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Potential of Soil Amendments and Jatropha Curcas Plant in the Remediation of Heavy Metals Contaminated Agricultural Land

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Potential of Soil Amendments and Jatropha Curcas Plant in the Remediation of Heavy Metals Contaminated Agricultural Land

R Leapheng, A J Effendi, and Q Helmy

[1]Department of Environmental Engineering, Institut Teknologi Bandung, Jl. Ganesha No. 10 Bandung 40132, Indonesia

Email: roeuyleapheng@yahoo.com

Abstract. Textile wastewater contaminated by heavy metal has been polluted to the agricultural land in Rancaekek, Bandung. To overcome the heavy metal contamination, phytoremediation technology has been proposed. Jatropha curcas plant with soil amendments (compost and EDTA) was utilized to investigate the heavy metal remediation in the contaminated soil. Five experimental treatments viz. S_0 S_1 S_2 S_3 and S_E were set up for ninety days. The plant growth behaviour, heavy metal accumulation, and translocation (TF) and bioaccumulation (BAF) factors were determined. The untreated soil was indicated as silty loam containing Cd, Cr and Pb concentrations approximately 0.79, 100.15, and 8.43 mg/kg, respectively. The heavy metals were highly accumulated in the plant for treatments S_3 and S_E compared to control S_0. The accumulation of Cd, Cr and Pb in different J. curcas tissues can be classified as follow: root > shoot > leaves. Bioaccumulation and translocation factor of Cd were greater than one (BAF, TF > 1) while Cr and Pb were less than one (BAF, TF < 1). The highly removal of heavy metal was found that Cd = 81.73 % and Cr = 41.15% in S3 while Pb = 65.20 % in S_E. To sum up, J. curcas species represented high TF and BAF in Cd removal, and low in Cr and Pb removal. It revealed that Jatropha curcas plant was suitable for phytoremediation of heavy metal contaminated soil, especially, combination with both compost and EDTA. Moreover, Jatropha curcas could be an emerging technology plant to alleviate the contaminated soil with multi-metal for sustainability of land resources.

1. Introduction

Rapid industrial development and urbanization have increased the quantity and diversity of toxic wastes on land. The textile industry is a technologically complex industry which strongly produced of fabric, yarns as well as sewing threat from natural fibres like cotton, jute, silk, and wool. Because of demand for textile products, textile wastewater contained many chemicals has been increasing proportionally, causing a major problem of environment and health [1]. In Indonesia, textile industry is one of largest industry ranking in top ten in the world and second in South East Asia. The textile and garment industry are one of Indonesia's oldest industries which used different type of chemicals during production process such as strong acids, strong alkalis, inorganic chlorinated compounds, hypochlorite of sodium, organic compound such as dye stuff, bleaching agent, finishing chemicals, starch, thickening agent, surface active chemicals, wetting and dispensing agents and salts of metals [2].

Many kind of metal concentrations such as Al, Cd, Co,Cr, Cu, Fe, Mn, Ni, Pb, Tl, and Zn were found in various textile fibres (cotton, acrylic, polyester, nylon, viscose, and polypropylene) of different colours (red, white, green, blue, yellow, orange, black, brown, purple, pink, navy, burgundy, beige, and grey) [3]. The quantities of heavy metals wastewater were discharged from this industry to agricultural land which might harmful to plant crops [4]. The heavy metals have potent cumulative properties in the soil, causing damage effect on crop as well as human health through food chain. The presence of heavy metals in soil will expose to the humans in the vicinity [5].

To remediate heavy metal contaminated soil, phytoremediation using non-food oil seed crop of Jatropha curcas plant species offered a cost-saving and/or environment-friendly method of treating the soil. It is a suitable plant to improve heavy metal accumulation based on transgenic approaches. *J. curcas*, commonly known as the physic nut belongs to the Euphorbiaceae family, is a fast-growing plant and high potential of the fibre materials [6]. Moreover, Jatropha is widely distributed and scattered in the tropics with multi-purpose uses such as biodiesel, organic fertilizer, medicinal value, and ingredient for animal feeds. This plant has ability to uptake metals and can easily adapt to stress environment and grows relatively fast [7]. In phytoremediation process, fibrous root of Jatropha played a role to absorb many metals in largest contaminated surface area. Those metals accumulation in root system may act as phytostabilization. Furthermore, stem tissue is useful for phytoextraction when those metals moved from soil through root and transport to aerial part of plant through xylem system plant [8].

To present high heavy metals accumulation in *J. curcas* plant, amendments using both compost and EDTA were observed to investigate the ability of metals mobility from soil into the plant. Some researchers studied that heavy metals may high removal from the contaminated soil using the combined compost and plant technology [9-11]. Moreover, compost amendment was preferable in remediated higher concentrations of heavy metals with planting the Jatropha curcas. EDTA has been the most widely used as chelates in studies of phytoremediation because of its high efficiency in extracting and enhancing the metal mobilization in soils by partially deteriorating the soil minerals and structure. EDTA chelating agent was purposed of desorbing heavy metals from soil matrix into soil solution to facilitate the transport of metals into xylem and increase translocation of metals from the roots to shoots of some fast growing, high biomass producing plants [12].

The objectives of the study were: to assess the availability of heavy metal in the contaminated soil with and without soil amendments, to determine the accumulation ability of Jatropha curcas on heavy metal, and to explore the soil amendments for enhancing the phytoremediation. Jatropha curcas as greenhouse plant aims to uptake metal pollutants from soil through root and shoot plant by determining its growth parameters and accumulation of heavy metals in different plant components. To achieve this purpose, the sub-objectives following are considered:

- To evaluate the enrichment factor (EF) of contaminated soil and compost.
- To define translocation factor (TF)from roots to shoots (stem and leaves).
- To determine the bioaccumulation factor (BAF) of metals by plant.
- To determine the percentages of heavy metal remediated.

2. Methodology

The research was conducted for six months started from March until September 2018 in water laboratory and greenhouse building, Institut Teknologi Bandung, Indonesia.

2.1. Contaminated soil characterization

In this study, contaminated soil samples using grid sampling (twelve grids) were selected from the paddy field in Rancaekek, West Java, Indonesia. Approximately 10 kg of soil in each grid was collected from the top-soil (0-20 cm) depth of soil surface layer. Then, the sample was kept in plastic bags and transported to the laboratory for physical and chemical characteristics analysis. The preliminary analysis parameters of contaminated soil were soil texture, pH and electro-conductivity (EC), organic carbon (OC) and organic matter (OM), total phosphorous (TP) and total nitrogen (TN), moisture content (MC) and C/N ratio, and heavy metal (Cd, Cr, and Pb).

2.2. Compost preparation

The compost used for soil amendment was made of rice straw shredded into category of particle sizes (2≤sieve≤12 mm) and animal manure such as cow, chicken and horse. A cylindrical In-vessel reactor contained 147L with 50 cm of diameter (interior diameter), and 75 cm of height was made by stainless steel sheet with thickness 1 mm [13] was used for compost production. The process was run for 28 days under aerobic condition at 7 LPM air flowrate with monitoring biomass temperature. Air was used as substrate for microorganisms, so the cellulose as well as lignin was degraded during rice straw composting [14]. Compost samples were taken from the top (1/10 depth), middle (Mid 4/ 10 depth) and bottom (Bottom 9/10 depth) layers [15]. The schematic of In-vessel vertical bioreactor was shown in Figure 1.

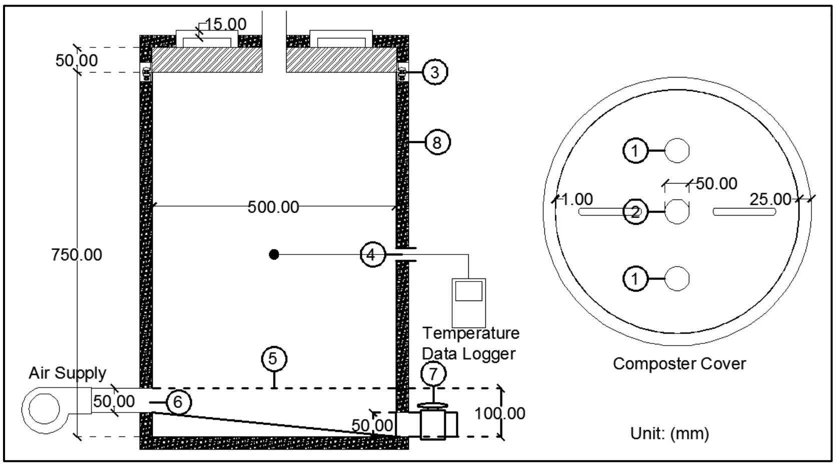

Figure 1. Schematic of In-vessel vertical bioreactor, where: (1) gas outlet, (2) water or nutrient inlet, (3) screws, (4) temperature measurement, (5) screen plate, (6) air inlet, (7) leachate drain, (8) fiberglass insulation.

2.3. EDTA trail laboratory
The tetrasodium salt of EDTA was used as amendment treatment or chelating agent aimed to mobilize heavy metals in the contaminated soil. In the laboratory, the EDTA salt at five doses such as 0 g EDTA/kg soil, 0.5 g EDTA/kg soil, 1.0 g EDTA/kg soil, 2.0 g EDTA/kg soil, and 3.0 g EDTA/kg soil were added into 100 mL five different Erlenmeyer flasks within 5 g of soil in order to find the optimum of EDTA dose for using in the pot experiments. Treatments were replicated three times. After added EDTA salt into the flask, the soil and EDTA solution were shaken by a shaker for 4 hours to enable the EDTA salt solubilize and bind heavy metal in the soil. After 4 hours, the sediments were settled to the bottom of the flask, and then filtered the solution before transferring into the tubes [16]. The decanted solutions were analyzed for the concentration of three toxic heavy metals such as chromium (Cr), cadmium (Cd), and lead (Pb).

2.4. Pot experiments
Jatropha curcas (local name in Indonesia: Jarak Pagar) was used as green technology plant for remediation contaminated soil which collected from local agriculture agency. It is noted that the plants were already grown in nursery. Healthy plants were especially selected as test plants range from 20-30 cm of height (with the same ages) for this study [10]. The pot treatments were used for triplicate analysis. A total of 60 experimental pots were set up for ninety days in five treatments viz. S0 (control without compost and EDTA), S1 (mixture compost/soil 1:1), S2 (mixture compost/soil 1:2), S3 (mixture compost/soil 1:3), and S_E (EDTA addition). Inside the pot was covered by plastic preventing of the leachate through the watering process. During experimental time, the physiological properties of J. curcas plants (root length, stem length, stem girth, leaf length, leaf breadth, and plant biomass), and physical and chemical properties of the remediated soil (randomized samples) were observed. After cultivating, the plants were harvested and washed with tap-water followed by three times rinse with deionized water. The plants were separated in root, stem and leaves, then dried and ground for analyzing heavy metal using AAS. The experimental pots of the phytoremediation process in this study were presented inFigure 2.

Figure 2. Pot experiments for five treatments, where: (S0) control, (S1) mixture compost/soil 1:1, (S2) mixture compost/soil 1:2, (S3) mixture compost/soil 1:3, and (SE) EDTA addition.

2.5. Analytical methods
The common term for measuring soil texture in the laboratory was particle size analysis (PSA) [17]. The moisture content was determined by using standard SNI 03-1965-1990 for soil's water content [18]. The pH (Method 4A) and EC (Method 3A1) of soil and compost samples were determined electronically to extract of the saturated soil using pH and conductivity meters with methods commonly ASPAC, respectively. These methods are based on a soil/water ratio 1:5 suspensions [19]. In this study, OC (Method 5310), TN (Method 4500-N), TP (Method 4500-P) and heavy metals (Method 3111) were analysed using Standard Methods for the Examination of Water and Wastewater [20]. However, Organic matter (OM) was calculated by multiplying the OC value by Van Bemmelen of 1·724 based on the assumption that OM contains 58% OC.

2.6. Mathematical analysis
Mathematical analysis was used to describe the context of numbers and functions related to theories. It is very useful to achieve the study purposes. The following mathematical formula were considered.

2.6.1. Enrichment factor (EF). EF was used to describe the metals of material or soil greater than metals in the earth's crust. It also used to assess the presence and intensity of anthropogenic contaminant deposition on surface soil [21], [22]. The EF value is calculated in Eq. (1).

$$EF = \frac{([C_a]/[X_a])soil}{([C_b]/[X_b])crust} \quad (1)$$

Where: C_a and X_a: the concentrations of desired and reference elements in the soil sample (mg/kg)
C_b and X_b: the concentrations of desired and reference elements in the earth crust (mg/kg)

Normally, the reference elements can be Al, Li, Sc, Ti, Zr, Mn and Fe. In this study, Mn was selected as the reference material being the most abundant element observed in the analysed soil samples. The element concentrations in the continental crust used as reference elements were characterized through [23].

2.6.2. Plant biomass. Plant biomass was measured separately according to leaves, stems, and roots of J. curcas plant. The dry weight of plant can be determined through the moisture content of the plant. The moisture content of the sample [18] was calculated in Eq. (2).

$$(\%)MC = \frac{W_w - W_d}{W_w} \times 100 \quad (2)$$

Where: W_w: Total weight of wet sample (g)
W_d: Total weight of dried sample (g)

2.6.3. Translocation (TF) and bioaccumulation (BAF) factors. The plant's ability to accumulate metals from soil and transfer metals through root to aerial part of plant was determined through the translocation factor [24]. Moreover, the metals BAF in the plant was calculated by the ratio of metals concentration in the plant tissues to metals concentration in the soil [25]. Both TF and BAF were formulated in Eq. (3) and (4).

$$TF = \frac{M_{shoot}}{M_{root}} \quad (3)$$

$$BAF = \frac{C_p}{C_{so}} \quad (4)$$

Where: M_{shoot}: Metal concentrations in stem and leaves of plant (mg/kg)
M_{root}: Metal concentrations in root plant (mg/kg)
C_p: Metal concentrations in aerial parts of the plant (mg/kg)
C_{so}: Metal concentrations in the soil (mg/kg)

2.6.4. Percentage of metal remediated (%). The percentage of metal remediated (%) described the metals removal from the contaminated soil [11] was presented in Eq. (5).

$$\%Metal(remediated) = \frac{C_m - C_r}{C_m} \times 100 \quad (5)$$

Where: C_m: Concentration of metals in polluted soil (mg/kg)
C_r: Concentration of metals in remediated soil (mg/kg)

2.7. Statistical analysis
Two-Way analysis of variance (Two-Way ANOVA) test at p value of 0.05 using excel was used for testing the significance of heavy metals concentrations results (in soil and plant parts). Results between concentration of Cd, Cr and Pb in the plant and contaminated soil were evaluated using a correlation analysis to inspect the effect of each treatment in terms of Cd, Cr, and Pb increment and reduction.

3. Result and Discussion

3.1. Compost production
The composting process can be described using three different temperature phases: the mesophilic 1 or moderate-temperature phase, the thermophilic or high-temperature phase, and mesophilic 2 or maturation phase [26]. The temperature curve during composting process was shown in Figure 3.

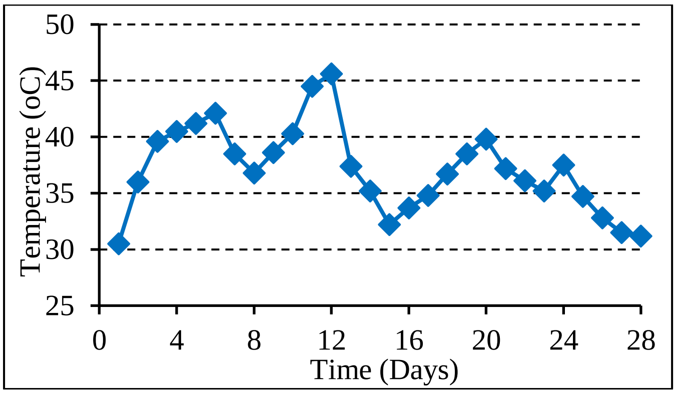

Figure 3. Temperature profile of composting.

In the mesophilic phase 1, the compost increased the temperature from 30.5 ºC at the first day up to 40 ºC of the stage. The increment of temperature may be due to microbial activity which meant that the microorganisms used C and N sources generating heat. The compost decomposed of soluble compounds, such assugars and organic acids and hence, pH can drop. After that, the temperature of compost reached a peak (45.6 ºC) in thermophilic phase within about 12 days. During, two weeks, the compost reached temperatures higher than 45°C, indicating that thermophilic bacteria facilitated degradation of carbon complex sources such as cellulose and lignin. These microorganisms may transform nitrogen into ammonia. Composting in high temperature of thermophilic can destroy all the types of pathogens. In mesophilic phase 2, it turned downward in the temperature 31.2 ºC at the end of composting after the thermophilic phase. Below 40°C, mesophilic organisms resume their activity and pH started to decrease slightly. At this last phase, the side reactions such as carbonaceous compounds condensation and polymerization occurred to form humic and fulvic acids. The composting phases such as mesophilic 1, thermophilic, and mesophilic 2 were described in [13], [27].

3.2. Characteristic of compost and contaminated soil

The physical and chemical properties of compost and contaminated soil were shown in Table 1. The table showed that soil contained chromium (Cr) higher than cadmium (Cd) and lead (Pb). The concentrations of Cr, Pb and Cd were about 100.15 mg/kg, 8.43 mg/kg and 0.79 mg/kg, respectively. The percentages of clay, sand and silt were specifically identified as silty loam soil. The pH value (5.62) was shown as low acidic condition because of heavy metals polluted soil, indicating metals easy to mobilize in soil.

Table 1. Summary of compost and contaminated soil characteristic.

	Compost	Contaminated soil
pH (-)	6.95 ± 0.015	5.62 ± 0.19
EC (ms/cm)	3.45 ± 0.047	2.66 ± 0.52
MC (%)	74.68 ± 0.49	51.86 ± 0.93
OC (%)	68.07 ± 1.95	23.61 ± 2.54
OM (%)	117.35 ± 3.36	40.7 ± 3.41
TN (%)	2.22 ± 0.05	0.78 ± 0.022
C/N (-)	30.69 ± 1.57	30.36 ± 2.02
TP (%)	0.56 ± 0.02	0.0055 ± 0.001
Cd (mg/kg)	0.85 ± 0.053	0.79 ± 0.034
Cr (mg/kg)	10.97 ± 1.25	100.15 ± 3.25
Pb (mg/kg)	5.37 ± 1.13	8.43 ± 0.44
Mn (mg/kg)	321.51 ± 5.73	271.63 ± 6.32
Clay (%)	-	4.83 ± 0.17
Sand (%)	-	31.17 ± 0.17
Silt (%)	-	55.25 ± 0.25

For the compost properties, the concentrations of Cd, Cr, and Pb were 0.85, 10.97, and 5.37 mg/kg, subsequently. pH (6.95) was alkalized to finally stabilize at values close to neutral. This value may occur the condition for bacterial activity (6.0-7.5) and fungal activity (5.5 to 8.0). This meant that there is not excess of nitrogen in the source material, with poor C: N ratio related to moister and high temperatures. The C/N (30.69) reveals that amount of carbon and nitrogen rich materials in the mixture were not higher than the ideal standard ranges from 15:1 to 35:1. This meant that the process may not tend to cool and to slow down and/or to overheat generating odors from the ammonia released. The ideal values of physical and chemical properties for compost production were presented in [27]. Although the moisture content of the compost (74.68%) was too wet material and caused insufficient oxygen that water will saturate the pores and interfere oxygenation through the material, but compost can be used for soil amendment can be maintained the moisture content about 70-75% [28]. This may act as remediation process of the heavy metals contaminated soil.

3.3. Bioavailability of metals-EDTA in the soil

Bioavailability of metals-EDTA in the soil was shown in Figure 4. The result showed that the amount of soluble Pb would still increase although the EDTA application rates higher than 3.0 g/kg soil. However, the concentrations of Cr and Cd were slightly decreased in the solution when the EDTA doses above 0.5 g/kg soil. It meant that the increase EDTA salt doses above 0.5 g/kg soil did not useful for increasing concentrations of Cr and Cd in the solution. This experiment showed that Cr and Cd were weakly adsorbed by soil which easily leached to the grownwater. Application of EDTA mostly enhanced the bioavailability of Pb concentration in the soil [29]. At dose 0.5 g/kg, the percentages binding of Cr, Cd and Pb were 20.25, 64.01, and 42.79 %, respectively.This indicated that the maximum solubilization Cr, Cd, and Pb in the contaminated soil could be applied EDTA dose at concentration 0.5 g/kg soil. The study of Liphadzi and Kirkham[16] showed that the EDTA rates at 0.5 and 1.0 g/kg soil were the optimum doses of heavy metal bioavailabilty.

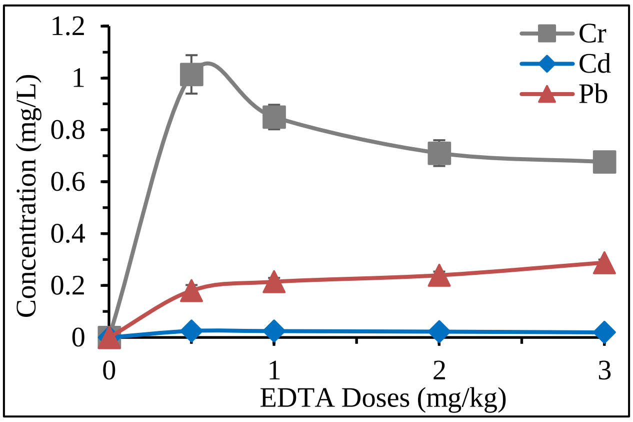

Figure 4. Concentration of solubilized heavy metal (Cd, Cr and Pb) in the contaminated soil at different EDTA rates.

3.4. Enrichment factor of heavy metal in compost and contaminated soil

The enrichment factor of metal is presented in Figure 5. The compost revealed that the value of 0.5 < EF < 1.5 including Cd, Cr and Pb, indicatingthe trace metal concentration may come entirely from natural weathering processes as well as the EF of Cd in contaminated soil. However, EF of Pb in contaminated soil equaled to 1.5, it meant that a significant portion of the trace metals was delivered from non-crustal materials so, these trace metals were delivered by other sources, like point and non-point pollution and biota [21]. Moreover, the The Cr of contaminated soil was higher value of EF than 2.0 indicating deficiency to minimal enrichment [30]. This meant that the trace metal was polluted by anthropogenic activities [11].

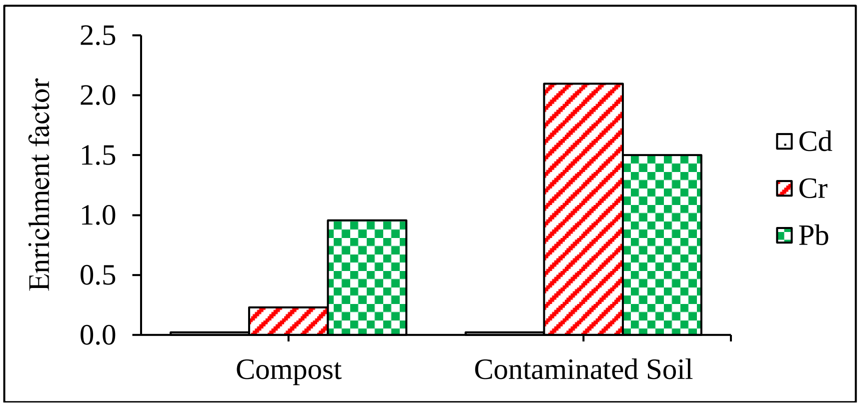

Figure 5. Enrichment factor of compost and contaminated soil.

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3.5. Heavy metal accumulation in Jatropha curcas plant

The accumulation of heavy metals (Cd, Cr, and Pb) in *J. curcas* tissues during experimental time were presented in Figure 6, Figure 7 and Figure 8. The capacity of various metals uptake in the plant tissues was found to be in the orders: Cr > Pb > Cd. Further statistical analysis using ANOVA revealed that the concentration of Cd, Cr and Pb in the plant tissues such as root, stem, and leaves was significantly different ($p \leq 0.05$) in each treatment. The accumulation of Cd in J. curcas can be classified as follow: stem> root > leaves while Cr and Pb was shown as: root > stem > leaves. It indicated that Cd is bioavailability and transferred from soil through root and continuously accumulated in stem tissue through xylem loading. Some of Cd was distributed into leaves part. The transportation of Cd from root to shoot system occurred by movement of metals involved with water transportation in the soil. However, Cr and Pb are immobilized through absorption by roots, adsorption onto root surface and precipitation within the area of plant roots. The root system can absorb multi-metals concentration although the stem showed high accumulation of Cd. The J. curcas root reduced the mobility of Cr and Pb to move toward shoot system. Fibrous root of *J. curcas* easily absorbed metals onto root surface.

The mechanism of heavy metals up taken into plant part were performed into three steps such as: first is the bioavailability and uptake of heavy metals from the soil through roots, second is translocation of heavy metals from roots to shoots through xylem loading, and third is the sequestration of heavy metals in leaves particularly in vacuoles [31], [32]. Due to the accumulation of metals concentration in the plant, the treatment S3 showed the highest Cd (2.63 mg/kg) concentration in the stem. Moreover, treatments S1, S2, and S3 presented the high ability of Cr accumulation root system compared to control S0 and SE. This meant that the addition compost in soil may enhance the mobility of metals in the soil and easily transfer to the part of *J. curcas*. The metals were available in the plant under reaction of microorganism in compost. The use of compost during phytoremediation can change the soil properties that influence the metals bioavailability in the soil [11]. However, treatment SE combination with EDTA showed high Pb accumulation in all parts of plant. The EDTA was significantly as chelating agent and found to be most effective in the mobility, solubility, and bioavailability of metals in the soil solution [16], [29].

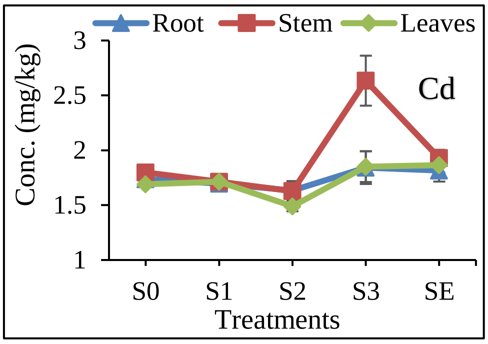

Figure 6. Concentration of Cd in the aerial parts of Jatropha curcas.

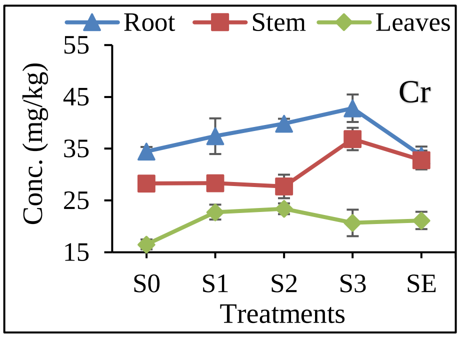

Figure 7. Concentration of Cr in the aerial parts of Jatropha curcas.

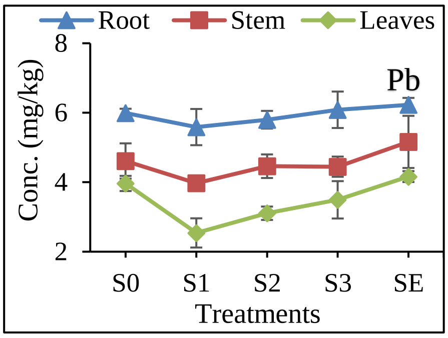

Figure 8. Concentration of Pb in the aerial parts of Jatropha curcas.

3.6. Bioaccumulation (BAF) and translocation (TF) factor of heavy metals in the plant

The bioaccumulation factor (BAF) from contaminated soil to component parts of *J. curcas*, expressed as the ratio of metal concentration in part divided by the concentration of metal in soil while the ratio of metals in root by metals in each part of plant described the translocation factor (TF). In this study, bioaccumulation and translocation factor values of the plant was shown inFigure 9 and Figure 10. The BAF value was found to be in the orders: Cd > Pb > Cr. BAF value of Cd were greater than 1 for all the treatments, indicating high transfer of Cd to *J. curcas* plant while Cr and Pb were lower than one (BAF<1). The BAF values of metals were not significantly different at p-value ($p < 0.05$). the treatment S1, S2 and S3 showed the high BAF value of Cr in the root. Moreover, S3 and SE presented high BAF of Cd in stem and Pb in root. This observation may be explained by the influence of compost on soil properties such as organic matter and pH [33]. These factors could affect metals solubility, mobility and bioavailability in soil [34].

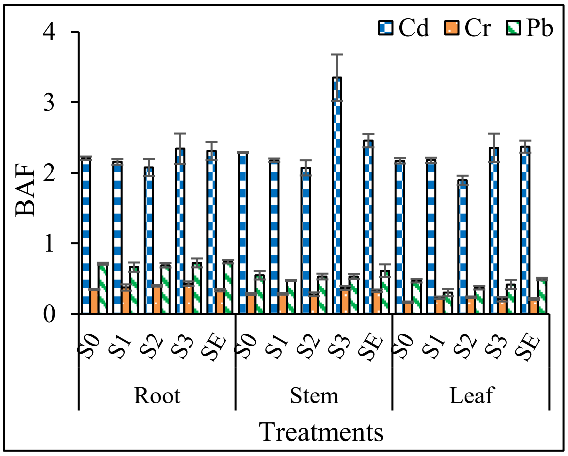

Figure 9. Bioaccumulation factor (BAF) of heavy metals in each part of Jatropha plant.

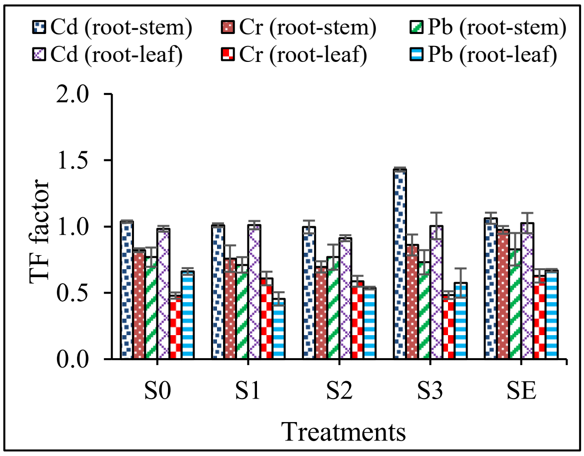

Figure 10. Translocation factor (BAF) of heavy metals in each part of Jatropha plant.

For translocation factor, only TF_{Cd} value was higher than1 ($TF > 1$) in both $TF_{stem/root}$ and $TF_{leaf/root}$, which indicated that the transportation of Cd to the stem and leaves of plants was easily uptaken by *J. curcas*. As for the TF value for the other two heavy metals, TF of Cr and Pb were lower than 1, which showed that it was not easier for Cr and Pb to move in other part of plants. The low TF value can be estimated that the heavy metals were accumulated in the root system of the plant [35]. Cd described high BAF and TF values greater than one (BAF, TF > 1), indicating that J. curcas may act as accumulator or hyper accumulator plant for up taking Cd. However, BAF and TF of Cr and Pb were lower than one (BAF, TF < 1) revealed as excluder plant. Several authors have reported that heavy metals (Cd, Cr, and Pb) accumulation and translocation from soil through roots to the aerial parts of the plant occurs when the BAF and TF were higher than 1, this value characterized of accumulator plants, while less than 1 presented as excluder plant [36], [37], [38].

3.7. Effect of treatments on physiological properties of J. curcas plant

The growth behavior of *J. curcas* was determined by measuring the physiological properties in Figure 11 and Figure 12. This study showed that although *J. curcas* survived in each treatment but the biomass was differently depended on the treatments. The total biomass increased by 45.78 %, 44.99 %, 36.19 %, and 34.30 % under treatments S3, S2, S1 and SE compared to control S0, respectively. The statistical analysis presented no significant difference at p-value ($p < 0.05$) in biomass under these treatments. This revealed that compost can provide the nutrient for the plant growth [7]. The plant in treatments S3 had highest average stem height (25.03 cm), followed by S1, whereas control S0 had the shortest stem height (23.07 cm). The plant in the treatments SE had highest average stem girth (25.03 cm), followed by S3 and S2. Highest root length was observed in SE treatment (22.47 cm), followed by controlandS2 treatment. Treatment S1 (18.77 cm) and S3 (18.23 cm) had lowest root length. The maximum value of leaf length (7.67 cm) and leaf breadth (7.10 cm) were found in the treatment S2.

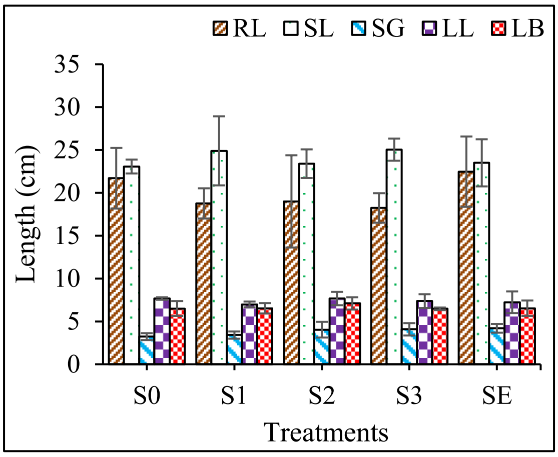

Figure 11. Physiological properties of J. curcas, where: (RL) root length, (SL) stem length, (SG) stem girth, (LL) leaf length, and (LB) leaf breadth.

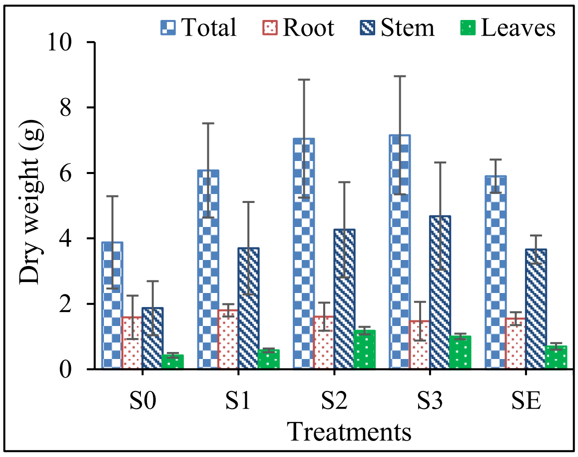

Figure 12. Plant biomass in each tissues of J. curcas viz. root, stem and leaves.

The increment in root biomass is in the order of 11.91 % and 1.25 % in treatment S1 and S2, respectively, indicating resistance of plants against high metal concentrations in rhizosphere. The root density and spatial distribution is an important factor in assessing phytoremediation efficiency of a plant. Plants with extensive root system are capable of trapping more heavy metals due to better exploration in soil [39]. The leaf length and leaf breadth of the plant was decreased highly in treatment S0 and SE compared to the initial length, causing the necrosis and chlorosis. However, the pots within compost provided good condition for leaves growth. This meant that the compost may provide the nutrient to each part of plant as well as leaves. Normally, chlorosis performed as yellowing leaves and necrosis as death leaves were caused by the deficiencies of the nutrients nitrogen, phosphorus, potassium, and magnesium [40].

3.8. Remediated heavy metal in the contaminated soil

The total remediated heavy metals in the soil was shown in Figure 13. The capacity of various metals removal from the contaminated soil was found to be in the orders: Cd > Pb > Cr. The highly removal of heavy metal was found that Cd = 81.73 % and Cr = 41.15% in S3 while Pb = 65.20 % in SE. This indicated that a gradual decrease in the Cd, Cr, and Pb content in the soil occurs, leading to a statistically significant correlation between the exposure time and the Cd, Cr, and Pb content ($p < 0.05$) in each treatment. These heavy metals were continuously up taken by J. curcas during the three months of experimental time.

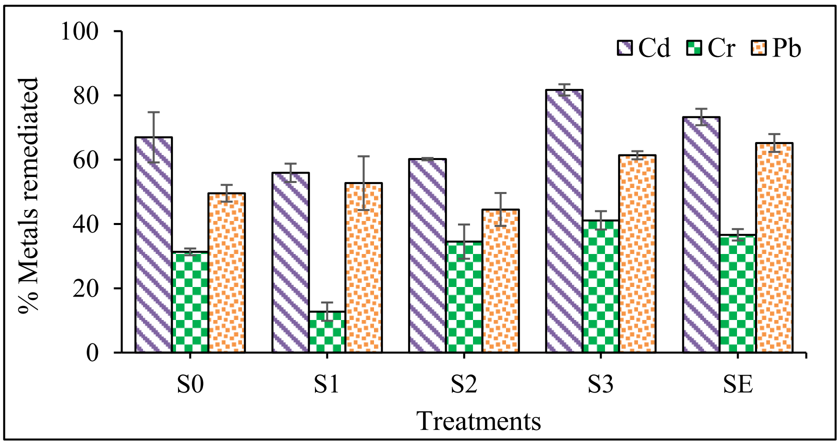

Figure 13. Figure with short caption (caption centred).

Metals content did not decrease in plants during the exposure period, which indicated that *J. curcas* species may be exposed for longer time and/or higher Cd concentrations while Cr and Pb lower decrease. Plants can absorb toxic ions of metals along with the beneficial ones because of the organic and chemical addition. Although the mixture compost 1:3 showed high reduction of heavy metals from the soil, the treatment S1 and S2 also revealed metals removal. This meant that metals up taken by plant in the compost treatment was faster than without compost in phytoremediation process [9], [10, [11]. This also showed that compost augmented phytoremediation metals polluted soil with improving carbon and nitrogen sources for soil microbes. In addition, EDTA-enhanced translocation of heavy metals, especially Pb, is also the most important role of EDTA in the context of heavy metals phytoremediation [16], [29].

4. Conclusion

To sum up, bioaccumulation and translocation factor of Cd were greater than one (BAF, TF > 1) while Cr and Pb were less than one (BAF, TF < 1). The highly removal of heavy metal was found that Cd = 81.73 % and Cr = 41.15% in S3 while Pb = 65.20 % in SE. This showed that the mobility of heavy metals in the plant were increased by soil amendments application compared with control check. The enhanced accumulation of Cr, Cd, and Pb in the shoot and root systems were observed in Jatropha curcas plant where the metals translocated from root to the parts of plants. Plants with both bioaccumulation factor (BAF) and translocation factor (TF) greater than one (TF and BAF > 1) for Cd have the potential to be used in phytoextraction, and (TF and BAF < 1) for Cr and Pb can be used in phytostabilization. *J. curcas* species represented high Cd, Cr and Pb removal in the contaminated soil. It revealed that J. curcas plant was suitable for both phytostabilization and phytoextraction of heavy metal contaminated soil, especially, combination with both compost and EDTA. Moreover, rice straw compost and EDTA agent could effectively utilized for enhancing phytoremediation while Jatropha curcas could be an emerging technology plant to uptake heavy metals from the contaminated soil. Characteristic of compost and contaminated soil.

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