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Effect of Composting Process, Particle Size and Shaking Time of Livestock Manure on the Adsorption of Cadmium and Nickel

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Abstract

A study was carried out on the adsorption of heavy metals on particles of composted manure to reduce the associated contamination risk in soils and plants. Therefore, adsorption behavior of Cd and Ni on fine (0.2 mm) and coarse (1 mm) particles of composted manure was investigated in an aqueous solution after 1 h and 2 h shaking time. Manure samples were used after composting for 40 days, 80 days and 120 days. There was also a fresh manure sample. Results showed that the higher adsorption of heavy metal was shown by the manure samples composted for longer days: 120 days>80 days>40 days>fresh manure. Finer manure particles enhanced adsorption of heavy metals than the coarser manure samples. Higher concentrations of Cd and Ni in the solution adsorbed more amount of the metal ion on manure samples. The adsorptive capacity of metals from the respective aqueous solution increased with increasing shaking time. This study indicated that the retention of heavy metals by composted manure from contaminated water may reduce the contamination risk of heavy metals in crops and soil runoff.

Keywords: Compost • Adsorption • Concentration • Metal ion • Heavy metals

Introduction

Heavy metal ions are non-biodegradable and tend to accumulate in the living organisms, causing several types of diseases and disorders. Some heavy metals might be very toxic even in very low concentrations [1]. The traditional methods for the metal removal from water include reduction, precipitation, ion exchange, electrochemical reduction, and reverse osmosis. Most of them involve higher capital costs with huge recurring expenses, which are not suitable for small-scale industries [2]. The use of natural and environmental friendly adsorbents is particularly beneficial for the development of cost-effective processes to remove heavy metals from wastewater [3]. Heavy metals in the soil are stabilized by the use of various soil amendments via the processes of adsorption, binding, or co-precipitation, which have been extensively researched [4]. Treatment of metal-bearing effluents has indicated that adsorption is the most effective among the physico-chemical processes. Adsorption with activated carbon has been used widely for removal of heavy metals [5]. Besides the versatility of carbon adsorbents in waste water treatment, it is still very costly. In the present years the use of low-cost materials as alternatives to carbon has been encouraged [6]. Adsorption is a process that explains the interaction between adsorbent and metal ion. The interaction of the species between liquid phase and solid surface results in adsorption. Thus, adsorption can be referred to as the process whereby a solute or species in a liquid or gas mixture is removed onto an adsorbent or a solid that is in contact with the fluid. Besides possessing a great surface area for attachment, the adsorbent also possesses higher affinity for the solute [7]. The important factors affect adsorption process include metals speciation and strength, soil type, pH, contact time and temperature, etc., among them pH is considered as the most significant factor due to its positive effects on the solubility and speciation of metals [8]. Therefore, it was necessary to carry out a research study on the adsorption process between heavy metals and sorbent of different size fractions to assess the associated environmental risk [9]. Adsorption is commonly used and is very successful, environmentally friendly and economical in low metal concentrations. Compared with the conventional methods, biosorption treatment has the benefits of low operating cost, higher efficiency and reduced toxic sludge generation. Several researchers have studied the removal of heavy metal ions from aqueous solutions.

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Kandah studied the removal of zinc ions using sheep manure waste. Zhang studied the adsorption of Pb, Cu and Zn from the simulated acid mine drainage using dairy manure compost. Lima and Marshall utilized activated carbon of broiler manure after activation to remove Cu from aqueous solution. The current study investigated the difference between the adsorption potential of fine and coarse particles of manure after a composting process for Cd and Ni using contaminated water.

Materials and Methods

The adsorbent used in this study was livestock manure which was composted for 40 days, 80 days and 120 days. The manure was co-composted with plants residues at large scale (3:1). The moisture contents of the compost were controlled to an approximate level of 20% at room temperature under aerobic conditions. Occasionally the manure was pulverized mechanically. The manure samples were brought to the laboratory, air-dried and sieved through a 2 mm sieve and stored in a polythene bags. The composted manure samples were air dried and sieved into fine and coarse particles by 0.2 mm and 1 mm sieves, respectively. Organic matter in the manure samples was determined by the dry combustion method. Available Heavy Metals (HM) namely Lead (Pb), Nickel (Ni), Zinc (Zn), Chromium (Cr), Copper (Cu) and Cadmium (Cd) in manure and soil samples were extracted with Diethylene Triamine Pentaacetic Acid (DTPA) mixture. The mixture was shaken for 3 hr, centrifuged at 2400 rpm for 30 min and the supernatant was filtered. The heavy metals contents in the filtrate were determined by Atomic Absorption Spectrophotometer (AAS). Composting manure and soil samples were analyzed for the following chemical parameters. The pH and Electrical Conductivity (EC) (1:5 w/v waste: water extract) were determined using a pH meter and a EC meter, respectively. Total carbon was determined by dry combustion using Nelson and Sommers method. The chemical properties of the manure samples are given in Table 1.

Parameters	Fresh	40 d	80 d	120 d
Total C (g kg^{-1})	430.4	383.3	357	321
Total Ca	157.4	165.9	236.7	210
Total Mg	176.2	269.5	317.2	365.7
Total K	725.5	865.7	890.8	956.6
Extractable Zn	67.6	62.6	60	54.4
Extractable Cu	25.4	18.9	16.8	19.2
Extractable Ni	12.4	9.5	7.3	7
Extractable Cd	8.9	9.8	8.4	8.1
EC (dS m^{-1})	3.4	3.6	3.9	4
pH (1: 5)	7.7	7.6	8.2	8.8

Note: d: days of composting; C: Carbon; Ca: Calcium; Mg: Magnesium; K: Potassium; Zn: Zinc; Cu: Copper; Ni: Nickel; Cd: Cadmium; EC: Electrical Conductivity Unit for all elements (mg kg^{-1}).

Table 1. Chemical properties of manure during composting.

Five gram of manure samples were shaken in Ni and Cd solutions separately for 1 h and 2 h. The contaminated solutions were prepared in a 1 L flask using 0, 50 and 150 mg L^{-1} of Ni and Cd. Thereafter, the solution mixtures were centrifuged at 5000 rpm for 15 min and the resulting supernatant solution was decanted and filtered by a 0.22 µm filter. The extracts were measured by Atomic Absorption Spectrophotometer (AAS). The experiment was a 4 × 3 × 2 × 2 factorial (composted manure samples, metal concentrations, size fraction, shaking time) resulting in 48 experimental units, arranged into a Randomized Complete Block (RCB) design. The experiment was replicated thrice. Data were statistically analyzed using Stat view software and results were expressed on oven-dry basis. Mean separation was done using LSD at P<0.05.

Results and Discussion

Metals adsorption was significantly affected by the addition of composted manure to the contaminated water. The initial heavy metal concentrations of 0, 50, 150 mg L^{-1} in the aqueous solutions were used to determine the sorption of respective metal cations of Cd and Ni on composted manure samples (Tables 2 and 3).

Manure size (mm)	Shaking time (hrs)	Cd solution (mg L^{-1})	Fresh manure	40 days	80 days	120 days
0.2	1	0	4.6 ± 0.4	4.8 ± 0.2	4.5 ± 0.5	4.4 ± 0.5

		50	42.2 ± 0.4	36.8 ± 0.6	28.2 ± 0.2	25.7 ± 0.7
		150	138.3 ± 0.7	132.4 ± 0.8	124.3 ± 0.5	120.4 ± 1
	2	0	5.6 ± 0.4	4.7 ± 0.3	4.1 ± 0.2	3.1 ± 0.2
		50	40.2 ± 0.8	32.5 ± 0.4	30.5 ± 0.4	28.4 ± 0.4
		150	133.0 ± 0.9	126.6 ± 0.1	118.1 ± 0.7	115.2 ± 0.2
1	1	0	4.2 ± 0.6	4.3 ± 0.1	3.4 ± 0.05	3.1 ± 0.4
		50	46.3 ± 0.6	39.5 ± 0.4	32.1 ± 0.4	29.2 ± 0.3
		150	141.1 ± 0.2	129.0 ± 1	123.3 ± 0.4	121.7 ± 0.2
	2	0	4.1 ± 0.9	4.2 ± 0.9	3.4 ± 0.2	3.2 ± 0.2
		50	43.2 ± 0.05	36.5 ± 0.3	35.8 ± 0.2	30.4 ± 0.5
		150	139.0 ± 0.9	126.9 ± 0.05	115.2 ± 0.1	112.5 ± 1.3
LSD (0.05)			3.4	4.5	4.4	5.7

Note: Cd: cadmium, m: mean values

Table 2. Adsorption of Cd (mg L^{-1}) by composted manure (treatments) after shaking, mean values and standard deviation.

Manure size (mm)	**Shaking time (hrs)**	**Ni solution (mg L^{-1})**	**Fresh manure**	**40 days**	**80 days**	**120 days**
0.2	1	0	6.2 ± 0.3	6.5 ± 0.5	5.2 ± 0.5	5.2 ± 0.5
		50	46.3 ± 0.6	40.8 ± 1.3	34.2 ± 0.9	29.7 ± 2
		150	138.1 ± 1.6	132.4 ± 2.4	118.3 ± 0.8	112.4 ± 1.1
	2	0	5.6 ± 0.6	5.5 ± 0.2	5.3 ± 0.7	5.2 ± 0.9
		50	47.2 ± 0.7	36.5 ± 1.8	32.5 ± 2.3	30.8 ± 2
		150	132.0 ± 1	121.0 ± 0.7	117.1 ± 2.0	109.2 ± 1
1	1	0	6.1 ± 0.9	6.2 ± 0.2	5.1 ± 0.7	5.0 ± 0.2
		50	47.3 ± 0.7	45.5 ± 0.6	36.1 ± 0.3	32.2 ± 1.4
		150	140.1 ± 0.3	130.0 ± 2	128.3 ± 1	120.7 ± 0.4
	2	0	7.9 ± 0.5	8.2 ± 0.6	7.4 ± 0.7	6.2 ± 0.9
		50	46.2 ± 0.6	42.5 ± 0.4	35.8 ± 0.05	29.4 ± 0.2
		150	137.0 ± 1	127.3 ± 0.6	124.2 ± 0.9	120.6 ± 0.8
LSD (0.05)			5.2	5	5.4	6.2

Note: Ni: Nickle, m: mean values

Table 3. Adsorption of Ni (mg L^{-1}) by the composted manure (treatments) after shaking, m and standard deviation.

The reduction of heavy metals concentrations in the extract was associated with the composting days of manure. Composted manure for longer days significantly adsorbed heavy metals. The composted manure differed for the release of both Cd and Ni as 120 days>80 days>40 days>fresh manure. Manure samples adsorbed more amounts of the metals (Cd and Ni) from the aqueous solution of higher concentrations (Tables 2 and 3). The adsorptions of Ni and Cd by the manure compost decreased with the increase in the particle sizes. The pattern of Cd and Ni adsorption remained identical during the study. Manure samples after a composting process enhanced adsorption of heavy metals than the fresh manure samples. The adsorption of Cd and Ni on manure samples was function of the shaking time. The manure particle size of the 0.2 mm released Cd up to 138.3, 132.4, 124.3 and 120.4 mg L^{-1} after shaking fresh manure, 40 d, 80 d and 120 d composted manure for 1 h, respectively in the 150 mg L^{-1} aqueous solution. The amount of Cd apparently reduced in the water extract after shaking the manure for 2 h. In the 1 mm PR size particle of manure, Cd released up to 141.1, 129.0, 123.3 and 121.7

mg L^{-1} after shaking of fresh manure, 40 d, 80 d and 120 d composted manure for 1 h, respectively in the 150 mg L^{-1} aqueous solution. In the manure material (0.2 mm) Ni was released after 1 h shaking the aqueous solution of 150 mg L^{-1} as 138.1, 132.4, 118.3 and 112.4 mg L^{-1} from fresh manure, 40 days, 80 days and 120 days composted manure, respectively while Ni concentrations were found as 132.0, 121.0, 117.1 and 109.2 mg L^{-1} after shaking time of 2 h. This showed that the adsorptive capacity of the manure from the respective aqueous solution increased with increasing shaking time. In the manure material (1 mm) Ni was released from the aqueous solution of 150 mg L^{-1} as 140.1, 130.0, 128.3 and 120.7 mg L^{-1} after shaking time of 1 h, respectively while Ni concentrations were 137.0, 127.3, 124.2 and 120.6 mg L^{-1} after shaking time of 2 h. The finer particles manure has a higher sorption capacity which enhanced the adsorption of heavy metals. This could be due to the increase in the number of sorption sites. This can be explained in terms of relatively greater number of active sites for metal actions. There is a general consensus that decreasing the average particle size of the adsorbent increases the surface area, which in turn increases the adsorption capacity.

The sorption of heavy metal may be due to the large number of sorption sites available for adsorption. Asrari, et al. associated the slower adsorption rate to the saturation of active sites and attainment of equilibrium state. Morcali, et al. reported that the adsorption was proportional to the contact time and a balance was achieved for Cu and Zn. Anirudhan and Sreekumari reported greater adsorption of Pb, Cu and Hg due to the contact time of these metal ions, and remained constant after an equilibration time. Whereas the contact time for the maximum uptake of metal ions by activated carbon was independent on the metal ions concentration. Organic wastes (household, green, animal manure and tree bark) are materials that have been effectively reported for heavy metal sorption from soils and water. Several wastes materials have been used to immobilize heavy metals, e.g., cocoa shells, rice milling by-products, sago waste, peanut shells, coir (coconut husk) and saw-dust. The ability of various particle size of adsorbent in adsorbing foreign materials may be different due to several physicochemical properties and it is commonly believed that fine soil particles have a greater ability to carry heavy metals than coarser particles because of lager specific surface area and more organic matter and Fe/Mn/Al oxides contents. It has been reported elsewhere that heavy metal solubility was the function of organic material in a soil treatment.

The sorption capacity considered as the amount of metal ions adsorbed per gram of sorbent. The amount of metal adsorbed per unit mass enhanced due to the presence of greater amount of metal in the aqueous solution. Adsorption of heavy metals increased by increasing the adsorbents concentrations in the water solution. Ahalya, et al. reported the rate of effective adsorption as a function of the initial concentration of metal ions. Chemical remediation has been used to decrease heavy metal solubility, leaching and bioavailability through adsorption onto mineral surfaces, formation of stable complexes with organic legends, surface precipitation, and ion exchange. It has been observed that the mechanism of metal removal from the aqueous metal solution involved four steps:

- Migration of metal ions from the bulk solution to the surface of the adsorbent.
- Diffusion through boundary layer to the biomass surface.
- Adsorption at a binding site.
- Intra particle diffusion into the interior of the biomass.

Conclusion

It is concluded that mixing of contaminated water with the manure waste can alter the extractability of heavy metals. Cadmium and Ni adsorption from the aqueous solution by manure samples was highly affected by shaking time, particle size and composting days of manure. The manure samples composted for 120 d after 2 h shaking time showed higher adsorption rate for both Cd and Ni. The finer manure particles adsorbed more heavy metals then coarse particles. Increasing contact time and metal concentration in the water resulted in higher adsorption. This study confirmed that the heavy metals can be immobilized from contaminated water using composted manure. Further studies to determine the effects of other organic material for remediating metal in wastewater are needed.

Conflicts of Interest

All authors declare that they have no conflicts of interest.

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