30</td><td>39.09</td><td>34.39</td><td colspan="2">40.09</td></tr>
<tr><td>150</td><td>67.86</td><td>59.97</td><td>50.41</td><td>46.68</td><td colspan="2">56.23</td></tr>
<tr><td>300</td><td>86.87</td><td>71.28</td><td>59.77</td><td>56.21</td><td colspan="2">68.53</td></tr>
<tr><td colspan="2">LSD 0.05</td><td colspan="4">LSD Pb x C = 0.3495</td><td colspan="2">LSD Pb =0.1747</td></tr>
<tr><td colspan="2">Biochar rate</td><td>50.22</td><td>43.28</td><td>37.40</td><td>34.39</td><td colspan="2">LSD C= 0.1747</td></tr>
</table>

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Conclusion

The application of Biochar to soil contaminated with lead can help reduce the extractbility and bioavaility of lead , particularly because Biochar increases the soil pH, The biochar reduced the leached lead, indicating that the lead was bound to the biochar in a way that did not allow it to dissolve with the water added during the washing process .

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