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Research Article

Tithonia diversifolia Compost for Decreasing the Activity of Mercury in Soil

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Abstract

Background and Objective: *Tithonia diversifolia* (*T. diversifolia*) compost could be used for reducing the effect of mercury (Hg) poisoning on heavy metal contaminated soil. Land and plants in Poboya Mining, Central Sulawesi, have been contaminated by mercury. This study aims to determine the decreasing activity of Hg^{2+} peanut and water spinach due to by the application of *T. diversifolia* compost. **Methodology:** The green house research was arranged a two-factorial randomized blocked design, in which the first factor was *T. diversifolia* compost rates including 0 (b_0), 10 (b_1), 20 (b_2), 30 (b_3), 40 (b_3) and 50 t ha^{-1} (b_4) and these condfactors were plant types including peanut (t_1) and water spinach (t_2). **Results:** Peanut grown on Hg^{2+} polluted soil added with 50 t ha^{-1} *T. diversifolia* compost has reduced level of soil Hg^{2+} by upto 71.53% whereas water spinach reduced by up to 67.58%. The addition of 50 t ha^{-1} *T. diversifolia* compost also significantly decreased the concentration of Hg^{2+} in the peanut and water spinach roots by up to 86.19 and 84.82%, respectively and that in the plant shoots by 65.93 and 75.04%. **Conclusion:** *Tithonia diversifolia* compost can be used for the recovery of agricultural land and plants contaminated by Hg^{2+}.

Key words: *Tithonia diversifolia* compost, mercury, agricultural land recovery, peanut and water spinach, reduced mercury level

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The use of *T. diversifolia* compost is one of the methods to reduce the mercury (Hg) poisoning in soil contaminated by heavy metals and to improve the nutrient availability and uptake in plants[1,2]. Active ingredients, which are organic acids (fulvic acid, humic acid and other organic compounds) can directly improve the fertility of the soil[3].

Fulvic and humic acids contained in organic compounds have an important role in bonding and reducing mercury activities in soil[4]. Humic and fulvic acids in *T. divesifolia* compost allow chelation or bonding to occur, which are organic compounds bonding to cations of heavy metals like Hg[5]. The formation of chelate Hg means that the Hg concentration in plants is reduced as the amount of metal in plant tissues depends on the amount of metal in the soil[6,7].

Mercury components spread widely in the soil, air, water and living organisms through complex processes of physical, chemistry and biological materials. The content extent of mercury in the soil on forest areas is lower than the one in the soil on agricultural areas[8]. Organic compounds on the higher ground of forest areas make the soil more resistant to Hg[8,9]. The normal range of Hg in the soil and plant is 0.01-0.3 ppm and the critical concentration ranges between 0.3-0.5 ppm[10,11].

The soil polluted and contaminated by Hg is the one around gold processing in Poboya, City of Palu in which Hg used in the gold processing is about 200-500 kg/day with an amalgamation technique[12]. The soil in Poboya is categorized as entisols, which are mineral soils newly developed and formed under the influence of dry climates. Their main material is dominated by mineral quartz, which is strongly resistant to dry-climate changes. It makes the corrosion from chemical reactions in the soil slow[13].

Based on the closure of entisols land in the region of Poboya divided into residences, lakes, forests, bushes, mixed gardens, rice fields and open field, most of 3,000 ha farmlands in the region of Poboya, City of Palu, have turned into mining areas and gold processing[14]. The contamination affects not only the soil around the gold processing but also lakes, air, lands, plants and even the health of human beings[15].

Some types of plants developed around the gold-processing area are nuts and vegetables. Plants used as experiments are from the type of peanuts and swamp cabbages. Both types have an ability and tolerance called as accumulator against heavy metals because they are still able to grow around the gold-processing area contaminated by mercury[10]. Hence, this research aims to analyze the ability of *T. diversifolia* to bond Hg in the soil and reduce the absorption of Hg^{2+} into plant tissues of vegetables in Poboya gold mines.

MATERIALS AND METHODS

Laboratorial experiments: The laboratorial experiments aimed at determining the concentration of mercury in soils and plant tissue. The experimental research used a factorial randomized block design (RBD). The first factor was *T. diversifolia* compost rates which consisted of 0 (b_0),10 (b_1), 20 (b_2), 30 (b_3), 40 (b_3) and 50 t ha^{-1} (b_4) while the second factor was plant types which included peanut (t_1) and water spinach (t_2). Each treatment was replicated three times. So, there were 24 experimental pots.

Duration study: The study duration was 5 months from November, 2016-April, 2017.

Peanut and water spinach as sample plant: Peanut and water spinach grown on 30 cm polybags were used as sample plants. The concentration of Hg^{2+} was determined 45 days after planting using Mercury Analyzer (AAS) in accordance with Mercury Analysis Manual by the Ministry of Environment of Japan[16].

Soil chemical and *T. diversifolia* compost characteristics: Other variables measured were initial soil chemical and *T. diversifolia* compost characteristics, including the analysis of pH (H_2O and KCl) using glass electrode pH-meter on 1:2.5 soil suspension, C-organic using Walkley-Black method[17]. Prune of *T. diversifolia* plant of 1000 g was composted using decomposer for about a month. Humic and fulvic acids of the mature compost were determined using 0.1 N NaOH.

Statistical analysis: The data resulted from the experiments were analyzed using F-test with the level of 95% (α 5%) and regression test.

RESULTS

Chemical composition of compost: The chemical composition of the *T. diversifolia* compost was varied (Table 1). The content of C-organic and N were 28.25 and 3.15%, respectively. Thus, the C/N ratio was 8.96 which is still above

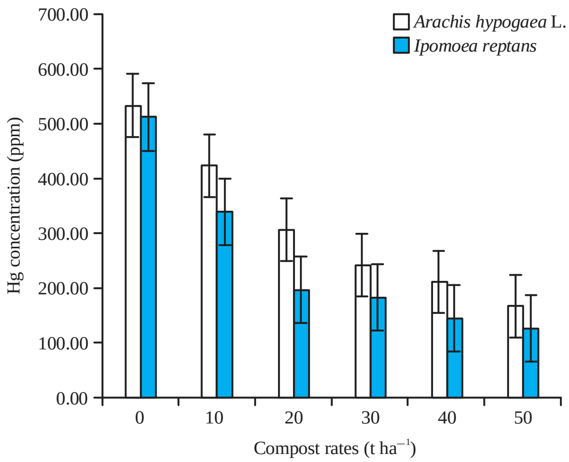

Fig. 1: Concentration of Hg^{2+} in soil added with *Tithonia diversifolia* compost

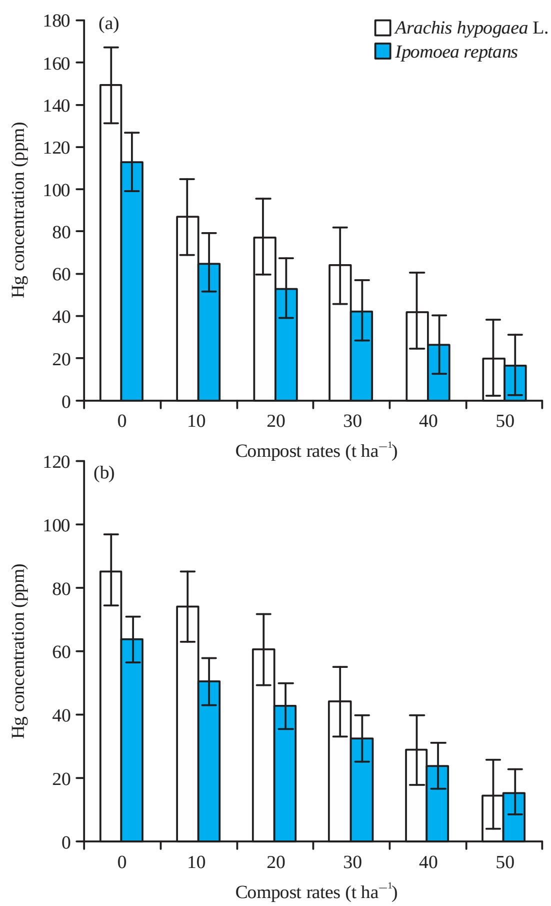

Fig. 2(a-b): Concentration of (a) Hg^{2+} roots *Ipomoea reptans* and *Arachis hypogea* L. and (b) Hg^{2+} crown *Ipomoea reptans* and *Arachis hypogea* L.

the critical level of C/N ratio to allow mineralization to occur. Therefore, the *T. diversifolia* compost used in this

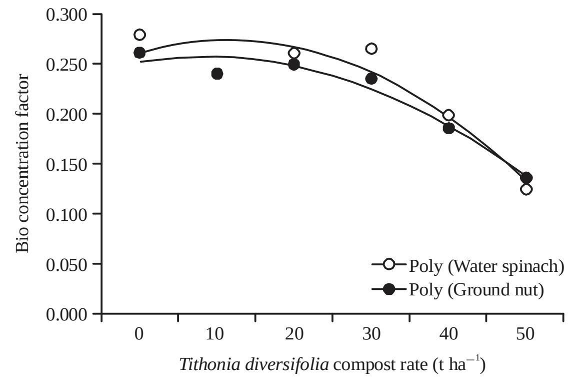

Fig. 3: Hg^{2+} bio concentration changes of ground nut and water spinach plants under increasing rate of *Tithonia diversifolia* compost

Table 1: Chemical characteristics of *Tithonia diversifolia* compost

Chemical characteristics	Concentration
pH H_2O	7.52
pH KCl	6.94
C-organic (%)	28.25
N-total (%)	3.15
P-total (%)	0.72
K-total (%)	4.23
Ca-total (%)	2.27
Mg-total (%)	1.21
Ratio C/N	8.96
Humic acid (%)	25.10
Fulvic acid (%)	5.41

research was easy to mineralize and released chemical substances that could rehabilitate polluted soil.

Concentration of Hg^{2+} in soil added with *T. diversifolia* compost: Figure 1 shows that mercury concentrations are consistently decreasing with the increasing rate of *T. diversifolia* compost. In the soils added with 50 t ha^{-1} *T. diversifolia* compost, the mercury concentrations decreased to 155.91 and 166.29 ppm where water spinach (B5T1) and groundnuts (B5T2) were grown, respectively.

Concentration of mercury in the peanut and water spinach: The concentration of mercury in the peanut plant was higher than that in the water spinach, both in the root and shoot (Fig. 2a, b). Figure 2a and b show that the concentration of Hg^{2+} in the plants decreases with the increasing rates of the *T. diversifolia* compost. It is due to the ability of the compost to release humic and fulvic acids (Table 1) that bond Hg^{2+} so that it becomes unavailable to plants. The ability of both plants to accumulate metal absorbed from soil is shown in Fig. 3.

DISCUSSION

The mercury polluted soil as plant grown media was a sandy loam which consisted of 17.43 sand fractions, 78.33% silt and 4.24% clay. The soil bulk density was 1.21 g cm^{-3}. Soil pH-$H_2$0 and pH-KCl were 6.90 and 6.00, respectively. The value of soil pH is a reflection of hydrogen ion solubility in soil as well as the soil acidity level. pH strongly affects the activity of metal distribution in soil and nutrient absorption by plants. The contents of soil C-organic and cation exchangeable capacity (CEC) were low, which were 1.13% and 10.21 me/100 g, respectively. The low C-organic and CEC are indicators that the content of soil organic matter is low, leading to depletion of humus, humic and fulvic acids as well as microorganisms biomass[18]. Soil with high organic matter content will have higher CEC than that with low content[19].

Mercury contained in the tailing waste of Poboya gold mining was at critical level (621.37 ppm) due to the use of a large amount of mercury in gold processing. As Mirdat, Patadungan and Isrun[11] found that 500 cc of mercury was expended for one processing activity, directly and indirectly affecting the land around it. The contents of humic and fulvic acids of the compost were 25.10 and 5.41%, respectively. These organic acids will affect the chemical characteristics of the soil. Organic acids such as humic, fulvic, acetate, oxalate, butyrate, lactate and citrate are substances which have high affinity to heavy metal including soil Hg[10].

The soil used to grow the plants was taken from Land Unit 2. The concentrations of mercury in the soil with no *T. diversifolia* compost added were 533.68 ppm and 512.97 ppm where groundnut (B_0T_1) and water spinach (B_0T_2) were planted, respectively. Much lower mercury concentrations were present in the soil when *T. diversifolia* compost was added. The concentration of heavy metals in plant can be an indicator of their presence in soil where the plants grow[20]. The decrease of mercury in the soil is strongly related to the formation of Hg-organic when Hg^{2+} bond with organic substances from the *T. diversifolia* compost. The *T. diversifolia* compost contains microorganisms that help the organic matter decompose[21-23]. Various organic acids such as humic and fulvic acids are then released to the soil solution. The humic and fulvic acids can react with Hg^{2+} in the soil solution[24,25].

The observation of the water spinach (*Ipomoea reptans*) and peanut (*Arachis hypogaea* L.) plants for 45 days after planting showed that the highest percentage of the decreasing mercury was found in soil where 50 t ha^{-1} *T. diversifolia* compost was added. It is suggested that the compost can be used for remediation of soil polluted by heavy metal through increasing heavy metal chelation reaction. Organic matter can form complex bonds with heavy metal called metal-organic complex. The formation of the metal-organic complex reduces the solubility of the heavy metal[7,26]. Furthermore, chelation by organic matter can drive the availability of metal in soil particularly humic and fulvic acids that have the ability to absorb metal. The concentration of chromium (Cr) and copper (Cu) decreased along with the increase of organic matter[27]. Singh *et al.*[27] also reported that the application of *Chromolaena odorata* L. compost suppressed the rate of Hg absorption by water spinach grown on soil containing mercury.

Heavy metal absorption by plants occurs through various ways. The heavy metals diffuse to root surface by ion exchanges and direct contact between the root and soil colloids. They also enter root system due to the presence of organic acids, such as malate, citrate, fumarate and phenolate. They reduce soil pH around the root system causing a large amount of metal substances to dissolve and be absorbed by the plant root[28]. The concentration of heavy metals within plants is affected by the length of contact time between the plants and the metals, the metal concentration in soil, plant morphology and physiology, plant age and plant type[29–32].

This research shows that the concentration of mercury in the peanut plant was higher than that in the water spinach both in root or crown (Fig. 2a and b). Plant root can absorb ions by a passive way through diffusion of ions into root endoderm is and by an active way when concentration gradient needs metabolic energy. Mercury adsorption occurs through a passive process where diffusion mechanism is predominant.

Applying *T. diversifolia* compost at various rates significantly affected ($p<0.01$) the concentration of mercury in both plants. For the growing period of 45 days, the largest decrease of mercury concentration of the groundnut plant occurred in the root (86.19%) at the B_5T_1 treatment, followed by the B_4T_1 (71.65%), B_3T_1 (57.03%), B_2T_1 (48.05%) and B_1T_1 (41.79%) treatments, whereas the decrease in the shoot was at the B_5T_1 (82.24%) treatment followed by the B_4T_1 (65.93%), B_3T_1 (48.39%), B_2T_1 (29.27%) and B_1T_1 (13.46%). In the water spinach, the highest reduction of mercury concentration was in the B_5T_2 (75.04%), followed by the B_4T_2 (62.26%), B_3T_2 (48.89%), B_2T_2 (32.93%) and B_1T_2 (21.00%) treatments. The reactivity of organic substances of the *T. diversifolia* compost on Hg^{2+} was greater in the root than that in the crown (Fig. 2a and b).

Factors controlling mercury (Hg^{2+}) accumulation in plant tissue are its concentration and metal types[33]. The results show that the concentration of Hg^{2+} in the plants decreases with the increasing rates of the *T. diversifolia* compost. It is due to the ability of the compost to release humic and fulvic acids (Table 1) that bond Hg^{2+} so it becomes unavailable to plants. Besides that, plants discharge enzymes and exudates capable to degrade organic contaminants in soils.

The enzymes released through root membrane function as metal reductant. After entering the root, Hg^{2+} moves upward through xylem and phloem tissue to other parts of the plant. To improve transportation efficiency, the metal is bonded by chelate molecules. The mercury then is accumulated in various parts of plants including roots, stems and leaves. Mercury absorbed by plants can evaporate through their leaves[34]. Some plants stored mercury more in root than the upper parts of the plants, suggesting that the mercury might be accumulated in the root after being absorbed by the root or xylem from soils.

The accumulation of Hg in the root of both plants was 1-2 times in magnitude compared to that in their shoot. Whereas in the planting media, it was 3-8 times higher than in the root. The plant ability to accumulate metal absorbed from soil can be estimated by the bioconcentration factor (BCF) value. The BCF value >1 indicates that a species has a potency as a heavy metal phytoremediator[35]. The low BCF values of both plants can be associated with the role of the compost added. This research also shows that the maximum ratio of Hg translocation from the root to the shoot (TF values) of both plants was less than 1 (0.74 and 0.93, respectively) under the 50 t ha^{-1} compost rate treatment. It indicates that Hg^{2+} was retained in the root tissue and only half was transferred to the shoot showing low mobility of Hg^{2+} from the root to the shoot or immobilization of Hg in the root.

Plants which accumulate heavy metals in their roots larger than in their shoots show that their roots recognize the heavy metals toxic elements[36]. The above equations explain that the increase of Hg-chelate in soils occurs simultaneously along with the increase of compost rate and reduction of plant bioconcentration to <1. Plants which have biological absorption coefficient (BAC) range of 0.1-1 can be categorized as moderate accumulator plants[37]. It can occur due to the role of a number of organic substances released from compost suppresses Hg activity even though the Hg concentration in soil is very high. Thus, the mercury polluted soil used in the research was poor in quality as the concentration of mercury was very critical.

An alternative for solving the problems is the use of organic matter/compost[38,39]. The humic and fulvic acids contained in the *T. diversifolia* were 25.10 and 4.1%, respectively. Both organic acids will affect the chemical characteristics of the soil including Hg. Organic acids such as humic, fulvic, acetate, oxalate, lactate and citrate have a high ability to form chelates with a number of metals in soil solution altering them to become unavailable for plants[4,40].

The distribution of mercury in soil around the gold processing area of Poboya of Palu City, Central Sulawesi Province was above the critical level where the range of mercury concentration was 1.26-8.19 ppm in bare land, 0.85- 2.62 ppm in cropped land and 0.57-0.76 pp min mixed plantation. The largest was in the processing area (84.15-575.16 ppm).

Applying 50 t ha^{-1} *T. diversifolia* compost reduced Hg^{2+} concentration by 71.53% in soil planted with groundnut and by 67.58% in that with water spinach. The decreases of Hg^{2+} concentrations were 86.19 and 84.82% in peanut root and water spinach root respectively, whereas in their shoots they were 65.93 and 75.04%, respectively. The concentration of Hg^{2+} decreases along with the increasing rates of *T. diversifolia* compost both in soil and plants. It is necessary to conduct research on using humic and fulvic acids extracted from *T. diversifolia* compost in comparison with the use of solid compost to soil polluted with mercury (tailing) in order to determine the efficiency and practicability of both materials.

CONCLUSION

Applying 50 t ha^{-1} *T. diversifolia* compost reduced Hg^{2+} concentration by 71.53% in soil planted with groundnut and by 67.58% in that with water spinach. The decreases of Hg^{2+} concentrations were 86.19 and 84.82% in peanut root and water spinach root, respectively, whereas in their shoots they were 65.93 and 75.04%, respectively. The concentration of Hg^{2+} decreases along with the increasing rates of *T. diversifolia* compost both in soils and plants.

It is necessary to conduct research on using humic and fulvic acids extracted from *T. diversifolia* compost in comparison with the use of solid compost to soil polluted with mercury (tailing) in order to determine the efficiency and practicability of both materials.

SIGNIFICANCE STATEMENT

This study reports that the ability of organic material (compost) *Tithonia diversifolia* binds mercury (Hg) at around the roots of the plant so as to reduce the absorption of mercury by plants. This study will help the researchers to uncover critical areas of organic compounds bonding to cations of heavy metals like Hg. Thus, a new theory regarding the *T. diversifolia* compost can be used for the recovery of agricultural land and plants contaminated by Hg^{2+}.

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