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A Four Year Study on The Effects of Manipulated Soil pH and Organic Matter Contents on Availabilities of Industrial-Waste-Origin Heavy-Metals in Tropical Soils

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ABSTRACT

A Four Year Study on The Effects of Manipulated Soil pH and Organic Matter Contents on Availabilities of Industrial-Waste-Origin Heavy-Metals in Tropical Soils (Salam, A.K.): Heavy metal toxicities and availabilities to plants are reported to be greatly affected by some soil master properties. This paper is a summary of a four year study to evaluate the effects of manipulated soil pH and organic matter contents on the changes in the availabilities of industrial-waste-origin heavy-metals in four different tropical soils. Soils with manipulated pH and organic matter contents were treated with model and industrial wastes containing appreciated amounts of heavy metals. Changes in availabilities of heavy metals were directly measured by analyzing the treated soils after incubation in laboratory and analyzing glasshouse and field growing amaranth (*Amaranthus tricolor* L.) and corn (*Zea mays* L.) plants. The results clearly showed that calcite ($CaCO_3$) and/or cassava-leaf compost were better than other lime and/or organic materials in lowering heavy metal availabilities in soil systems. However, the degree of their effects were greatly dependent on heavy metals and soil types. In general, soil of Banjaragung/Sri Bawono (Alfisols) showed the highest adsorption capacity, followed by soil of Gedongmeneng/Sidosari (Oxisols) and Tanjungan (Ultisols). Adsorption capacity of soil of Gisting (Inceptisols) could not be enhanced by addition of lime and/or compost, even though its adsorption capacity with respect to heavy metals was relatively high. The degree of the decrease in heavy metal availabilities by lime and/or cassava-leaf compost treatments was also greatly dependent on the levels of the added materials. In general, cassava-leaf compost additions at higher levels tended to redissolve heavy metals if added at higher levels of lime (>2.5 ton ha^{-1}). Calcite and/or cassava-leaf compost showed positive effects on plant growth in soils contaminated with heavy metals from wastes. In addition to decreasing heavy metal availabilities in soils, these materials also decreased Cu accumulation in plant roots and shoots. The addition of industrial waste of up to 80 ton ha^{-1} (glasshouse conditions) and 60 ton ha^{-1} (field conditions) generally improved plant growths and yields if added with lime and/or cassava-leaf compost.

Keywords: Cassava-Leaf Compost, Heavy Metals, Liming, Industrial Wastes, Organic Matter, Tropical Soils

INTRODUCTION

Most heavy metals in the soil environment are potentially toxic to the living things, particularly at increasingly high concentrations caused by unwise disposals of industrial wastes. However, as pointed out previously (Salam and Helmke, 1998; Parfitt et al., 1995; Rodella et al., 1995; Alloway, 1990; McGrath et al., 1988), some researchers are convinced that heavy metal concentrations in soils may probably be adjusted to a "safer" levels by manipulating some soil chemical properties such as soil pH, organic matter contents, and cation exchange capacity (CEC), that directly or indirectly control heavy metal solubilities. They argue that enhancing the soil pH and organic matter content may increase the soil

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CEC due to increasing dehydrogenation of organically and inorganically bound-H on soil functional groups. These processes may then increase adsorption of heavy metal cations and, thereby, may lessen the soil labile pools of heavy metals easily absorbed by plant roots. Lower concentrations of heavy metals may lessen their toxicities and allow absorption of essential heavy metal elements such as Cu and Zn at "safer" and more suitable levels to plants.

This paper is a summary of a four year study conducted in Lampung during 1995-1999 to evaluate the effects of manipulated soil pH and organic matter contents on chemical and biological availabilities of industrial-waste-origin heavy-metals in four tropical soils.

MATERIALS AND METHODS

Laboratory Studies

This research was conducted in three phases: (a) laboratory studies, (b) glasshouse studies, and (c) field studies. Laboratory studies were intended to select ameliorants (lime and organic compost materials) most effective in lowering heavy metals of model waste and industrial waste origin in tropical soil systems. Soil samples were collected from A_p horizons of Tanjungan South Lampung (Ultisols), Gedongmeneng Bandar Lampung (Oxisols), Banjaragung East Lampung (Alfisols), and Gisting Tanggamus (Inceptisols). Tanjungan and Gedongmeneng soils represented low adsorption capacity soils and Banjaragung and Gisting soils represented high adsorption capacity soils. Selected soil physical and chemical characteristics are listed in Table 1.

After a treatment with lime [$CaCO_3$, $Ca(OH)_2$, or $CaMg(CO_3)_2$] at a rate to enhance the soil pH 0 or 2 units or with organic compost (leaf of cassava [*Manihot esculenta* Crantz], corn [*Zea mays* L.], alang-alang [*Imperata cylindrica* [L.] Beauv.], or soybean [*Glycine max* L.]) at a rate equivalent to 0 or 10 ton ha^{-1}, a 300 g of thoroughly mixed ground soil sample (105C oven-dry equivalent) per experimental unit was spiked with a model waste to increase soil heavy metals (Cu, Cd, Zn, and Mn) 0 or 10 mg kg^{-1} and was moistened with distilled water to reach a 40% moisture content (v/w). Model waste was a simple mixture of heavy metal standard solution prepared at 75 mg L^{-1} for the respective heavy metals. Soil heavy metal availabilities were analyzed by using the DTPA method (Baker and Amacher, 1982) after an eight week incubation at room temperature. All experimental units were replicated three times.

Table 1. Selected physical and chemical characteristics of the experimental soils[1]

Soil Property	Banjar-agung	Sri Bawono	Cihea	Gisting	Gedong-meneng	Sidosari	Tan-jungan
pH H_2O (1:2)	4.97	4.43	5.80	4.50	5.21	5.11	4.65
CEC (cmol$_c$ kg^{-1})	15.5	16.3	-	11.60	3.99	-	4.35
Organic C (g kg^{-1})	18.4	9.00	23.4	15.4	12.2	12.8	14.4
Total N (g kg^{-1})	1.70	1.60	1.30	2.37	1.50	0.94	1.20
C/N Ratio	10.8	5.63	18.0	6.50	8.13	13.6	12.0
Soil Fractions							
- sand (%)	22.0	20.2	21.2	35.6	45.6	41.2	23.6
- silt (%)	21.2	21.2	31.0	22.2	19.6	26.0	29.6
- clay (%)	56.8	58.6	47.8	42.2	34.8	32.8	46.8

[1] After Salam et al. (2000; 1999a, 1997c)

Organic compost was prepared before the experiment. Small chunks of leaves of cassava, soybean, alang-alang, and corn plants were separately and thoroughly treated with 250 g urea and 200 g $CaCO_3$ and were allowed to decompose in moist condition. To fasten the composting processes, the organic materials were thoroughly mixed every other day. Composts were air-dried and ground after their C/N ratios reached values of 10-12 (about 60 days). Composting plant leaf for field experiment was done with a similar method, conducted in field with a greater amount of plant leaf materials.

The most effective ameliorants were further investigated to study their behaviors in lowering heavy metals in soils of 200 g (105 C oven-dry equivalent) per experimental unit. Lime ($CaCO_3$) was given at rates equivalent to 0, 2.5, 5, and 10 ton ha^{-1}, arranged factorially with organic compost (cassava-leaf compost) treatment at rates equivalent to 0, 5, 10, and 20 ton ha^{-1}. In addition to control units (without heavy metal addition), the experimental units were also treated with a model waste to increase soil Cu, Zn, and Pb 10 mg kg^{-1} and Cd 5 mg kg^{-1} or with a metal-spoon industrial waste at a rate equivalent to 100 ton ha^{-1}. Metal spoon industrial waste was collected from PT Star Metal Wares Jakarta and contained 754 mg Cu kg^{-1} and 44.5 mg Zn kg^{-1} with a pH of 7.30. After a thorough mixing, all experimental units were brought to a 40% moisture content (v/w) by addition of distilled water. Changes in soil heavy metal availabilities were analyzed after a four weeks incubation at room temperature. All experimental units were replicated three times.

Glasshouse Studies

Glasshouse studies were intended to evaluate the biological response of corn and amaranth on the changes in soil available metals caused by addition of lime and/or organic compost materials. Soil samples were collected from A_p horizons of Gedongmeneng (Oxisols), representing low adsorption capacity soils, Banjaragung East Lampung (Alfisols) and Cihea Cianjur West Java (Vertisols), representing high adsorption capacity soils. To determine rates of industrial waste with heavy metals manageable by soil pH and organic matter content manipulation, a preliminary study was conducted in laboratory using a 200 g soil sample (105C oven-dry equivalent) per experimental unit. Treatments were arranged factorially with three replications, including soil sample (Gedongmeneng, Banjaragung, and Cihea), lime (at rates equivalent to 0, 2.5, and 5 ton $CaCO_3$ ha^{-1}), cassava-leaf compost (at rates equivalent to 0, 5, and 10 ton ha^{-1}), and industrial waste (at rates equivalent to 0, 10, 20, and 40 ton ha^{-1}). Soil mixtures were moistened with distilled water to 40% (v/w) by addition of distilled water after a thorough mixing. Heavy metal availabilities were analyzed after a four week incubation at room temperature.

Glasshouse studies were conducted by using a 400 g soil sample (105 C oven-dry equivalent) per experimental unit. Lime was given at rates equivalent to 0, 2.5, and 5 ton $CaCO_3$ ha^{-1} and cassava-leaf compost at rates equivalent to 0, 5, and 10 ton ha^{-1}, arranged factorially with waste treatments (W_1, W_2, W_3, W_4, and W_5). W_1 was without waste addition. W_2 was a model waste addition to increase soil Cu, Zn, and Pb 10 mg kg^{-1} and Cd 5 mg kg^{-1} and W_3 was a model waste addition to increase the soil heavy metals four times of that caused by W_2 addition. W_4 was industrial waste at a rate equivalent to 20 ton ha^{-1} and W_5 80 ton ha^{-1}. After a thorough mixing and addition of distilled water to reach a 40% moisture content (v/w), soil mixtures were incubated. Seedlings of amaranth or corn seed were planted after a one week incubation. Soil heavy metal availabilities (extractable by water, 2 *N* $CaCl_2$, and 0.05 M DTPA) and plant absorption were measured after a four week growing periods. All experimental units were replicated three times.

Field Studies

Field studies were conducted to evaluate the biological response of corn and amaranth on the changes in soil available heavy metals of industrial waste origin caused by lime and/or organic compost additions in field conditions. Farmers' field in Sri Bawono East Lampung (Alfisols) and Sidosari Natar South Lampung (Oxisols) were used for these studies. Plots measuring 4 m by 4.5 m and 2 m by 2 m (50 cm apart between plots and 100 cm apart between blocks/replications) were prepared for corn and amaranth, respectively. After land preparation (clearing and soil tillage), lime (at 0 and 5 ton $CaCO_3$ ha^{-1}) and cassava-leaf compost (at 0 and 5 ton ha^{-1}) arranged factorially were thoroughly treated to a soil depth of 15 cm. Industrial waste (at rates of 0, 15, and 60 ton ha^{-1}) was given at the same soil depth one week after lime and cassava-leaf compost treatments. Seeds of corn and amaranth were planted one week after waste treatment. Corn seed were planted with distances of 25 cm by 75 cm and amaranth with a density of 1 g seeds per 1 m by 2 m. Basalt fertilizers for corn were 300 kg urea, 150 kg SP-36, and 150 kg KCl per ha, all given at planting time except for one half of the urea given at 6 week after planting (WAT). Amaranth was only fertilized with urea at 20 g per experimental unit, given at 2 and 4 WAT. Soil heavy metal availabilities and plant absorption were analyzed at harvest time. All experimental plots were replicated four times.

RESULTS AND DISCUSSION

Effectiveness of Lime Materials

An increase in soil pH by lime treatment may drive some important changes in soil systems, among which is an increase in soil ability to adsorb cations. The presence of OH^- ions may detach H^+ ions bound chemically in various soil functional groups to form neutral water molecules. This process may enhance the number of the surface negative charges on soil colloids and may eventually adsorb soluble heavy metal cations from soil water or shift the adsorbed cations to higher bonding energies. This phenomenon was consistently shown by Cu, Cd, Zn, and Mn in soils of Banjaragung, Gedongmeneng, and Tanjungan (for example, see Fig. 1).

The degree in the decrease in soil soluble heavy metals by lime treatment was dependent of heavy metals and soil types (Table 2). In general, the degree of the decrease in soil available heavy metals by lime treatment decreased as follows: Tanjungan > Banjaragung > Gedongmeneng for Zn and Cu and Gedongmeneng > Tanjungan > Banjaragung for Cd and Mn. Soil acidification and increase in heavy metal concentrations caused by model waste treatment did not change these orders.

Because no leaching occurred, the decrease in soil available heavy metals was completely attributed to the immobilization by soil particles, particularly related to adsorption process and to a lesser extent to precipitation process. The degree of the immobilization of heavy metals by soils caused by lime treatment is more obviously understood by eveluating the values of % recovery of the respective heavy metals. Values of % recovery indicate the percentages of added heavy metals extractable by DTPA after an incubation process. Low values indicate high immobilization and high values low immobilization. Values > 100 indicate dissolution or detachment of heavy metals previously immobilized, while negative values indicate the precipitation or adsorption of indigenous heavy metals previously soluble. Dissolution or precipitation may occur in response to the changes in soil pH caused by the acidity of waste model.

Values of % recovery of heavy metals (except for Mn) in Gedongmeneng soils and Banjaragung were all lower than those in Tanjungan soils (Table 3). This indicates that soils of Gedongmeneng and Banjaragung possessed higher adsorption capacities compared to soil of Tanjungan, even though

Table 2. Average in the decrease of available heavy metals in tropical soils by lime treatment.

Heavy Metal Treatment mg kg^{-1}	Soil	Zn	Cu	Cd	Mn
		%[1]			
0	Tanjungan	43.4	46.1	31.1	31.7
	Gedongmeneng	17.4	10.7	46.3	37.4
	Banjaragung	33.0	32.1	31.0	21.0
	Gisting	(-) 92.3	(-) 187	(-) 196	24.3
10	Tanjungan	34.0	41.0	11.6	24.8
	Gedongmeneng	1.11	24.7	18.5	32.1
	Banjaragung	17.1	34.3	19.5	18.1
	Gisting	(-) 85.2	(-) 129	1.05	(-) 49.9

[1] Calculated as follows: $[\{M_{(o)} - (\Sigma M_{(x)}/3)\}*100/M_{(o)}]$ where $M_{(x)}$ was available heavy metals in soils treated with lime x, x included $CaCO_3$, $Ca(OH)_2$, and $CaMg(CO_3)_2$, and $M_{(o)}$ was available heavy metals in unlimed soils [After Salam et al., 1997 a].

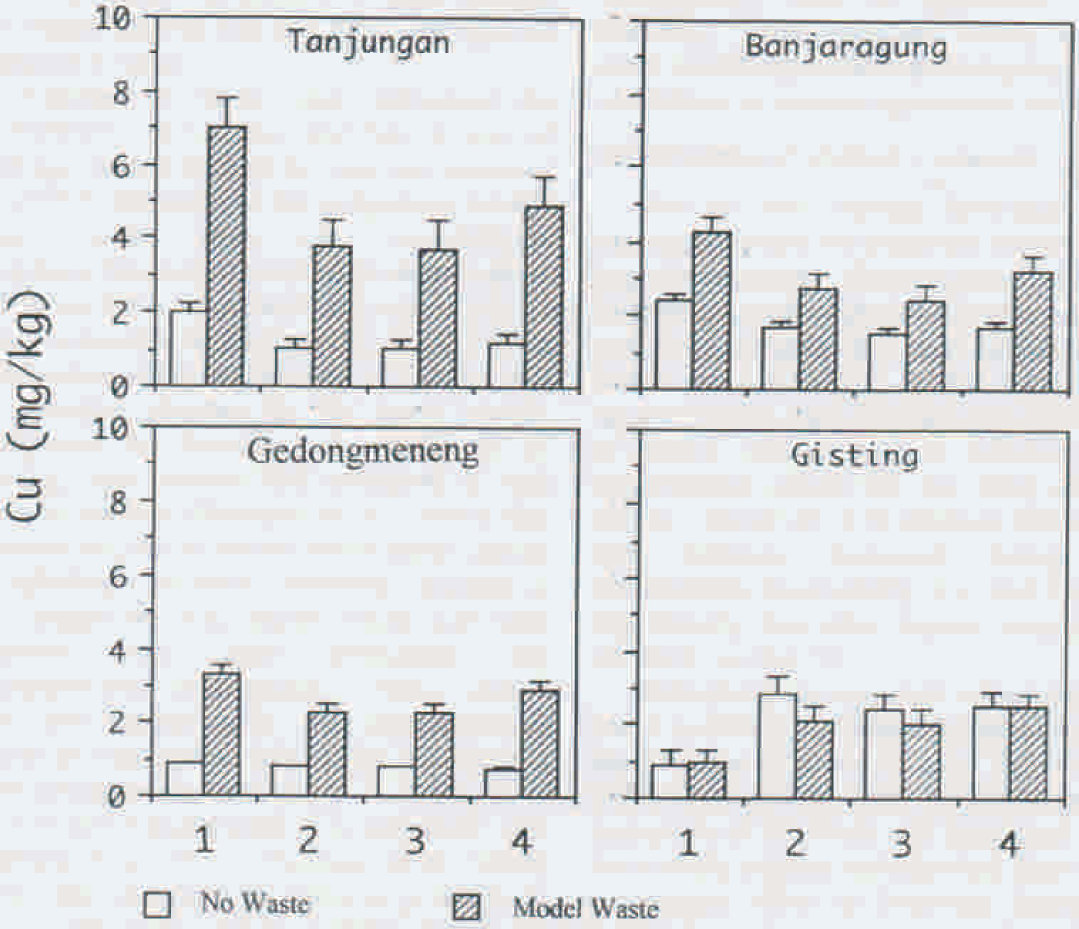

Fig. 1. Change in Cu availability in four tropical soils caused by lime treatments (1 = Control, 2 = $CaCO_3$, 3 = $Ca(OH)_2$, and 4 = $CaMg(CO_3)_2$) [After Salam et al., 1997a].

the increase in the adsorption capacity by lime treatment in soil of Tanjungan was higher (Table 2). This property was probably related to sesquioxides in soils of Gedongmeneng and Banjaragung that possessed high specific adsorption capacities. Specific adsorption is less dependent on pH changes than is clay mineral surface that dominated soil of Tanjungan. Based on values of % recovery, the adsorption capacity of soils decreased in order of Banjaragung > Gedongmeneng > Tanjungan while the soil preference towards heavy metals follows the order of Cu > Cd > Zn, in agreement with previous reports (Alloway, 1990). Comparison of soil adsorption capacity towards Mn based on % recovery values was difficult to make because the added Mn was too low compared with its indigenous value.

Addition of model waste decreased the availabilities of Cu, Zn, and Mn in soil of Gisting. Added Cu and Zn were not extracted by DTPA and parts of the indigenous soluble heavy metals were even immobilized. Available Mn was lowered even significantly; 4.6 times lower in unlimed soil and 7.5 times lower in limed soils (Salam et al., 1999f). This observation indicates that soil of Gisting was an effective adsorber for the heavy metals. Allophane, the dominant mineral in soil of Gisting, was reactive and possessed a high specific surface (Paterson et al., 1991) that enabled this soil to adsorb heavy metal cations at significant amounts. However, changes in pH caused by acid model waste and lime addition may have stimulated the decomposition of allophane. Heavy metals then precipitated with the decomposition results and the availabilities of Cu, Zn, and Mn were consequently lowered.

The above explanation is in agreement with Paterson et al (1991). Paterson et al. (1991) shows that allophane is stable in a relatively narrow pH range and its stability is directly related to the activity of Al^{3+} in soil solution. For example, at pAl = 8.00, allophane is stable at pH range between 5.5 to 6.5. This range in narrower at pAl > 8.00. Based on this theory, it was very likely that the decrease in soil pH caused by waste model addition hastened the decomposition of allophane and caused the decrease in the availabilities of Cu, Zn, and Mn through precipitation processes forming oxides or hydroxyoxides.

Based on the above findings, it is obvious that lime is more useful for soils of Tanjungan, Gedongmeneng, and Banjaragung than for soil of Gisting. $CaCO_3$ was as effective as $Ca(OH)_2$ and both were more effective than $CaMg(CO_3)_2$ in enhancing soil pH and lowering heavy metal availabilities. However, even though $CaCO_3$ theoretically shows a lower neutralization power, it is more widespreadly used in agriculture than is $Ca(OH)_2$. Concerning this reason, $CaCO_3$ is more promising to use in lowering heavy metal solubilities in polluted agricultural soils.

Effectiveness of Organic Composts

Due to their various functional groups, organic materials are important sources for soil negative charges. Dehydrogenation of these functional groups may enhance the number of negative charges that may adsorb cations. Based on this theory, it was expected that organic matter may decrease the availabilities of heavy metals in soil systems. The experimental results did not show consistent results. However, it is obvious that cassava-leaf compost decreased heavy metal availabilities (particularly Cu and Zn) more significantly that other organic materials (for example, see Fig. 2).

Role of organic materials in lowering heavy metal availabilities become more important in the presence of lime (Fig. 3). Increasing soil pH by lime addition may have stimulated the ionization of H^+ from soil functional groups. As a result, organic materials and lime showed a synergic effect in lowering heavy metal availabilities due to a more significant increase in soil adsorption capacity. However, it was apparently shown that the effect of lime (for example $|\Delta Cu/\Delta CaCO_3|$) decreased with the increase in the level of organic materials, probably due to an increase in soluble organic materials able to chelate heavy metals at higher levels of organic materials, particularly at high lime levels (> 2.5 ton ha^{-1}). This phenomenon was consistently shown by soils of Banjaragung, Gedongmeneng, and Tanjungan (Salam et al., 1998a). Due to the instability of its allophane minerals pointed out previously, soil of Gisting show a contrary phenomenon; the availabilities of Cu and Zn increased by the increasing levels of lime and organic material addition (Salam et al., 1997c).

The increase in the availability of Cu in soils was a result of a significant dissolution of Cu of waste particles in soil systems with pH lower than that of industrial waste (pH of industrial waste was 7.30). Even though the industrial waste increased the soil pH drastically, it linearly increased the soil available Cu due to high concentration of Cu in the industrial waste (Salam et al., 1999a; 1998a; 1997d). Copper initially adsorbed on waste particles may have dissolved in soil solution with a significantly lower pH. The decrease in soil pH very likely also decreased the bonding energy of Cu on soil particles, making Cu was easier to be extracted by DTPA. Parts of Cu of industrial waste origin may have also precipitated, particularly at high levels of lime and industrial waste additions. However, the presence of organic materials did not influence the availability of Cu of industrial waste origin (Salam et al., 1999a). But, it was apparent that soil of Banjaragung showed a higher adsorption capacity towards Cu than did soil of Gedongmeneng.

Table 3. Percentage of heavy metals of model waste origin extracted from limed soils (% recovery).

Soil	Lime	Zn	Cu	Cd	Mn
		%[1]			
Tanjungan	Control	523	49.8	147	65.0
	$CaCO_3$	321	27.5	131	62.0
	$Ca(OH)_2$	371	26.7	128	(-) 26.0
	$CaMg(CO_3)_2$	396	37.0	133	3.00
Gedongmeneng	Control	73.0	24.4	60.3	(-) 90.0
	$CaCO_3$	67.0	14.5	49.0	310
	$Ca(OH)_2$	90.2	15.0	42.8	410
	$CaMg(CO_3)_2$	124	21.9	56.8	(-) 40.0
Banjaragung	Control	110	19.1	48.8	(-) 70.0
	$CaCO_3$	24.0	10.8	46.9	150
	$Ca(OH)_2$	46.0	9.50	31.7	150
	$CaMg(CO_3)_2$	44.0	15.8	39.6	(-) 200
Gisting	Control	(-) 2.20	0.80	93.2	(-) 459
	$CaCO_3$	4.00	(-) 7.10	87.3	(-) 858
	$Ca(OH)_2$	(-) 27.0	(-) 3.50	95.4	(-) 812
	$CaMg(CO_3)_2$	(-) 22.3	0.300	93.8	(-) 582

[1] Calculated as follows: [$M_{(x)t}$-$M_{(x)o}$*100/M) where $M_{(x)t}$ was heavy metals available in soils treated with lime x and model waste; x included $CaCO_3$, $Ca(OH)_2$, and $CaMg(CO_3)_2$; $M_{(x)o}$ was heavy metals available in soils treated with lime x but not treated with model waste; and M was total of heavy metals added through model waste (in this experiment was 10 mg kg^{-1}) [After Salam et al., 1997a].

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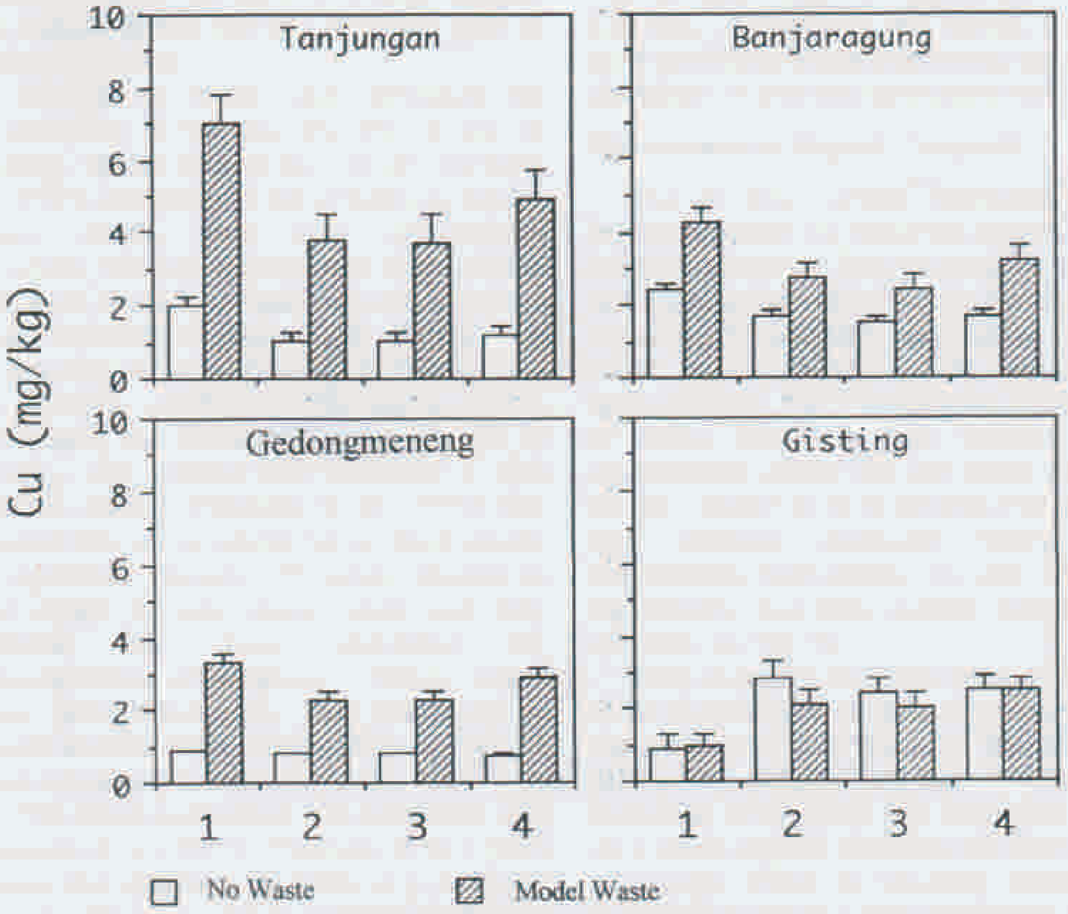

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Role of organic materials in lowering heavy metal availabilities become more important in the presence of lime (Fig. 3). Increasing soil pH by lime addition may have stimulated the ionization of H^+ from soil functional groups. As a result, organic materials and lime showed a synergic effect in lowering heavy metal availabilities due to a more significant increase in soil adsorption capacity. However, it was apparently shown that the effect of lime (for example $|\Delta Cu/\Delta CaCO_3|$) decreased with the increase in the level of organic materials, probably due to an increase in soluble organic materials able to chelate heavy metals at higher levels of organic materials, particularly at high lime levels (> 2.5 ton ha^{-1}). This phenomenon was consistently shown by soils of Banjaragung, Gedongmeneng, and Tanjungan (Salam et al., 1998a). Due to the instability of its allophane minerals pointed out previously, soil of Gisting show a contrary phenomenon; the availabilities of Cu and Zn increased by the increasing levels of lime and organic material addition (Salam et al., 1997c).

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Gisting	Control	(-) 2.20	0.80	93.2	(-) 459
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	$Ca(OH)_2$	(-) 27.0	(-) 3.50	95.4	(-) 812
	$CaMg(CO_3)_2$	(-) 22.3	0.300	93.8	(-) 582

[1] Calculated as follows: [$M_{(x)1}$-$M_{(x)0}$*100/M) where $M_{(x)1}$ was heavy metals available in soils treated with lime x and model waste; x included $CaCO_3$, $Ca(OH)_2$, and $CaMg(CO_3)_2$; $M_{(x)0}$ was heavy metals available in soils treated with lime x but not treated with model waste; and M was total of heavy metals added through model waste (in this experiment was 10 mg kg^{-1}) [After Salam et al., 1997a].

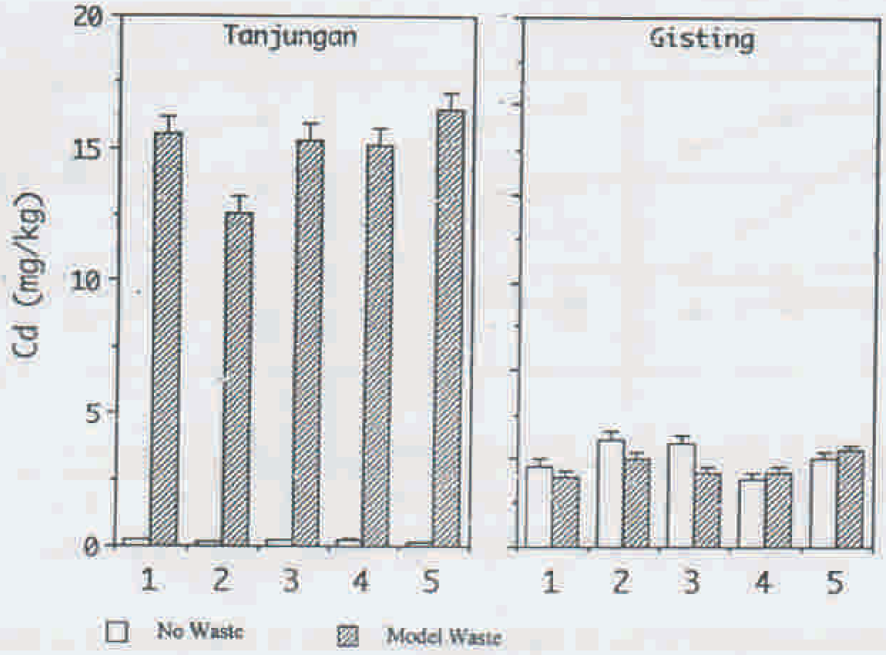

Fig. 2. Change in Cd availability in four tropical soils caused by plant-leaf compost treatments (1 = Control, 2 = Cassava, 3 = Corn, 4 = Alang, and 5 = Soybean) [After Salam et al., 1997b].

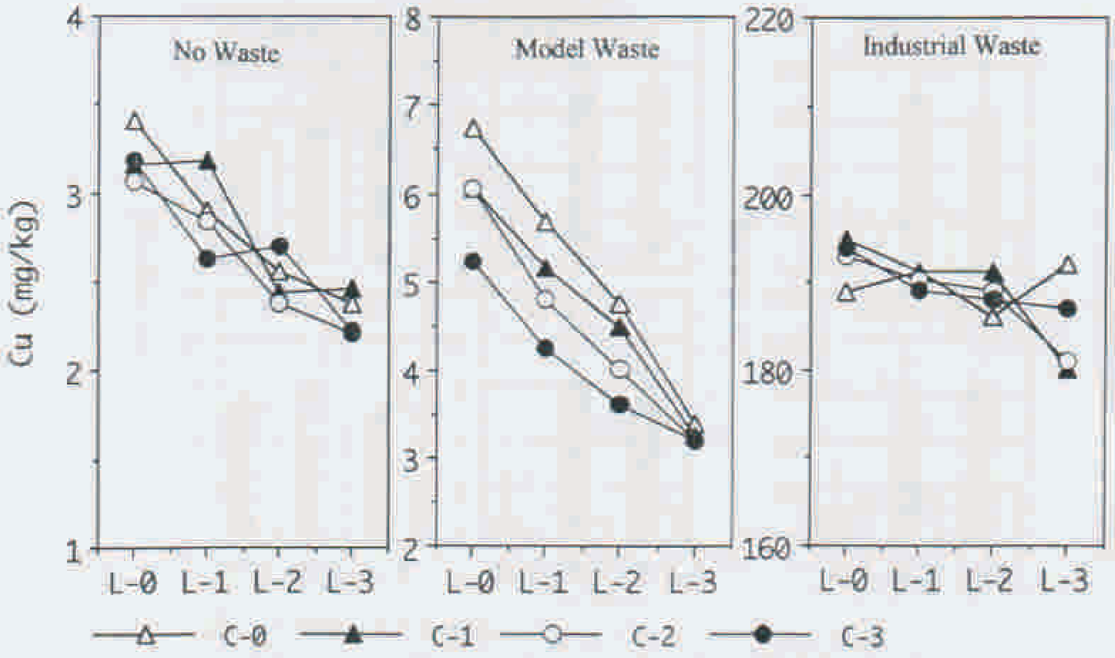

Fig. 3. Availability of Cu in soil of Banjaragung at several levels of lime and cassava-leaf compost (Lime L-0 = 0, L-1 = 2.5, L-2 = 5.0, and L-3 = 10 ton $CaCO_3$ ha^{-1} and Compost C-0 = 0, C-1 = 5, C-2 = 10, and C-3 = 20 ton ha^{-1}) [After Salam et al., 1998a].

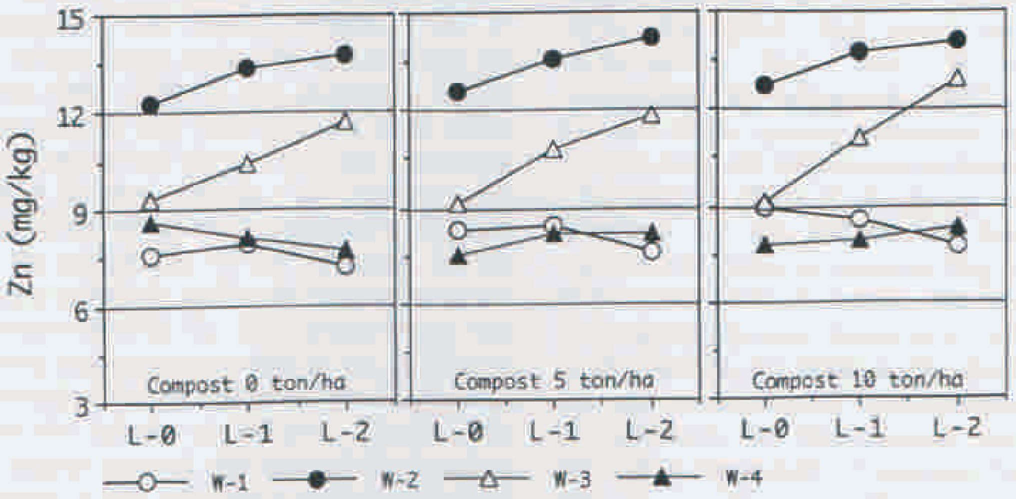

Fig. 4. Change in Zn availability of industrial waste origin in soil of Banjaragung caused by lime and/or cassava-leaf compost treatments (Lime L-0 = 0, L-1 = 2.5, and L-2 = 5 ton $CaCO_3$ ha^{-1}; Industrial Waste W-1 = 0, W-2 = 10, W-3 = 20, and W-4 = 40 ton ha^{-1}) [After Salam et al., 1998b; 1998c].

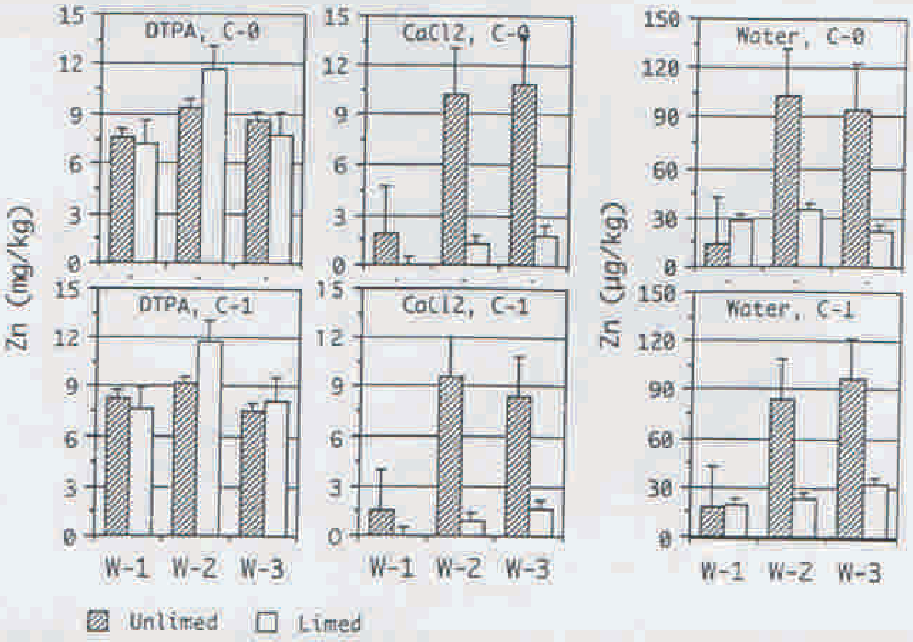

Fig. 5. Changes in soil labile Zn of industrial waste origin in soil of Banjaragung caused by lime and/or cassava-leaf compost treatments (Compost C-0 = 0 and C-1 = 5 ton ha^{-1}; Industrial Waste W-1 = 0, W-2 = 20, and W-3 = 40 ton ha^{-1}) [After Salam et al., 1998c].

The availability of Zn significantly increased by industrial waste addition, but decreased by addition at levels > 10 ton ha^{-1} (at 10 > 20 > 40 > 0 ton ha^{-1}) in all soils (Cihea, Banjaragung, and Gedongmeneng) (Fig. 4). This phenomenon cannot be explained by the current data. One of the possibility is that waste colloids may have become more active in soil systems and showed a greater preference towards Zn than towards Cu. However, the adsorbed Zn was so easily extracted at high pH that the availability of Zn increased by the increase in soil pH; unlike the exchangeable Zn and water-Zn (Fig. 5). This phenomenon was probably occurred as a result of the shifting of the adsorbed Zn towards lower bonding energy due to the increase in soil pH. The Zn data also clearly showed that soil of Banjaragung possessed a high adsorption capacity than did soil of Gedongmeneng; in agreement with the Cu data (Salam et al., 1999a; 1997d).

Glasshouse and Field Effects of Lime and Organic Materials

Plant Growth and Yields. Heavy metal addition through the model waste drastically affected the glasshouse growth of amaranth. However, the growth of amaranth was in general better (as indicated by changes in plant height, wet and dry weights of shoots and roots, and plant leaf area) in soil of Banjaragung than that in soil of Gedongmeneng (Salam et al., 1999b), probably because of the greater adsorption capacity of Banjaragung soil with respect to heavy metals. The negative effect of the heavy metals was alleviated by the addition of lime and/or cassava-leaf compost addition (Fig. 6). This phenomenon was, however, not observed in Gedongmeneng soils (Salam et al., 1998b).

In contrast, the addition of industrial waste was shown to stimulate the glasshouse growth of amaranth in Banjaragung soil. W_5 stimulated the growth of amaranth better than did W_4. However, this positive effect decreased with lime addition and increased with cassava-leaf compost addition, probably due to the changes in Zn availability (that increased with lime and decreased with cassava-leaf compost addition). This phenomenon was not observed in

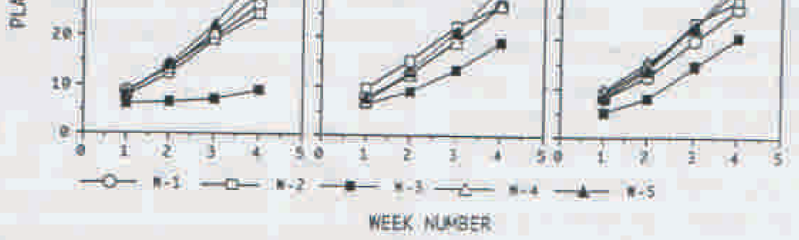

Fig. 6. Changes in the glasshouse growth of amaranth in soil of Banjaragung treated with wastes, lime, and cassava-leaf compost (Lime L-1 = 0, L-2 = 2.5, and L-3 = 5 ton $CaCO_3$ ha^{-1}; Compost C-1 = 0 and C-3 = 10 ton ha^{-1}; Waste W-1 = Control, W-2 = Waste Model 1, W-3 = Waste Model 2, W-4 = Industrial Waste 1, and W-5 = Industrial Waste 2) [After Salam et al., 1999b).

Gedongmeneng soil. Inconsistently, the field growth of amaranth were decreased by industrial waste addition in Sidosari soil (of the same soil type as Gedongmeneng soil) and Sri Bawono soil (of the same type as Banjaragung soil), and the presence of lime and/or cassava-leaf compost in general attenuated the negative effect of heavy metals of industrial waste (Figs. 7 and 8).

To a lesser extent, the glasshouse growth of corn was depressed by heavy metals of model waste origin and the presence of lime and/or cassava-leaf compost in general lowered this negative effect in Banjaragung soil. However, this phenomenon was also not observed in Gedongmeneng soil (Salam et al., 1999d). In contrast, the addition of industrial waste stimulated the growth of corn in Banjaragung soil, but this effect was lowered by lime addition. Consistently, this phenomenon was also not observed in Gedongmeneng soil.

The addition of industrial waste also decreased the field growth of corn in Sidosari soil and increased it in Banjaragung soil. The presence of lime and/or cassava-leaf compost in general improved the field growth of corn in both soils. For example, corn plant height increased as high as 8.33% if Sidosari soil was treated with 15 ton ha^{-1} industrial waste and 5 ton $CaCO_3$ ha^{-1} and increased as high as 11.8% if the waste addition was coupled by lime and cassava-leaf compost additions (Salam et al., 1998d). In addition to a lowered heavy metal availabilities, this phenomenon was probably related to the role of organic matter in increasing soil moisture and availing some plant nutrients. Lime may also have enabled better absorption of plant nutrients by corn roots.

The field growth of corn was not well correlated with the corn yield (Fig. 9). Industrial waste addition decreased corn yield and so did the lime and/or compost addition at 0 level waste. Addition of industrial waste at 15 and 60 ton ha^{-1} in Sidosari soil decreased corn yield 10.6 and 28.7%, respectively, probably due to the increase in Cu availability caused by the industrial waste addition. However, corn yield was better with an addition of lime. For example, the addition of industrial waste at 15 ton ha^{-1}, that decreased corn yield 10.6%, increased the corn yield as high as 3.7% if lime was also applied. Addition of industrial waste at 60 ton ha^{-1}, that decreased corn yield 28.7%, increased the corn yield as high as 4.6% if lime was also applied. The increase in the corn yield was related to the decrease in Cu availability by lime addition, especially at waste addition of 15 ton ha^{-1} (Salam et al., 1998d).

In contrast, the addition of industrial waste in Sri Bawono soil increased corn plant height and yield. For example, addition of 15 and 60 ton ha^{-1} increased the corn yield 22.3 and 34.7%, respectively (Fig. 9). Addition of lime and/or cassava-leaf compost also increased the corn yield. For example, addition of industrial waste at 60 ton ha^{-1} coupled with lime and cassava-leaf compost addition at 5 ton ha^{-1} increased the corn yield 45.1%. This phenomenon was related to the decrease in the availabilities of Cu and Zn due to the addition of lime and cassava-leaf compost.

The changes in plant yields are not necessarily good from the point of view of plant productivity because plant yields did not increase significantly by industrial waste, lime and cassava-leaf compost treatments (particularly in Sidosari soil). However, from the stand point of ecology, the treatment combination is very useful in the management of soils contaminated by industrial wastes.

Availabilities and Absorption of Heavy Metals. Availabilities of heavy metals in soils were in general decreased by lime and/or cassava-leaf compost treatments. The degree of changes in the availabilities of Cu and Zn in the root zones of field growing amaranth and corn at 15 ton ha^{-1} industrial waste treatment is presented in Table 4. The decrease in the growth of amaranth and its improvement were related to the changes in these heavy metal availabilities and their absorption (Fig. 10).

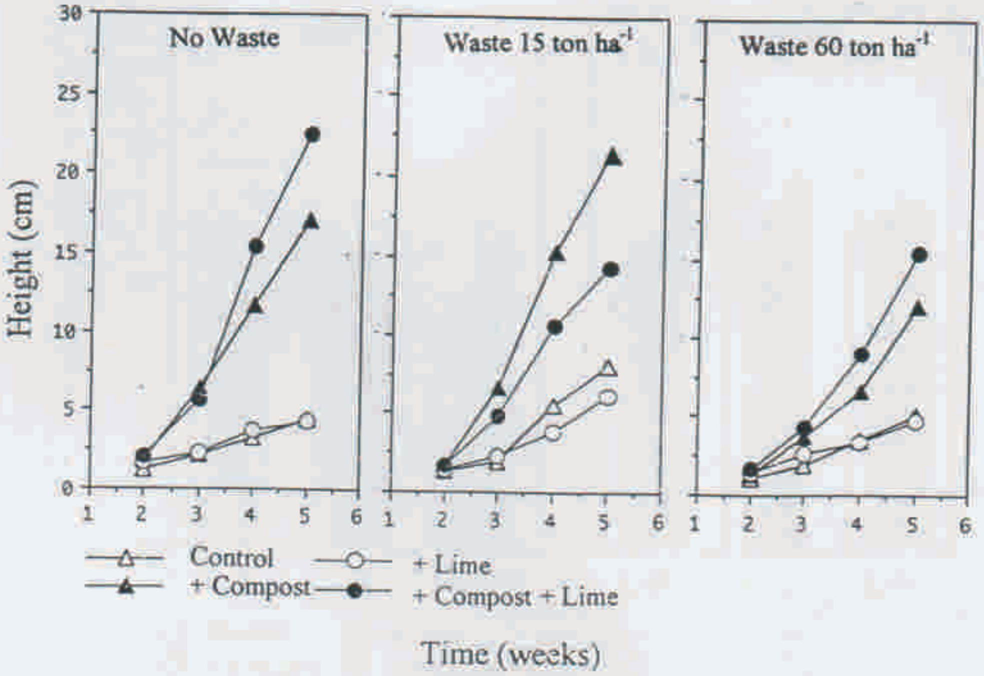

Fig. 7. Changes in the field growth of amaranth in soil of Sidosari caused by treatments with industrial waste, lime, and cassava-leaf compost [After Salam et al., 1999c].

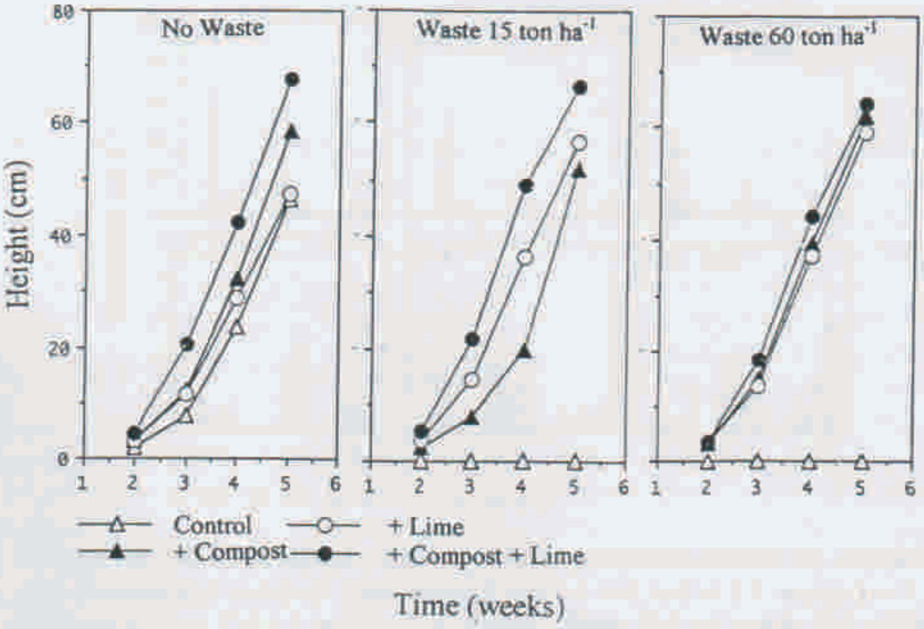

Fig. 8. Changes in the field growth of amaranth in soil of Sri Bawono caused by treatments with industrial waste, lime, and cassava-leaf compost [After Salam et al., 1999c].

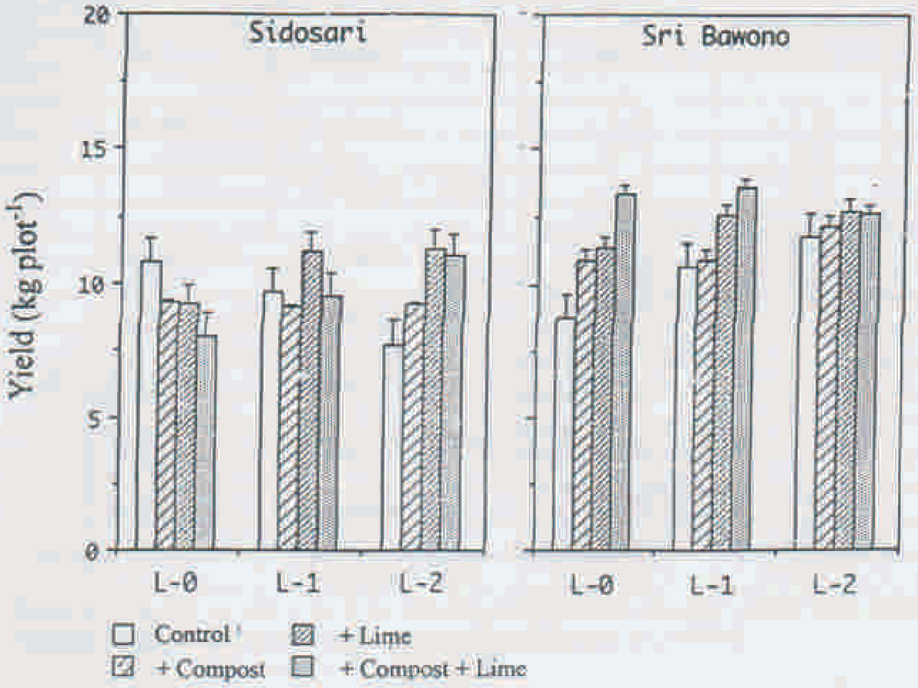

Fig. 9. Changes in corn yield in Sidosari and Sri Bawono soils caused by industrial waste, lime, and cassava-leaf compost treatments (Waste L-0 = Control, L-1 = 15 ton ha^{-1}, and L-2 = 60 ton ha^{-1}; Moisture Content 14%; Plot Size 4 m x 4.5 m) [After Salam et al., 1998d].

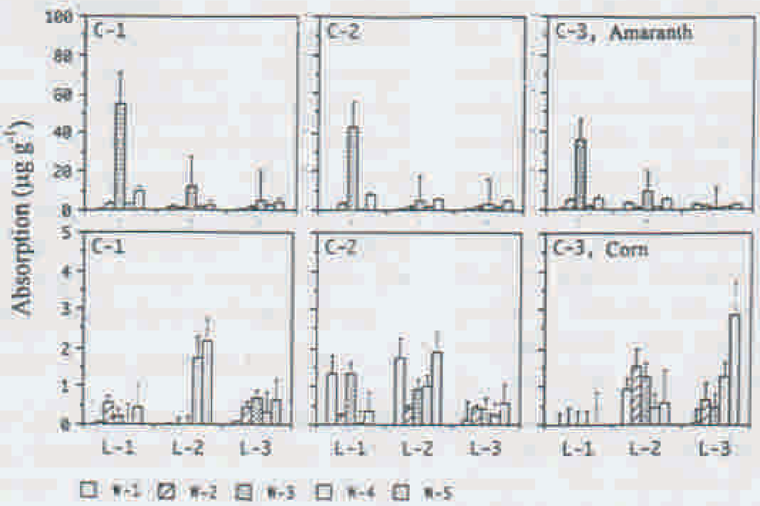

Fig. 10. Changes in Cu absorption by amaranth and corn plants caused by industrial waste, lime, and cassava-leaf compost treatments (Lime L-1 = 0, L-2 = 2.5, and L-3 = 5 ton $CaCO_3$ ha^{-1}; Compost C-1 = 0, C-2 = 5, and C-3 = 10 ton ha^{-1}; Waste W-1 = Control, W-2 = Model Waste 1, W-3 = Model Waste 2, W-4 = Industrial Waste 1, and W-5 = Industrial Waste 2) [After Salam et al., 1999e].

Table 4. Changes in Cu and Zn availabilities in field-growing amaranth and corn root zones as affected by treatments with industrial waste at 15 ton ha^{-1}, lime and cassava-leaf compost.

Plant	Soil	Treatment	ΔCu[1]	ΔZn	ΔpH
Corn	Sidosari	+ Compost	- 1.45	+ 4.42	+ 0.14
		+ Lime	-35.9	- 11.8	+ 1.31
		+ Compost + Lime	- 44.5	- 22.3	+ 1.23
	Sri Bawono	+ Compost	+ 8.71	+ 18.6	+ 0.04
		+ Lime	- 8.44	- 1.05	+ 1.14
		+ Compost + Lime	- 23.7	- 7.37	+ 0.97
Amaranth	Sidosari	+ Compost	+ 8.02	- 3.36	- 0.07
		+ Lime	- 19.0	- 15.0	+ 1.35
		+ Compost + Lime	- 24.0	- 7.94	+ 1.43
	Sri Bawono	+ Compost	- 13.0	+ 0.59	+ 0.03
		+ Lime	- 22.6	- 2.55	+ 1.77
		+ Compost + Lime	- 14.5	+ 17.8	+ 1.83

[1] ΔX (where X = Cu, Zn, or pH) was X in soil after treated with compost and/or lime substracted by X in soil without compost and/or lime treatments [After Salam et al., 1999f].

In general, the availabilities of heavy metals in soil systems was increased by waste addition. As a result, the growth of plants were inhibited because heavy metal absorption by plants increased. The presence of lime and/or cassava-leaf compost lowered the availability of heavy metals of waste origin. This change eventually lowered heavy metal absorption by plant roots. As a result, the inhibition of plant growth by the increasing heavy metal concentration from waste addition was attenuated. This phenomenon was clearly demonstrated by glasshouse amaranth in the high adsorption capacity soil of Banjaragung.

SUMMARY AND CONCLUSIONS

Calcite ($CaCO_3$) and/or cassava-leaf compost were better than other lime and/or organic materials in lowering heavy metal availabilities in soil systems. However, the degree of their effects were greatly dependent on heavy metals and soil types. In general, soil of Banjaragung/Sri Bawono (Alfisols) showed the highest adsorption capacity, followed by soil of Gedongmeneng/Sidosari (Oxisols) and Tanjungan (Ultisols). Adsorption capacity of soil of Gisting (Inceptisols) could not be enhanced by addition of lime and/or compost, even though its adsorption capacity with respect to heavy metals was relatively high. The degree of the decrease in heavy metal availabilities by lime and/or cassava-leaf compost treatments was also greatly dependent on the levels of the added materials. In general, cassava-leaf compost additions at higher levels tended to redissolve heavy metals if added at higher levels of lime (>2.5 ton ha^{-1}). Calcite and/or cassava-leaf compost showed positive effects on plant growth in soils contaminated with heavy metals from wastes. In addition to decreasing heavy metal availabilities in soils, these materials also decreased Cu accumulation in plant roots and shoots. The addition of industrial waste of up to 80 ton ha^{-1} (glasshouse conditions) and 60 ton ha^{-1} (field conditions) generally improved plant growths and yields if added with lime and/or cassava-leaf compost.

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