LOWERING HEAVY METAL SOLUBILITIES IN TROPICAL SOILS BY LIME AND CASSAVA-LEAF COMPOST ADDITIONS

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ABSTRACT

Heavy metal is one of the environmental pollutants most detrimental to the lives of animals and human beings and may come into human tissues through food chains with soil as one of the main routes. Because plant roots absorb soluble heavy metals, studies on heavy metal solubilities in soils are important. This research was to evaluate the use of lime and cassava-leaf compost to lower heavy metal solubilities in some tropical soils. Soil samples were collected from A_p horizons (topsoils) of 3 soil orders, i.e. Ultisol Tanjungan, Oxisol Gedongmeneng, and Alfisol Banjaragung; all were collected from Lampung, Indonesia. Soil samples were spiked with a standard solution containing Cd, Cu, and Zn and were factorially treated with lime ($CaCO_3$) at 4 levels (0, 2.5, 5, and 10 ton ha^{-1}) and cassava-leaf compost at 4 levels (0, 5, 10, and 20 ton ha^{-1}), and incubated at room temperature and 40% moisture content for 4 weeks. The results showed that lime and/or cassava-leaf compost consistently increased the soil pH, but at addition of 10 ton $CaCO_3$ ha^{-1} the soil pH of all experimental units were close to neutrality. The major part of the added Cu was adsorbed by all soils; while the most part of the added Cd was soluble in soil water or weakly held by soil particles. Copper solubility in all soils consistently decreased with the addition of lime and/or cassava-leaf compost. Addition of lime and/or cassava-leaf compost also decreased Cd solubility, but the addition of high level compost at high addition of lime (> 2.5 ton $CaCO_3$ ha^{-1}) generally increased the solubility of Cd in all soils. The most part of the added Zn was adsorbed by soils of Banjaragung and Gedongmeneng, but only a small part of the added Zn was adsorbed by soil of Tanjungan. The solubility of Zn decreased with lime and/or cassava-leaf compost addition, but, similar to Cd, addition of high level compost increased Zn solubility at high level of lime addition. These observations show that all soils can be used to immobilize heavy metals. Lime and/or cassava-leaf compost can be used to reduce the solubilities of heavy metals in all soils, particularly at low levels of lime and cassava-leaf compost additions.

Keywords: cadmium, cassava-leaf compost, copper, lime, tropical soils, zinc

INTRODUCTION

Even though some heavy metals are required at small quantities by plants and animals, all are detrimental to animal and human health at high concentrations. Health hazards caused by heavy metal accumulation in human tissues have been recorded from various parts of the world (Alloway, 1990c; Baker, 1990; Steinnes, 1990; Lagerwerff, 1982). Minamata desease caused by Hg accumulalation and *Itai-itui* desease caused by Cd accumulation in human tissues are the most monumental examples of the detrimental effects of heavy metals (Alloway, 1990c). Trend in the production and use of heavy metals in modern industries (Alloway, 1990a) suggest that various heavy-metal related problems may probably arise in the future, particularly if heavy metal pollutants in the environment are not managed properly.

Soil is one of the most important routes for heavy-metal-pollutant intake by human beings through food chains. Heavy metal from various sources may accumulate in soils and/or be absorbed by plant roots. Fortunately, plant roots can only absorb water soluble and/or weakly held heavy metals on soil solid surfaces (generally referred to as available heavy metals). Plants roots cannot absorb strongly held heavy metals due to the high energies plant roots should expense in exchange to these elements. Therefore, heavy metal adsorption onto soil solid surfaces is very important to lower heavy metal accumulation in plant tissues.

There are several methods suggested by soil researchers to lower heavy metal availabilities to plants (Ma et al., 1995; 1993), among which addition of lime and/or compost are reasonable for tropical soils, that show high pH-dependent charges. Generally soil researchers agree that liming may decrease heavy metal solubilities in soils (Ma and Lindsay, 1995; 1990; Salam, 1995; Workman and Lindsay, 1990; Sanders, 1982). Lime may increase soil pH and may in turn neutralize OH^- and Al^{3+} in soil sulution and those attached on soil solids. This process may eventually increase soil adsorption capacities with respect to heavy metal cations as a result of the increase in the negative charges on soil solid surfaces, that were initially occupied by adsorbed H^+ and Al^{3+}. Organic matters may increase soil adsorption capacity due to their functional groups, that may give negative charges if dehydrogenized (Rodella et al., 1995; Alloway, 1990b; Helling et al., 1964). Because dehydrogenization of organic matters' functional groups may increase with the increase in soil pH, the increase in soil pH caused by liming may increase organic matter adsorption capacity with respect to heavy metals (Lindsay, 1979). Heavy metal chelation by soluble organic matter may also precipitate heavy metals if the molecular weight of related organic matter is high enough (Keeney and Wildung, 1986; Kabata-Pendias and Pendias, 1992).

Addition of lime and/or organic matter, therefore, may decrease the solubilities of heavy metals in tropical soils. However, data on this phenomenon in tropical soils is scarce. The objective of this research was to evaluate the changes in heavy metal solubilities (Cu, Cd, and Zn) in tropical soils (Ultisol, Oxisol, and Alfisol) spiked with heavy metal standard solution and treated with lime ($CaCO_3$) and cassava-leaf compost.

MATERIALS AND METHODS

Soil samples (Ultisol Tanjungan, Oxisol Gedongmemeng, and Alfisol Banjaragung) were collected from Lampung (0-20 cm). After an air-drying, each soil sample was ground, mixed thoroughly, and screened to 2 mm. Selected physical and chemical properties of soil samples are listed in Table 1. All soils were relatively acid and low in organic C and total N.

Two hundred grams (105^{o}C oven-dry equivalent) of soil sample was used as an experimental unit. Experiment was conducted with 2 treatment factors and was arranged factorially with 3 replications. The treatment factors were: (1) lime and (2) cassva-leaf compost. Lime ($CaCO_3$) was added at (in ton ha^{-1}): 0 (L-0), 2.5 (L-1), 5.0 (L-2), and 10 (L-3). Cassava-leaf compost was also added at 4 levels i.e.

(in ton ha^{-1}): 0 (C-0), 5 (C-1), 10 (C-3), and 20 (C-4). A simple solution containing 50 ppm Cu and Zn and 25 ppm Cd was also added to increase concentrations of Cu and Zn in soils as much as 10 mg kg^{-1} and Cd 5 mg kg^{-1}. All experimental units were replicated 3 times.

After a thorough mixing, each experimental unit was put in a polyethylene bag, moistened with distilled water to 40%, and incubated at room temperatue. During incubation, all experimental units were closed to lower water evaporation. Chemical properties of each experimental unit were determined after a 4 week incubation. Chemical properties determined included: pH (H_2O 1:2) and soluble heavy metals, including Cu, Cd, and Zn. Soil reaction (pH) was determined by pH-electrode and soluble heavy metals with DTPA method (Baker and Amacher, 1982). All analyses were conducted with moist soil sample but all data are presented on dry weight basis.

Table 1. Selected physical and chemical properties of soils used in this experiment*.

Soil Property	Tanjungan	Gedongmeneng	Banjaragung
Texture			
Sand (%)	23.6	45.6	22.0
Silt (%)	29.6	19.6	21.1
Clay (%)	46.8	34.8	56.8
pH 6.02	5.54	4.86	
Organic C (%)	1.44	1.22	1.84
Total N (%)	0.12	0.15	0.17
C/N 12.0	8.13	10.8	
Heavy Metals (mg kg^{-1})			
Cu	1.81	0.910	3.41
Cd	0.089	0.140	0.155
Zn	2.68	6.74	10.1

* avg. of 3 replicates

RESULTS AND DISCUSSION

Change in soil pH is an indicator for changes in solubilities of heavy metals in soils. In general, heavy metal solubilities decrease with the increase in soil pH due to the increase in metal adsorption by soil particles at increasing soil pH. Changes in soil pH caused by addition of $CaCO_3$ and/or cassava-leaf compost are depicted in Fig. 1. Addition of standard solution actually decreased soil pH due to its acid solvent. However, lime addition consistently increased all soils pH to neutrality at the highest lime level. Effect of cassava-leaf compost on soil pH was also shown in Fig. 1, but its role at increasing soil pH was lower at high levels of lime additions. All these pH changes were negatively correlated with heavy metal solubilities in soils. As shown later on, the increase in soil pH decreased heavy metal solubilities in all soils. Changes in heavy metal solubilities as affected by lime and/or cassava-leaf compost additions in all soils are depicted in Figs.2, 3, and 4 for Cu, Cd, and Zn, respectively.

The solubility of Cu apparently decreased with lime and/or cassava-leaf compost additions (Fig. 2). However, it was also apparent that the effect of lime on Cu ($\Delta Cu/\Delta CaCO_3$) decreased with the increase in cassava-leaf compost addition. This suggests the possibility of an increase in concentrations of soluble organic materials in soil solution, that may have chelated and kept Cu in soluble forms. Concentrations of active organic chelating agents generally increase with the increase in soil pH due to an increase in dehydrogenization of their functional groups. Another possibility is the shifting of Cu forming bondings with lower energies with solid organic matter. Organic matter may have bonded Cu weaker than clay.

Similar to Cu, Cd solubility also decreased with the increase in lime and/or cassava-leaf compost additions (Fig. 3), in a negative correlation with the changes in soil pH. It was also shown that the decrease in Cd solubility by lime addition was lower at high cassava-leaf compost addition. Addition of lime at rates of more than 5 ton

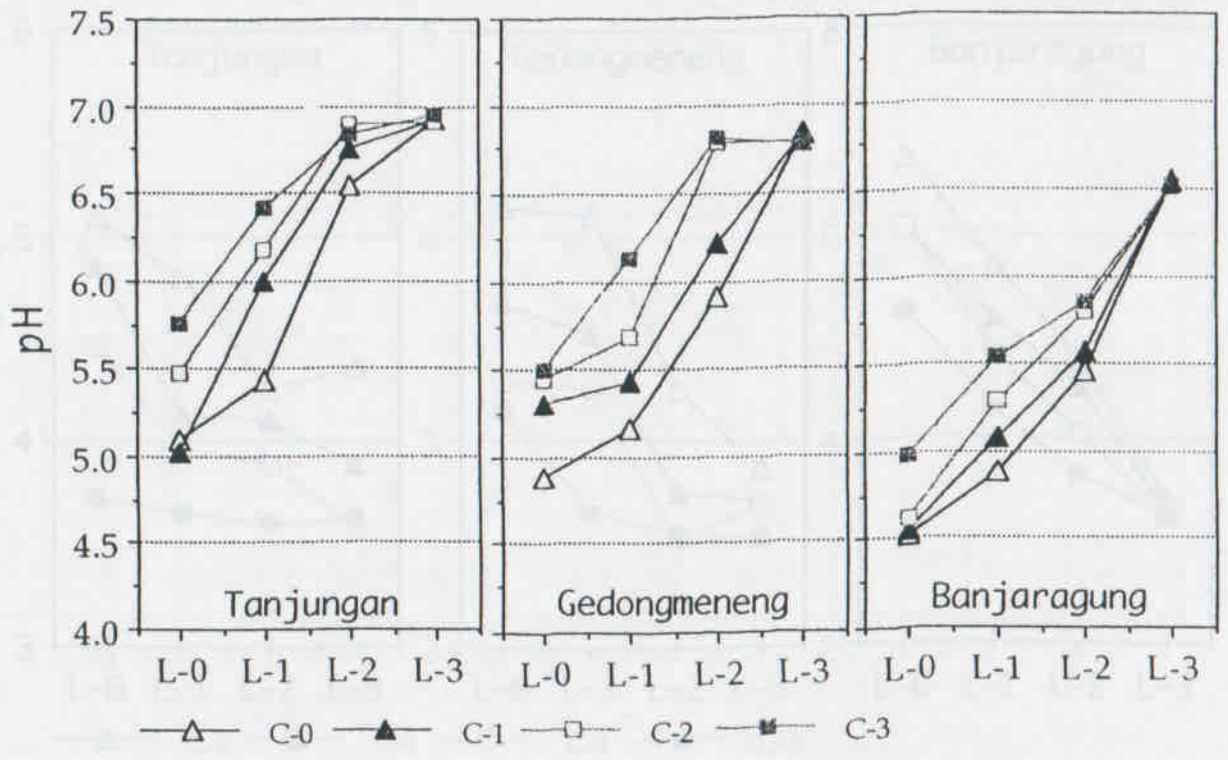

Fig. 1. Soil pH as affected by lime and/or cassava-leaf compost treatments (Lime L-0 0, L-1 2.5, L-2 5.0, and L-3 10 t $CaCO_3$ ha^{-1} and compost C-0 0, C-1 5, C-2 10, and C-3 20 t ha^{-1}).

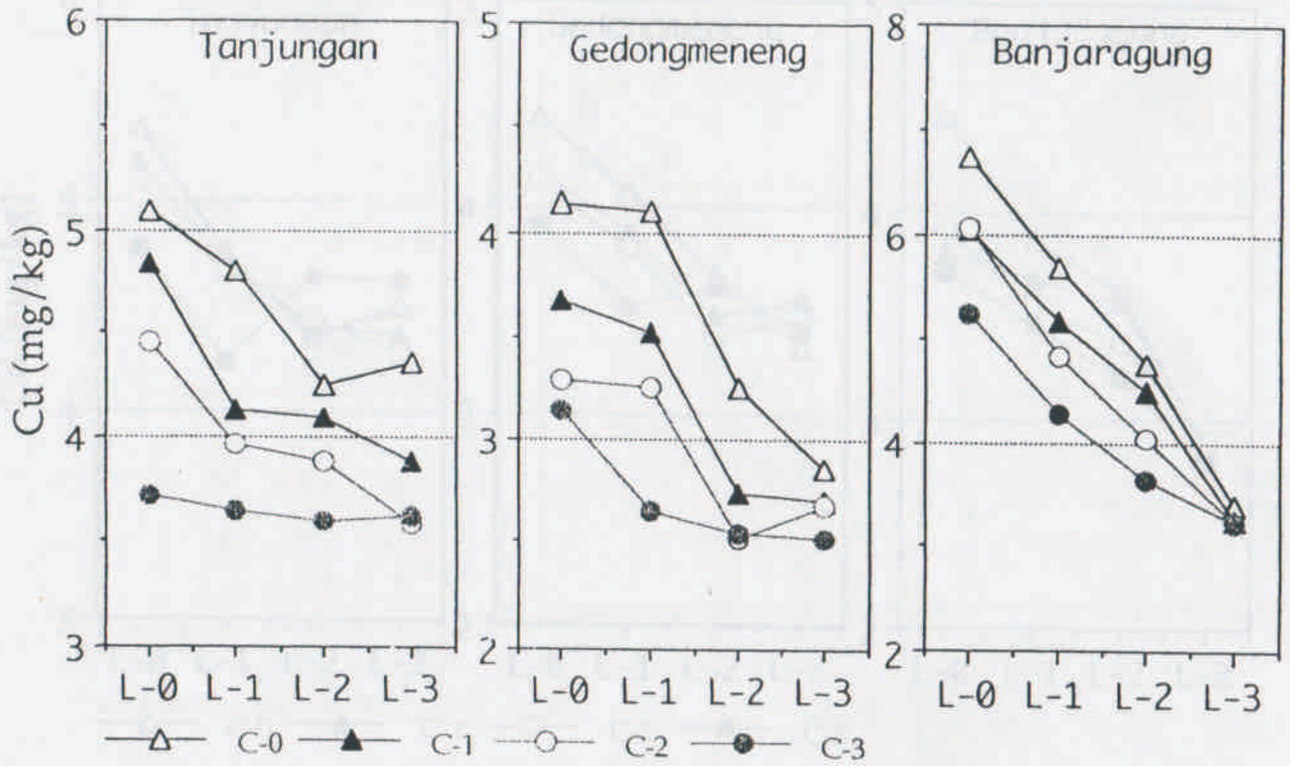

Fig. 2. Soluble Cu as affected by lime and/or cassava-leaf compost treatments (Lime L-0 0, L-1 2.5, L-2 5.0, and L-3 10 t $CaCO_3$ ha^{-1} and compost C-0 0, C-1 5, C-2 10, and C-3 20 t ha^{-1}).

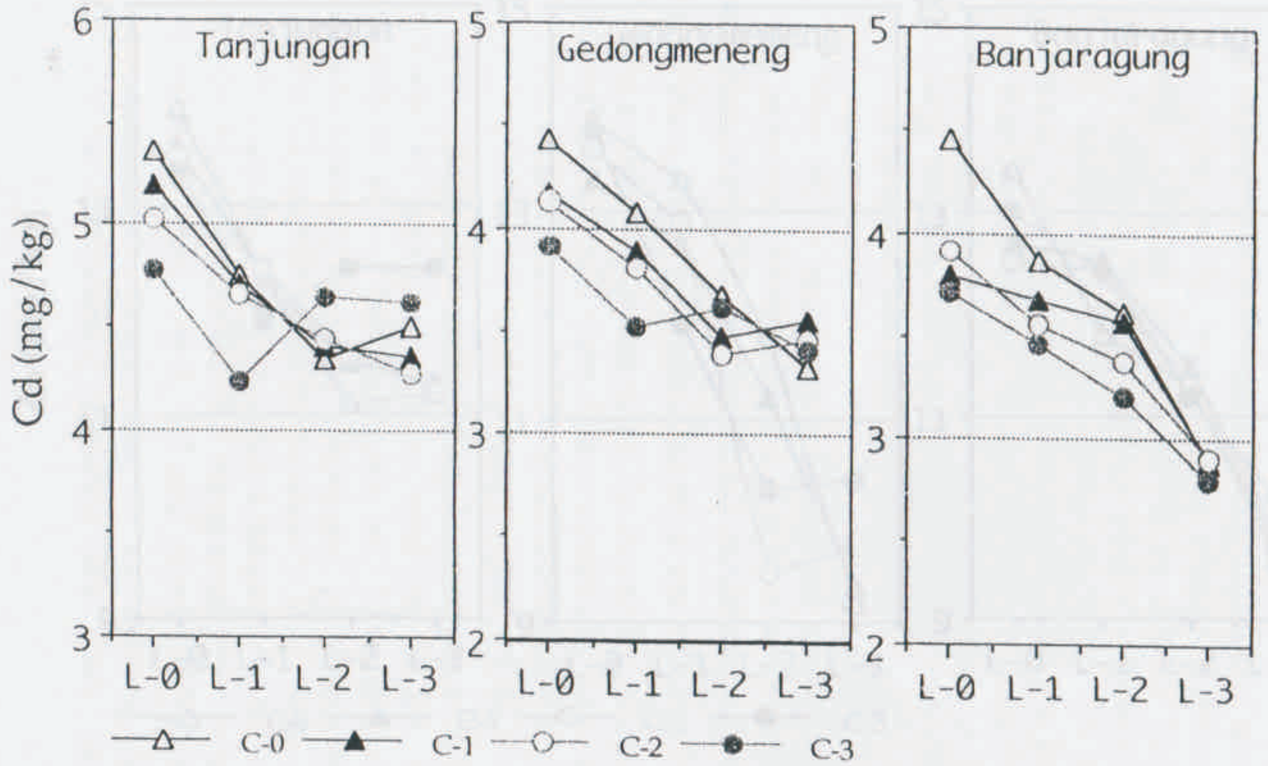

Fig. 3. Soluble Cd as affected by lime and/or cassava-leaf compost treatments (Lime L-0 0, L-1 2.5, L-2 5.0, and L-3 10 t $CaCO_3$ ha^{-1} and compost C-0 0, C-1 5, C-2 10, and C-3 20 t ha^{-1}).

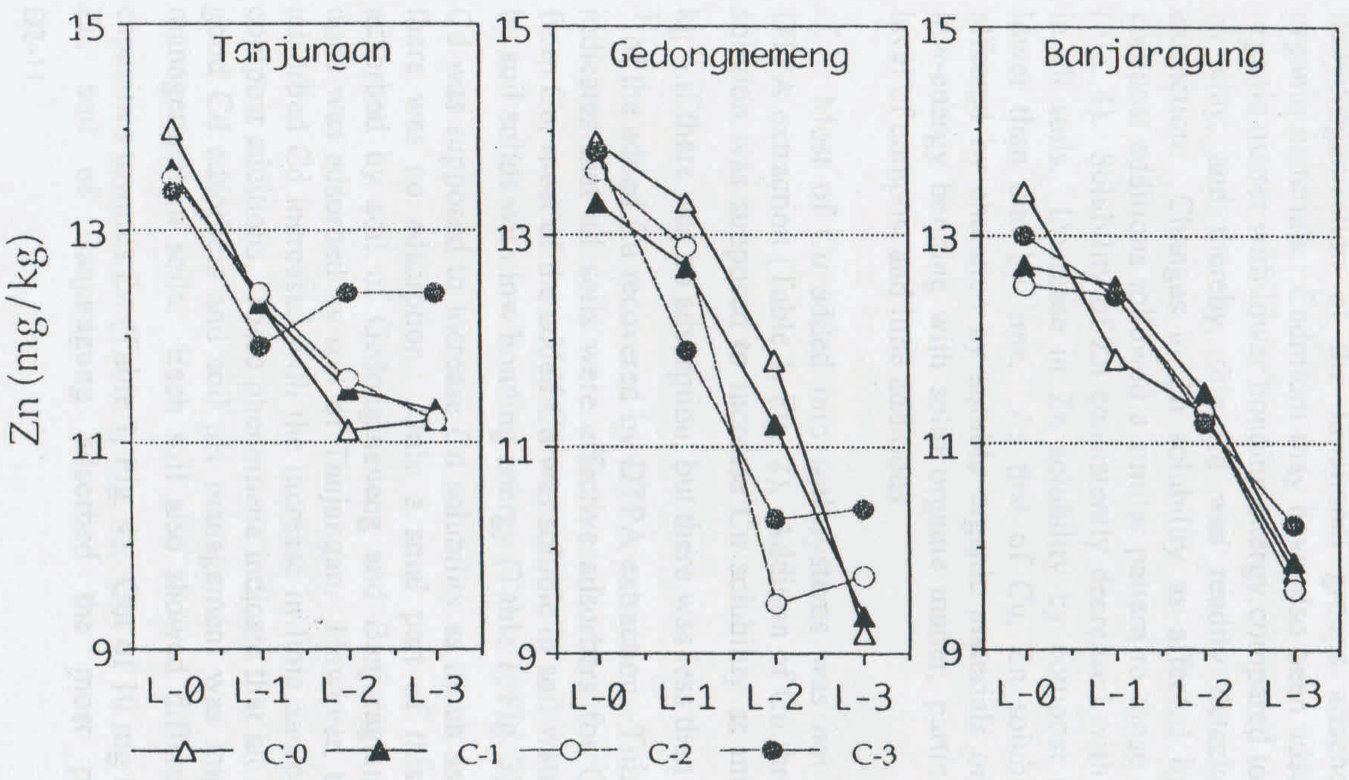

Fig. 4. Soluble Zn as affected by lime and/or cassava-leaf compost treatments (Lime L-0 0, L-1 2.5, L-2 5.0, and L-3 10 t $CaCO_3$ ha^{-1} and compost C-0 0, C-1 5, C-2 10, and C-3 20 t ha^{-1}).

ha^{-1} indeed caused Cd solubility higher at high levels of compost additions, particularly in soils of Tanjungan and Gedongmeneng. This phenomenon is possibly associated with the increase in concentration of active chelating agent at high levels of compost additions with the increase in soil pH as a result of increased dehydrogenization of the functional groups attached to soluble organic materials. Cadmium may have also been adsorbed by solid organic matter with lower bonding energy compared to that adsorbed by clay, and thereby, this Cd was readily detached by DTPA extraction. Changes in Zn solubility as affected by lime and/or compost additions followed a similar pattern to those of Cu and Cd (Fig. 4). Solubility of Zn consistently decreased with lime addition in all soils. Decrease in Zn solubility by compost treatment was lower than that by lime. As that of Cu, Zn solubility was also affected by chelation by soluble organic materials or formation of low-energy bonding with solid organic matter, particularly at high level of compost and lime additions.

Most of Cu added into soil systems was not recovered by DTPA extraction (Table 1, Fig. 2). Addition of Cu through standard solution was supposed to increase Cu solubility as much as 10 mg kg^{-1} if there was no adsorption, but there was less than 3 to 4 mg kg^{-1} of the added Cu recovered by DTPA extraction. This phenomenon indicates that all soils were effective adsorbers for Cu. Different from Cu, most of the added Cd was soluble in soil water or adsorbed by soil solids with low bonding energy (Table 1, Fig. 3). Addition of Cd was supposed to increase Cd solubility as much as 5 mg kg^{-1} if there was no adsorption. Only a smal part of this amount was adsorbed by soil of Gedongmeneng and Banjaragung and almost none was adsorbed by soil of Tanjungan. However, the amount of adsorbed Cd increased with the increase in lime and/or cassava-leaf compost additions. These phenomena indicate that all soils were not good Cd adsorbers and soil pH management was important in Cd management in soils. Each soil also showed different adsorption capacities towards Zn (Table 1, Fig. 4). Out of 10 mg kg^{-1} of added Zn, soil of Banjaragung adsorbed the most part, soil of

Gedongmeneng adsorbed a small part, and soil of Tanjungan adsorbed none. This phenomenon shows that soil of Banjaragung was a good Zn adsorber and Tanjungan was not a goor Zn adsorber

CONCLUSIONS

Lime and/or cassava-leaf compost consistently increased the soil pH, but at addition of 10 ton $CaCO_3$ ha^{-1} the soil pH of all experimental units were close to neutrality. The major part of the added Cu was adsorbed by all soils; while the most part of the added Cd was soluble in soil water or weakly held by soil particles. Copper solubilities in all soils consistently decreased with the addition of lime and/or cassava-leaf compost. Addition of lime and/or cassava-leaf compost also decreased Cd solubility, but the addition of high level compost at high addition of lime (> 2.5 ton ha^{-1}) generally increased the solubility of Cd in all soils. The most part of the added Zn was adsorbed by soils of Banjaragung and Gedongmeneng, but only a small part of the added Zn was adsorbed by soil of Tanjungan. The solubility of Zn decreased with lime and/or cassava-leaf compost addition, but, similar to Cd, addition of high level compost increased the Zn solubility at high level lime addition. These observations show that all soils can be used to immobilize heavy metals. Lime and/or cassava-leaf compost can be used to reduce the solubilities of heavy metals in all soils, particularly at low levels of lime and cassava-leaf compost addition.

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