Short communication

Siam weed (*Chromolaena odorata* L.) for phytoremediation of artisanal gold mine tailings

A. Hamzah[1], Z. Kusuma[2], W. H. Utomo[2]* and B. Guritno[2]

[1] Tribhuwana Tunggadewi University, Jl. Telaga Warna, Malang 65144, Indonesia; [2]International Research Centre for Management of Mining and Degraded Lands; Brawijaya University, Jl. Veteran, Malang 65145, Indonesia.

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Abstract

The potential of *Chromolaena odorata* to remove Hg and Pb from tailings from cyanidation processing of artisanal gold mining at Lombok, Indonesia was investigated in a glasshouse experiment. The tailings were amended with farmyard manure (FYM) and biochar added with 5 and 10 g kg^{-1} $FeSO_4$ before growing *C. odorata* plants. *Chromolaena odorata* grew well on amended tailings, but it did not grow on untreated tailings. Application of organic amendments and $FeSO_4$ decreased tailing pH from 9.2 up to 6.6 (e.g., FYM+10 g $FeSO_4$ kg^{-1} soil) and increased its organic C and N, P, K levels. Total absorption of Hg in *C. odorata* plants ranged from 5.8 to 8.7 mg kg^{-1} and Pb from 55 to 61 mg kg^{-1} in the amended substrates.

Keywords: Organic amendments, Biochar, Artisanal mining

Small-scale gold mining called artisanal mining is increasing in Indonesia and is estimated to reach 713 spots in Sumatra, Java, Kalimantan, Sulawesi and East Nusa Tenggara (Aspinall, 2001). Although mining activities have been capable of contributing to employment and improve societal welfare, artisanal mining has led to environmental problems due to heavy metal contamination. Artisanal mining in Indonesia mostly use the cheap and easy mercury amalgamation technique for gold recovery, which results in mercury contamination of the environment. Krisnayanti et al. (2012) reported as high as 3000 mg kg^{-1} Hg in amalgamation tailings and 1900 mg kg^{-1} in cyanide tailings in Lombok, Indonesia. Phytoremediation has been widely recommended for removing heavy metals from the environment. The plants used for reclaiming contaminated sites are called "hyper accumulators", which absorb and accumulate high amount of metal without experiencing phytotoxicity and are therefore capable of growing in unfavorable medium and produce high biomass yields. Hartley et al. (2009) observed very low organic C content and very high pH in the tailing of artisanal gold mining at Sekotong, Lombok, Indonesia, which necessitates addition of soil amendments such as farmyard manure (FYM) or more resistant organic sources such as biochar in conjunction with sulfur containing materials, such as elemental sulfur, $Al_2(SO_4)_3$, or $FeSO_4$ (McCauley et al., 2009). This study examined the potential of *Chromolaena odorata* plants to remove heavy metals, especially mercury (Hg) and lead (Pb) from tailing of artisanal gold mining, following additions of various soil amendments.

The glasshouse experiment was carried out at the Tribhuwana Tunggadewi University, Malang, Indonesia. Tailing of cyanidation gold processing

*Author for correspondences: Email <wanihadi@ub.ac.id>.

were collected from artisanal gold mining at West Lombok, Indonesia. These tailings were air-dried, crushed, and passed through a 2.0 mm diameter sieve. The treatments included: (1) FYM + 5 g $FeSO_4$ kg^{-1} soil, (2) FYM + 10 g $FeSO_4$ kg^{-1} soil, (3) biochar + 5 g $FeSO_4$ kg^{-1} soil, (4) biochar + 10 g $FeSO_4$ kg^{-1} soil, and (5) no amendment as control, arranged in a completely randomized design with three replications. FYM was obtained from a local farmer at Malang, Indonesia and the biochar was prepared by pyrolysis of FYM. Some characteristics of tailings, FYM, and biochar used in this experiment are presented in Table 1.

Ten kg of crushed air-dried tailing (water content of about 14%) was put in a plastic pot (15 kg capacity), watered to about field capacity, incubated for 30 days, and planted with *C. odorata.* Ten gram N, P, and K fertilizers from urea (46% N), super phosphate 36 (36% P_2O_5), and potassium chloride (50% K_2O) were applied at planting time, and the plants were grown in a glasshouse for four months. During the experiment, water content was maintained at about field capacity by daily watering. Soil samples were collected 30 days after incubation for analysis of pH, organic C, total mercury (Hg), total lead (Pb). Plant height, leaf number, dry biomass, and the content of Hg and Pb were determined at harvest. The plant samples (leaves, stems, and roots) were washed with tap water, rinsed with deionized water, and oven-dried at 60–70°C for 72 h. The samples were ground in an electric mill and homogenized by thorough mixing.

Total Hg and Pb in soils and plants were extracted using HNO_3 and $HClO_4$ and soluble Hg and Pb using HCl, HNO_3, and $K_2Cr_2O_7$ (EPA, 1988), and the concentration of Hg and Pb determined by Atomic Absorption Spectrometry (AAS). Soil pH was measured in 1:2.5 ratio of soil and de-ionized water. The Walkley and Black wet oxidation method determined soil organic C. The data were analyzed using ANOVA in Minitab Program ($p = 0.05$).

Solubility of Hg and Pb were not significantly influenced by soil amendments (Table 2). Theoretically, a decrease in tailing pH would increase the solubility of heavy metals (McCauley et al., 2009), but it seems that the pH changes in this study (up to 6.6) did not influence metal solubility. Application of amendments significantly influenced the tailing pH, organic C, available P, exchangeable K, and N content (Table 2). Both FYM and biochar application increased organic C in the tailings. Tailing pH decreased with application of $FeSO_4$, and pH change was higher as the $FeSO_4$ rate increased. The pH changes in FYM applied tailing was higher compared to that in biochar treated tailing. This might be due to a lower FYM pH (Table 1). The results in Table 2 further show that the content of P and K increased as pH approached neutrality, which is normal. Availability of P in alkaline condition is generally low because of P fixation by calcium (McCauley et al., 2009).

Chromolaena odorata did not survive on untreated tailings. Even on amended tailings, it exhibited ab-

Table 1. Tailing, farmyard manure (FYM), and biochar characteristics from West Lombok, Indonesia.

Properties	Tailing	Farmyard manure	Biochar
pH (H_2O)	9.1	6.8	8.2
Organic C (%)	0.21	13.48	25.77
Total N (%)	0.13	1.14	0.52
K (cmol kg^{-1})	0.11	1.00	1.23
CEC (cmol kg^{-1})	13.23	–	39.62
Hg (mg kg^{-1})	247.24	–	–
Pb (mg kg^{-1})	134.26	–	–

CEC: Cation exchange capacity

Table 2. Some characteristics of tailings from West Lombok, Indonesia treated with amendments 30 days after incubation.

Treatment	pH	C (mg kg^{-1})	Total N (mg kg^{-1})	Total P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})	Soluble Hg (mg kg^{-1})	Soluble Pb (mg kg^{-1})
FYM + 5 g $FeSO_4$ kg^{-1} soil	7.3ab	0.29b	0.02b	92.4bc	4.5c	0.3a	9.3a
FYM + 10 g $FeSO_4$ kg^{-1} soil	6.6a	0.25b	0.02b	119.9c	5.6c	0.4a	10.9a
Biochar + 5 g $FeSO_4$ kg^{-1} soil	7.4b	0.36c	0.20b	60.7b	1.9b	0.2a	10.2a
Biochar + 10 g $FeSO_4$ kg^{-1} soil	7.1ab	0.36c	0.02b	89.1b	2.5b	0.1a	10.3a
Control	9.2c	0.02a	0.008a	12.4a	0.1a	0 0	

Means followed by the same letters, in same column was not significantly different (p=0.05)

normal growth characteristics (curly and chlorotic leaves, with brown spots). As can be seen from Table 3, plants grew well in the FYM treated tailing than biochar treated tailing, presumably due to the better fertility status of tailing treated with FYM. Growth of *C. odorata* improved as the rate of $FeSO_4$ increased, this was reasonable, because the pH approached neutrality (Table 2). Hg and Pb uptake were significantly influenced by organic amendments (Table 4). In general, Hg and Pb absorption of *C. odorata* in FYM treated substrate was higher compared to that of biochar treated tailing. Hg and Pb absorption also increased with increasing rate of $FeSO_4$ in the biochar treatment owing to pH changes (Table 2). It is widely known that the solubility of most heavy metals increases as soil pH decreases (Temminghoff et al. 1997). In addition, the higher CEC of biochar would make the affinity of biochar to any chemical compound higher compared to FYM (Hartley et al., 2009), which in turn decreased the availability of metals for plant growth. More than 50% of the absorbed metals accumulated in the foliage–with only a relatively small proportion in stems and roots.

Table 3. Growth characteristics of 120-day-old *Chromolaena odorata* on tailings from West Lombok, Indonesia treated with amendments.

Treatments	Plant height (cm)	Leaf number/plant	Dry biomass g/plant
FYM + 5 g $FeSO_4$ kg^{-1} soil	112.8b	112b	97.7b
FYM + 10 g $FeSO_4$ kg^{-1} soil	119.4b	129b	128.8c
Biochar + 5 g $FeSO_4$ kg^{-1} soil	84.6a	90a	62.0a
Biochar + 10 g $FeSO_4$ kg^{-1} soil	87.9a	91a	68.0a

Means followed by the same letters, in same column was not significantly different (p=0.05)

Table 4. Effect of FYM, biochar and $FeSO_4$ application on the uptake of Hg and Pb by 120-day-old *Chromolaena odorata* plants grown on tailings from West Lombok, Indonesia treated with amendments.

Treatments	Mercury (Hg)				Lead (Pb)			
	Total (mg kg^{-1})	Leaves (%)	Stem (%)	Roots (%)	Total (mg kg^{-1})	Leaves (%)	Stem (%)	Roots (%)
FYM + 5 g $FeSO_4$ kg^{-1} soil	8.9b	53.5a	22.6a	23.9a	57.0ab	55.6a	20.2a	24.2a
FYM + 10 g $FeSO_4$ kg^{-1} soil	8.7b	52.1a	24.6a	23.3a	58.2ab	56.2a	15.6a	28.2a
Biochar + 5 g $FeSO_4$ kg^{-1} soil	5.8a	57.0a	20.6a	22.4a	55.0a	55.3a	15.2a	29.5a
Biochar + 10 g $FeSO_4$ kg^{-1} soil	8.0b	52.5a	21.5a	26.0a	61.0b	57.3a	18.6a	24.1a

Means followed by the same letters, in same column was not significantly different (p=0.05)

Application of organic amendments in conjunction with $FeSO_4$ decreased tailing pH from 9.2 up to 6.6 (FYM+10 g $FeSO_4$ kg^{-1} soil), besides increasing organic C and N, P, and K levels. *Chromolaena odorata* has a good potential for removal of Hg and Pb from artisanal gold mining, because of its ability to accumulate high concentrations of these metals without experiencing toxicity. Total absorption of Hg varied from 5.8 (FYM + 5 g $FeSO_4$ kg^{-1} soil) to 8.7 mg kg^{-1} (FYM + 10 g $FeS0_4$ kg^{-1} soil), and Pb from 55.0 (biochar + 5 g $FeSO_4$ kg^{-1} soil) to 61.0 mg kg^{-1} (biochar +10 g $FeSO_4$ kg^{-1} soil).

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