Available online at:
http://journal.unila.ac.id/index.php/tropicalsoil
DOI: 10.5400/jts.2018.v23i1.11-18

Tropical Soil Labile Fractions of Copper in the Experimental Plots ±Ten Years after Application of Copper-Containing-Waste

Abdul Kadir Salam and Kiat Ginanjar

Department of Soil Science University of Lampung
Bandar Lampung, Indonesia 35145, e-mail: axauam@gmail.com

Received 30 October 2017/ accepted 29 December 2017

ABSTRACT

Copper is reported to be retained in soils for a quite long time particularly in soil treated with some amendments. This research was intended to evaluate the soil labile fractions of Cu ±10 years after application of Cu-containing industrial waste, lime, and cassava-leaf compost. Soil samples were taken from topsoils and subsoils of ±10 years old experimental plots set up in 1998 and factorially treated with a metal-spoon industrial waste at 0, 15, and 60 Mg ha^{-1}, lime at 0 and 5 Mg ha^{-1}, and cassava-leaf compost at 0 and 5 Mg ha^{-1}. The measured Cu labile fractions were compared to those in soils sampled at ±1.5 years and ±3 years after treatments. The results showed that the soil Cu labile fractions in waste treated soils were higher than those in the control treatments eventhough their concentrations decreased with the years of sampling. Lime showed a decreasing effect on soil labile Cu fractions, but the effect decreased with the years of sampling. The effect of cassava-leaf compost application on soil Cu labile fraction was in general not evidenced ±10 years after treatment.

Keywords: Cassava-leaf compost, copper, heavy metals, industrial waste, lime

ABSTRAK

Tembaga (Cu) dilaporkan tertahan di dalam tanah dalam waktu yang relatif lama khususnya bila tanah dikapur. Penelitian ini dilakukan untuk mempelajari fraksi labil Cu ± 10 tahun setelah tanah diperlakukan dengan limbah industry mengandung Cu, kapur, dan kompos daun singkong. Contoh tanah diambil dari top soil dan subsoil lahan percobaan berumur ± 10 tahun yang dibuat pada tahun 1998 dan secara factorial diperlakukan dengan limbah industry sendok logam pada tingkat 0, 15, and 60 Mg ha^{-1}, kapur pada tingkat 0 dan 5 Mg ha^{-1}, dan kompos daun singkong pada tingkat 0 dan 5 Mg ha^{-1}. Fraksi labil Cu dibandingkan dengan fraksi labil Cu tanah pada ± 1.5 dan ± 3 tahun. Hasil penelitian menunjukkan bahwa fraksi labil Cu dalam tanah yang diperlakukan limbah industry lebih tinggi dari pada perlakuan control walaupun konsentrasinya secara umum menurun dengan waktu pengambilan contoh tanah. Kapur menurunkan fraksi labil Cu namun pengaruhnya menurun dengan waktu. Tidak ditemukan pengaruh aplikasi kompos daun singkong terhadap fraksi labil Cu.

Kata kunci: Kapur, kompos daun singkong, limbah industri, logam berat, tembaga

INTRODUCTION

Heavy metals are by definition the elements with relatively high atomic density of > 6 g cm^{-3} or specific gravity of > 5 g cm^2. This category of elements is one of the research major focuses in soil science because the roles and effects of heavy metals are very important in the environment. Some heavy metals are needed by plants and animals at relatively small amounts. For example, Cu and Zn are considered as micro-elements for plant growth; therefore, they are needed by plants, even though only in relatively small amounts. On the contrary, some of the elements such as Cd and Pb are not needed by the living things. Both categories of these elements show similarity, they are toxic to the living things at concentrations relatively higher than their critical levels. For examples, the total concentrations of Cu in soils must not exceed 60 mg kg^{-1}; that of Zn must be below 70 mg kg^{-1}; while Cd and Pb must be < 9 and 100 mg kg^{-1}, respectively (Ross 1994a). These values are the toxic boundaries for plants.

However, the concentrations of heavy metals in soils are subject to natural and anthropogenic sources (Juracek and Ziegler 2006; Biasioli *et al.*

2007; Benke *et al.* 2008; Berenguer *et al.* 2008; Lin *et al.* 2008; Cakmak *et al.* 2010; Alloway 2012; Tu *et al.* 2012; Kargar *et al.* 2013; Adams *et al.* 2014). The study of Berenguer *et al*. (2008) reported that the long-term use of liquid swine manure significantly increased the concentrations of Cu and Zn in soils. Moreover, the long-term application of cattle manure significantly increased the soil total and EDTA-extractable Cu and Zn (Benke *et al.* 2008). The concentrations of Cu, Ni, Hg, Pb, Cd, and As in the sediment samples at electronic waste recycling plant at Guiyu, Guangdong, China significantly increased above the reference background concentrations (Guo *et al.* 2009). Therefore, heavy metals in soil environment must be one of our concern.

Heavy metals in soil environment are distributed in several forms with decreasing bioavailability: free ions, complex ions, exchangeable forms, precipitates, and minerals (Salam 2017). Among these, free ions and to some extent complex ions and exchangeable forms, are the most mobile and potential to affect the living things because these forms are directly related to plant root absorption and heavy metal toxicities (Salam 2001; Daoust *et al.* 2006; Salam 2017). Therefore, the behaviors of these labile fractions of heavy metals in soils must be understood. This may include their behaviours related to the dynamics of some soil key properties such as soil cation exchange capacity (CEC), pH, and reaction time.

Soil adsorption capacity – part of it is expressed as CEC – is the most important soil property that influences heavy metal immobilization. This property may be improved by the addition of ameliorants. For examples, some researchers employed organic matters/biosolids (Salam *et al.* 2001; 2005; 2017; Tokunaga *et al.* 2003; Brown *et al.* 2004; Stehouwer *et al.* 2006; Schroder *et al.* 2008; Brown *et al.* 2009; Kukier *et al.* 2010; Mamindy-Pajany *et al.* 2014; Tang *et al*. 2014; Pukalchik *et al*. 2017) or P fertilizers such as TSP and rock phosphate (Brown *et al.* 2004; Kilgour*et al.* 2008; Moseley *et al.* 2008). Organic matter is believed to provide functional groups such as phenolic and carboxyl in significant amounts and to increase soil CEC (Ross 1994b; Parfitt *et al.* 1995; Rodella *et al.* 1995; Salam 2001). The study of Lin *et al.* (2008) reported that Cu tended to be preferentially bound by Fe-oxides and organic matter. Some other ameliorants were also developed to immobilize heavy metals by precipitation, for examples by employing Na_2HPO_4, hidroxyapatite, or rock phosphate (Ma *et al.* 1990 1994 1995; Rabinowitz 1993; Ruby *et al.* 1994).

As repeatedly reported by several researchers (Salam 1999 2001; Adams *et al.* 2004; Bang and Hesterberg 2004; Quaghebeur *et al.* 2005; He *et al.* 2006; Brown *et al.* 2009; Bolan *et al.* 2014; Malinowska 2017), the soil adsorption capacity or CEC is positively related to the changes in soil pH. In general, soil CEC increases with the increase of pH of soils with variable charges. The increase is due to the dehydogenation of soil particle surfaces in the presence of increased concentration of OH^-. The increase in soil CEC increases the adsorption of heavy metals. For example, it was reported that amendment of 5 Mg ha^{-1} $CaCO_3$ on soil contaminated with industrial waste significantly increased the soil pH dan decreased the labile heavy metals extracted using several chemical extractants (Salam 2000; 2001; 2017). This behavior then increases the residence time of heavy metals in soils and decreases their availabilities to plants and mobilities in soil environment. The study of Daoust *et al.* (2006) lately reported that Cu partitioning and its toxicity were significantly affected by pH greater than by organic matter and clay content.

This research was intended to evaluate the soil labile fraction of Cu ±10 years after soil treatments with Cu-containing industrial waste, lime, and cassava-leaf compost.

MATERIALS AND METHODS

Experimental Design

Soil samples were taken from topsoils and subsoils in the experimental plots set up in July 1998, located in Sidosari, Natar, South Lampung. Treatments were previously set up in a randomized block design, consisting of 3 factors, namely industrial waste of metal spoon, lime (dolomite), and cassava-leaf compost, with 3 replications. The industrial waste of metal-spoon, which contained high amounts of Cu and Zn, was obtained from PT Star Metal Wares Jakarta. The pH of the industrial waste was 7.30 and the contents of Pb, Cd, Cu and Zn in the waste were 2.44 mg kg^{-1}, 0.12 mg kg^{-1}, 754 mg kg^{-1}, and 44.6 mg kg^{-1}, respectively (Salam *et al.* 2005).

The industrial waste was applied and thoroughly plowed to 30 cm soil depth at rates of 0, 15, and 60 Mg ha^{-1}. Lime and cassava-leaf compost were both applied and thoroughly mixed to the same soil depth one week later at rates of 0 and 5 Mg ha^{-1}. The lime used was $CaCO_3$. The cassava-leaf compost was prepared as reported previously by Salam (2001). The rates of industrial waste, lime, and cassava-leaf compost were selected through a series of preliminary experiments reported previously

Table 1. The existing treatment units in the experimental plots at Sidosari, Natar, Lampung.

Waste (W)	Lime (L)	Compost (C) C_0	C_1
W_0	L_0	$W_0L_0C_0$	$W_0L_0C_1$
	L1	$W_0L_1C_0$	$W_0L_1C_1$
W_1	L_0	$W_1L_0C_0$	$W_1L_0C_1$
	L_1	$W_1L_1C_0$	$W_1L_1C_1$
W_2	L_0	$W_2L_0C_0$	$W_2L_0C_1$
	L_1	$W_2L_1C_0$	$W_2L_1C_1$

Notes:
W = Waste (W_0= 0, W_1= 15, and W_2= 60 Mg ha^{-1}), L = Lime (L_0= 0 and L_1= 5 Mg ha^{-1}); and C = Compost (C_0= 0 and C_1= 5 Mg ha^{-1}).

(Salam 2000). Each plot measured 4.5 m long and 4 m wide, 50 cm apart between plots and 100 cm apart between blocks. The complete experimental treatments are listed in Table 1. The experimental plots were set up in 1998 and planted with corn, dryland paddy, and left bare in between.

Soil Sampling and Data Anaysis

Soil sampling was conducted on 15 February 2009 (±10 years after treatment). Composite topsoil (0-15 cm) and subsoil (15-30 cm) samples were taken diagonally from 5 points in each plot. Soil samples were air-dried, ground to pass a 2-mm-sieve, and mixed thoroughly before analysis. The soil Cu labile fraction was determined using DTPA method (Baker and Amacher 1987) and the soil pH was measured using a pH electrode.

The data obtained in the current study were compared to those of ±1.5 years after treatment (Amirulloh 2000) and ±3 years after treatment (Prihatin 2002).

RESULTS AND DISCUSSION

Copper was chemically retained in the soil for more than 10 years since soil treatment with Cu-containing industrial waste in July 1998. Analysis of variance (Anova) shows that the industrial waste application significantly enhanced the soil labile factions of Cu (Table 2). Test of Least Significant Difference (LSD-Test) also shows the significance of this effect, particularly by the addition of the industrial waste at 60 Mg ha^{-1} (Table 3). The concentration of Cu at the addition of 60 Mg ha^{-1} was 3.93 times compared to that at Control at 0 – 15 cm, while that at 15- 30 cm was 2.55 times. The application of industrial waste at 15 Mg ha^{-1} also showed tendencies to increase the concentrations of Cu, *i.e.* 1.82 times and 1.49 times at 0 – 15 and 15 – 30 cm, respectively. The increases were clearly attributed to the fact that the industrial waste contained relatively high amount of Cu (Salam *et al.* 2005).

Table 2. Analysis of variance of the changes in labile Cu concentration in a tropical soil treated with Cu-containing industrial waste, lime, and cassava-leaf compost after a particular period of time since treatment (Transformation of $\sqrt{x}$) (Ginanjar 2009).

Treatment	Time (years) ± 1.5[1)]		± 3 [2)]		± 10	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
W	**	**	**	**	**	**
C	ns	ns	ns	**	ns	ns
L	**	ns	ns	ns	ns	ns
WxC	ns	ns	ns	**	**	**
WxL	ns	ns	**	ns	**	**
CxL	ns	ns	ns	**	ns	ns
WxCxL	ns	ns	**	**	ns	**

Notes: W = Waste; C = Cassava-Leaf Compost; L = Lime; * = Significant at 5% significance level; ** = Significant at 1% significance level; ns = Not Significant at 5% and 1% significance levels; [1)]Amirulloh (2000); [2)]Prihatin (2002).

Table 3. The effect of waste application on the concentrations of Cu labile fraction in a tropical soil ±10 years after treatment (Transformation of $\sqrt{x}$) (Ginanjar 2009).

Waste Levels ($Mg\ ha^{-1}$)	Soil Depth (cm)	
	0-15	15-30
	--------------- $mg\ kg^{-1}$ ------------	
0	2.68 a	1.78 a
15	3.62 a	2.17 a
60	5.31 b	2.84 b
LSD 5%	1.01	0.64

Note: The values followed by the same letters in the same column are not significantly different at 5% significance level.

However, the concentrations of soil labile Cu in general decreased significantly with year of sampling, particularly at the addition level of 60 Mg waste ha^{-1}. The concentrations of labile Cu at ±1.5 years were higher than those at ±3 years and those at ±3 years were higher than those at ±10 years (Figure 1, 2, and 3). The relative concentrations of labile Cu in the topsoils treated with 60 Mg waste ha^{-1} and 5 Mg lime ha^{-1} decreased from 0.67 at ±1.5 years to 0.54 at ±3 years and to 0.39 at ±10 years. The relative concentration of Cu is expressed as Cu/Cu_0-1.5, *i.e.* the ratio of the concentration of Cu at a particular time of sampling to that of the Control (No Compost and No Lime) at ±1.5 years. The relative concentrations of labile Cu at waste level of 60 Mg ha^{-1} are listed in Tabel 4.

Table 4. The relative concentrations of Cu (Cu/Cu_0-1.5) in the topsoils treated with 60 Mg ha^{-1} of waste.

Treatment Unit	± 1.5 years	± 3 years	± 10 years
No C, No L	1.00	0.77	0.19
No C, With L	0.67	0.54	0.39
With C, No L	0.80	0.60	0.21
With C, With L	0.55	0.64	0.17

The decreasing pattern of Cu was also observed with the application of industrial waste at 15 Mg ha^{-1} with a little rise at 10 years after waste application (Figure 2). This decreasing pattern was not observed in the subsoil (15-30 cm). The reasons are that the industrial waste was applied on topsoil (0-15 cm) and the Cu in the subsoil was originated from the topsoil moved downwards by leaching,

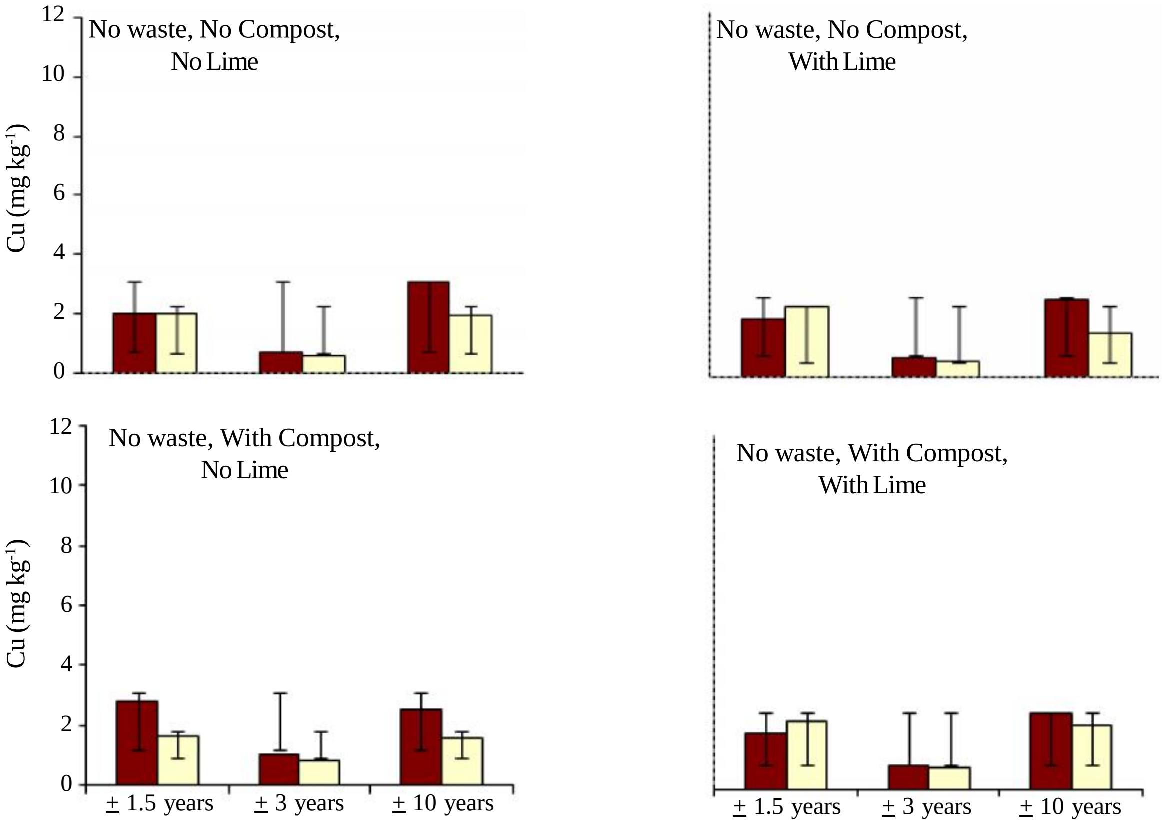

Figure1. The effect of industrial waste, lime, and cassava-leaf compost on the concentration of a tropical soil labile fraction of Cu (Transformation of $\sqrt{x}$) at waste level 0 Mg ha^{-1} (compost 5 Mg ha^{-1} and lime 5 Mg ha^{-1}). Sources:Amirullah (2000); Prihatin (2002) and Ginanjar (2009). ■: 0-15 cm, □: 15-30 cm.

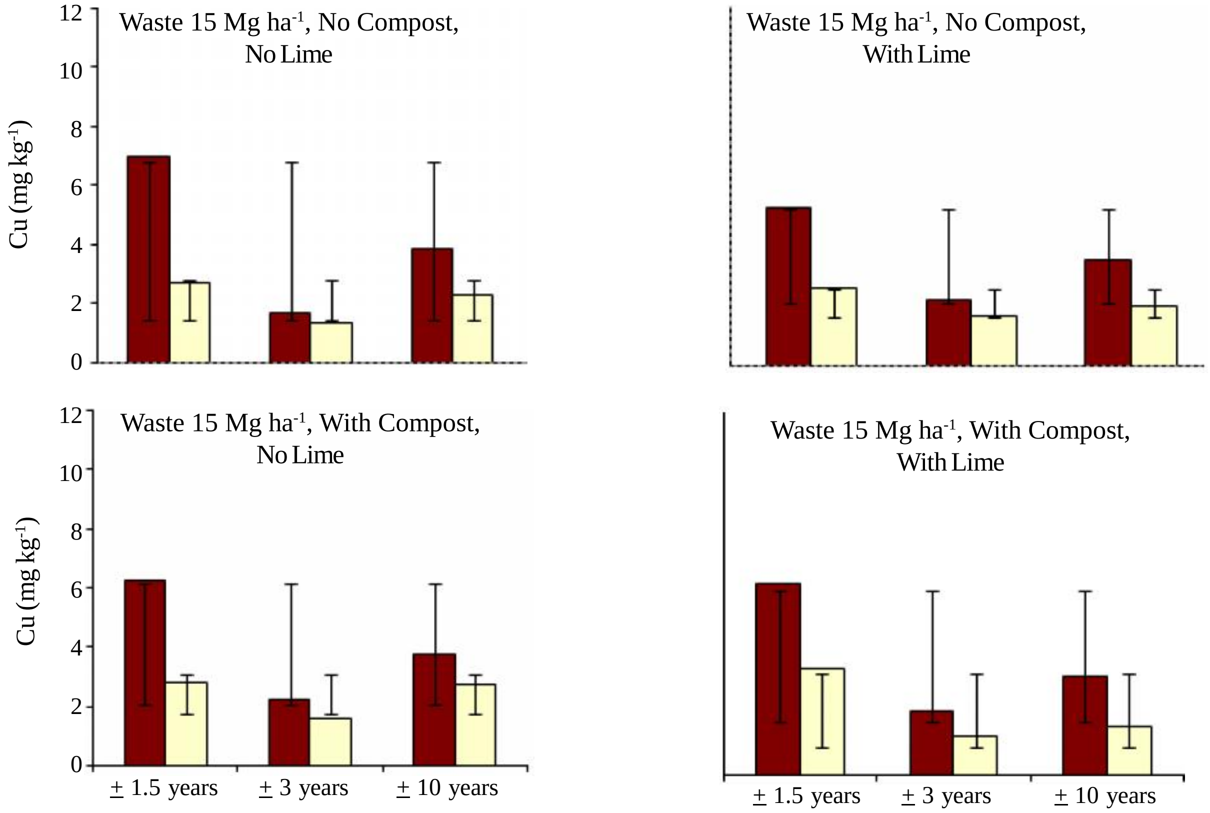

Figure 2. The effect of industrial waste, lime, and cassava-leaf compost on the concentration of labile fraction of Cu (Transformation of $\sqrt{x}$) at waste level of 15 Mg ha^{-1} (compost 5 Mg ha^{-1} and lime 5 Mg ha^{-1}). Sources: Amirullah (2000); Prihatin (2002) and Ginanjar (2009). ■: 0-15 cm, □: 15-30 cm.

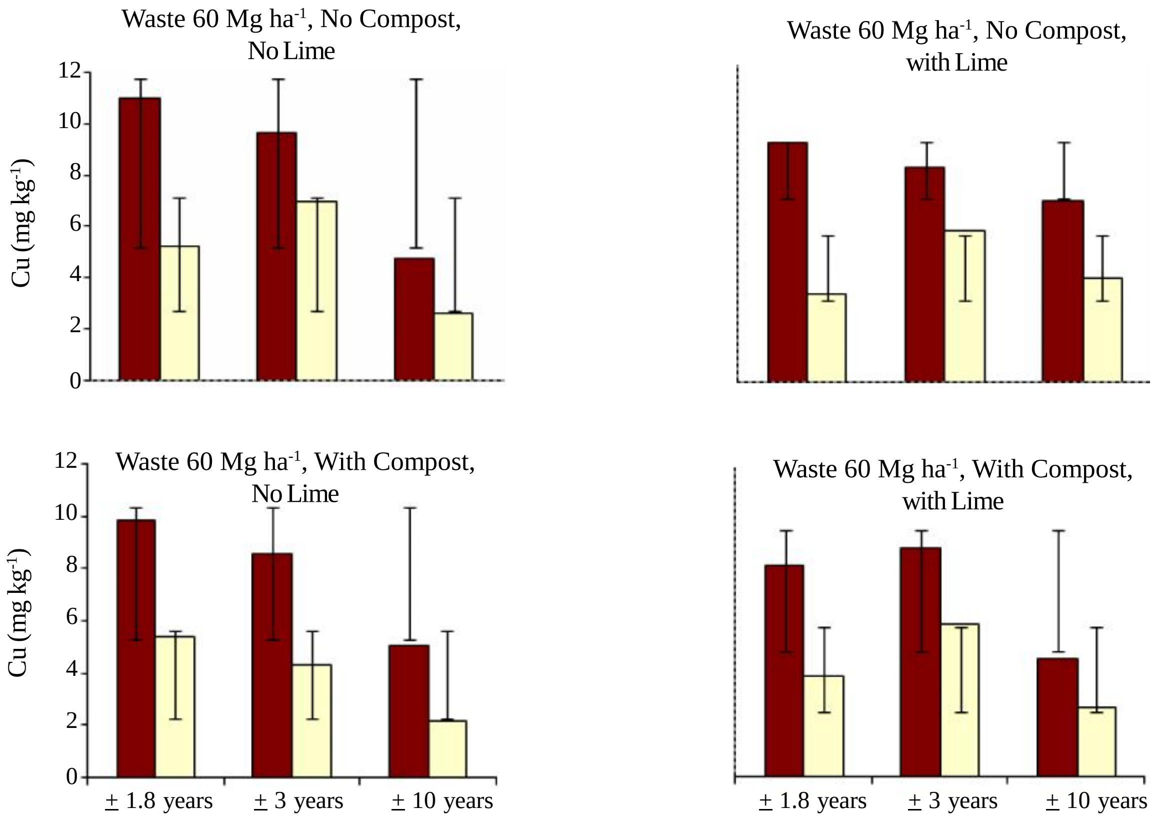

Figure 3. The effect of industrial waste, lime, and cassava-leaf compost on the concentration of a tropical soil labile fraction of Cu (Transformation of $\sqrt{x}$) at waste level of 60 Mg ha^{-1} (Compost 5 Mg ha^{-1} and Lime 5 Mg ha^{-1}). Sources: Amirullah (2000); Prihatin (2002) and Ginanjar (2009). ■: 0-15 cm, □: 15-30 cm.

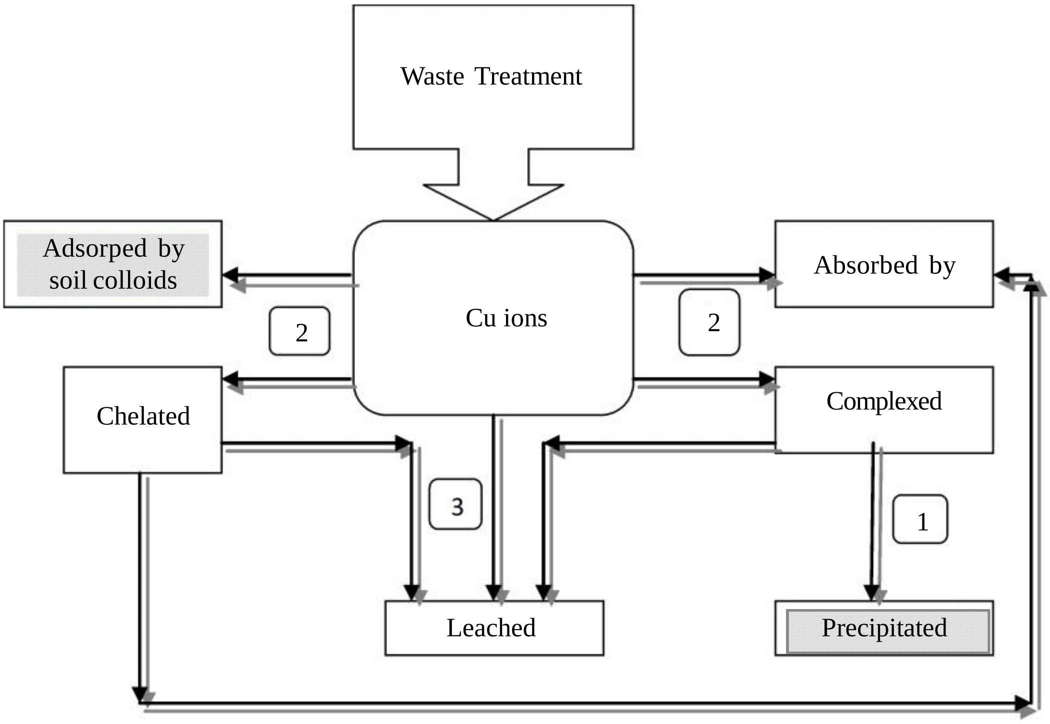

Figure 4. The possibility of the waste-origin Cu removal from soil labile fractions ±10 years after waste treatment (1 – Adsorption or precipitation, 2 – Absorption by plant roots, 3 – leaching).

which were greatly depended on the grown crops, rainfall, and water percolation rates (Figure 4).

The decreasing trend in the concentration of Cu for the last ±10 years was due to several possibilities: (1) enhanced retainment by soil adsorption surfaces or by precipitation, (2) absorbed by plant roots, and (3) leached by percolating water to subsoil or groundwater, as described in Figure 4.

Based on the observation, the first possibility was unlikely. First, at ±10 years after treatment, the effect of lime had decreased significantly and, based on Anova, the effect on decreasing Cu labile fractions was not significant (Table 2). Second, the interaction of industrial waste of 15 Mg ha^{-1} and lime tended to decrease the concentration of soil labile Cu. However, the effect was not significant. On the contrary, the interaction with industrial waste of 60 Mg ha^{-1} in fact increased the concentration of soil labile Cu. The interaction of industrial waste and cassava-leaf compost also significantly decreased the soil labile Cu. However, the materials from compost were easily decomposed. Therefore, the logical possibility causing the decrease in the concentrations of labile Cu with time was Cu absorption by plant roots or Cu translocation into subsoil or groundwater (Figure 4). The complexation of Cu with soil humic substances may have mobilized Cu ions, so that it was more easily transported and/or absorbed by plant roots. In fact, Cu is more easily complexed by organic substances.

CONCLUSIONS

Copper of industrial-waste-origin was retained in soil for more than 10 years. The concentrations of labile Cu in general decreased with year of soil sampling. However, part of the Cu from industrial waste was translocated, probably absorbed by plant roots and/or moved into subsoil and/or groundwater through soil body.

ACKNOWLEDGEMENTS

This research funding was provided by The Directorate General of Higher Education The Department of National Education through "Hibah Kompetitif Penelitian Sesuai Prioritas Nasional" in 2009.

REFERENCES

Adams ML, FJ Zhao, SP McGrath, FA Nicholsonand BJ Chambers. 2004. Predicting cadmium concentrations in wheat and barley grain using soil properties. *J Environ Qual* 33: 532-541.

Alloway BJ. 2012. Sources of heavy metals and metalloids in soils. *Heavy Metals Soils* 22: 11-50.

Amirulloh. 2000. Tinggalan Unsur Mikro Kelompok Logam Berat Asal Limbah Industri dalam Tanah yang Telah Diperlakukan dengan Kapur dan Kompos Daun Singkong. [Bachelor Thesis]. University of Lampung, Bandar Lampung (in Indonesian).

Baker DEand MCAmacher. 1987. Nickel, copper, zinc, and cadmium. In: AL Page, RH Miller, and DR Keeney (eds). Methods of Soil Analysis Part 2 Chemical and Microbiological Properties. 2nd ed. SSSA Inc., Madison, pp. 323-336.

Bang JS and D Hesterberg. 2004. Dissolution of trace element contaminants from two coastal plain soils as affected by pH. *J Environ Qual* 33: 891-901.

Benke MB, SPIndraratne, X Hao, C Chang and TB Goh. 2008. Trace element changes in soil after long-term cattle manure applications. *J Environ Qual* 37: 798-807.

Berenguer SC, F Santeveri, J Boixadera and J Lloveras. 2008. Copper and zinc soil accumulation and plant concentration in irrigated maize fertilized with liquid swine manure. *Agron J* 100: 1056-1061.

Biasioli M, HGreman, T Kralj, F Madrid, E Diaz-Barrientos and F Ajmone-Marsan. 2007. Potentially toxic elements contamination in urban soils. *J Environ Qual* 36: 70-79.

Bolan N, A Kunhikhrisnan, R Thangarajan, J Kumpiene, J Park, T Makino, MB Kirkham and K Scheckel. 2014. Remediation of heavy metal(loid)s contaminated soils – to mobilize or to immobilize? *J Hazard Mater* 266: 141-166.

Brown S, RF Chaney, J Hallfrisch, JA Ryanand WR Berti. 2004. *In situ* soil treatments to reduce the phyto- and bioavailability of lead, zinc, and cadmium. *J Environ Qual* 33: 522-531.

Brown S, A Svendsen and C Henry. 2009. Restoration of high zinc and lead tailings with municipal biosolids and lime: a field study. *J Environ Qual* 38: 2189-2197.

Cakmak D, E Saljnikov, V Mrvic, M Jakovljevic, Z Marjanovic, B Sikiric and SMaksimovic. 2010. Soil properties and trace elements contents following 40 years of phosphate fertilization. *J Environ Qual* 39: 541-547.

Daoust CM, C Bastien and L Deschenes. 2006. Influence of soil properties and aging on the toxicity of copper on compost worm and barley. *J Environ Qual* 35: 558-567.

Ginanjar K. 2009. Fraksi Labil Tembaga dan Seng dalam Tanah pada 10 Tahun Setelah Perlakuan dengan Limbah Industri. [Bachelor Thesis]. University of Lampung, Bandar Lampung (in Indonesian).

GuoY, C Huang, H Zhang and Q Dong. 2009. Heavy metal contamination from electronic waste recycling at Guiyu, Southern China. *J Environ Qual* 38: 1617-1626.

He ZJ, M Zhang, XE Yangand PJStoffella. 2006. Release behavior of copper and zinc from sandy soils. *Soil Sci Soc Am J* 70: 1699-1707.

Juracek KE and AC Ziegler. 2006. The legacy of leaded gasoline in bottom sediment of small rural reservoirs. *J Environ Qual* 35: 2092-2102.

Kargar M, P Jutras, OG Clark, WH Hendershot and SO Prasher. 2013. Trace metal contamination influenced by land use, soil age, and organic matter in Montreal tree pit soil. *J Environ Qual* 42: 1527-1533.

Kilgour DW, RB Moseley, MO Barnett, KS Savage and PM Jardine. 2008. Potential negative consequences of adding phosphorus-based fertilizers to immobilize lead in soils. *J Environ Qual* 37: 1733-1740.

Kukier U, RL Chaney, JA Ryan, WL Daniels, RH Dowdy and TC Granato. 2010. Phytoavailability of cadmium in long-term biosolids-amended soils. *J Environ Qual* 39: 519-530.

Lin C, I Negev, G Eshel and A Banin. 2008. *In situ* accumulation of copper, chromium, nickel, and zinc in soils used for long-term waste water reclamation. *J Environ Qual* 37: 1477-1487.

Malinowska E. 2017. The effect of liming and sewage sludge application on heavy metal speciation in soil. *B Environ Contam Tox* 98: 105-112.

Mamindy-Pajany Y, S Sayen, JFW Mosselmans and EGuillon. 2014. Copper, nickel, and zinc speciation in biosolid-amended soil: pH adsorption edge, ?-XRF and ?-XANES investigations. *Environ Sci Technol* 48: 7227-7244.

Ma QY, SJ Traina and TJ Logan. 1990. *In situ* lead immobilization by apatite. *Environ Sci Technol* 27: 1803-1810.

Ma QY, SJ Traina, TJ Logan and JA Ryan. 1994. Effects of aqueous Al, Cd, Cu, Fe(II), Ni, and Zn on Pb immobilization by hydroxyapatite. *Environ Sci Technol* 28: 1219-1228.

MaQY, TJ Logan and SJ Traina. 1995. Lead immobilization from aqueous solution and contaminated soils using phosphate rocks. *Environ Sci Technol* 29: 1118-1126.

Moseley RA, MO Barnett, MA Stewart, TL Mehlhorn, PA Jardine, M Ginder-Vogel and S Fendorf. 2008. Decreasing lead bioaccessibility in industrial and firing range soils with phosphate-based amendments. *J Environ Qual* 37: 2116-2124.

Parfitt RL, DJ Giltrapand and JS Whitton. 1995. Contribution of organic matter and clay minerals to the cation exchange capacity of soils. Commun. *Soil Sci Plant Anal* 26: 1343-1355.

Prihatin F. 2002. Pengaruh Tinggalan Limbah Industri, Kapur, dan Kompos Daun Singkong terhadap Ketersediaan Cu dan Zn pada Beberapa Kedalaman Tanah Ultisol Sidosari Natar Lampung Selatan.[Script].University of Lampung, Bandar Lampung (in Indonesian).

Pukalchik M, M Panova, M Karpukhin, O Yakimenko, K Kydralieva and V Terekhova. 2017. Using humic products as amendment to restore Zn and Pb polluted soil: a case study using rapid screening phytotest endpoint. *J Soils Sediments*. https://doi.org/10.1007/s11368-017-1841-y.

Quaghebeur M, A Rate, Z Rengel and C Hinz. 2005. Desorption kinetics of arsenate from kaolinite as influenced by pH. *J Environ Qual* 34: 479-486.

Rabinowitz MB.1993. Modifying soil lead bioavailability by phosphate addition. *Bull Environ ContamToxicol* 51: 438-444.

Ranur S. 2009. Status Pergerakan Tembaga dan Seng dalam Tubuh Tanah di Desa Sidosari Natar, Lampung Selatan, pada 10 Tahun Setelah Perlakuan dengan Limbah Industri. [Script].University of Lampung, Bandar Lampung. (in Indonesian).

Rodella AA, KR Fisherand JCAlcarde. 1995. Cation exchange capacity of an acid soil as influenced by different sources of organic matter. *Commun Soil Sci Plant Anal* 26: 2691-2967.

Ross SM 1994a. Sources and forms of potentially toxic metals in soil-plant systems.In: SM Ross (ed.). Toxic Metals in Soil-Plant Systems. John Willey & Sons, Ltd.,New York.pp. 3-25.

Ross SM 1994b. Retention, transformation, and mobility of toxic metals in soils. In: SM Ross (eds). *Toxic Metals in Soil-Plant Systems*. John Willey and Sons, Ltd., New York. pp.63-152.

Ruby MV, A Davis and A Nicholson. 1994. *In situ* formation of lead phosphates in soils as a method to immobilize lead. *Environ Sci Technol* 28:646-654.

Salam AK. 2000. 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. *J Tropical Soils* 11:31-46.

Salam AK. 2001. Manajemen Fraksi Labil Logam Berat di dalam Tanah untuk Pertanian dan Lingkungan. University of Lampung Press, Bandar Lampung. 62p. (in Indonesian).

Salam AK, S Bakrie and F Prihatin. 2005. Depth-wise distribution of extracted Cu and Zn in cultivated field-plots three years after treatment with a Cu- and Zn-containing waste, lime, and cassava-leaf compost. *J Trop Soils* 11: 9-14.

Salam AK. 2017. Management of Heavy Metals in Tropical Soil Environment. Global Madani Press, Bandar Lampung. 257p.

Schroder JL, H Zhang, D Zhou, N Basta, WR Raun, ME PayMg and A Zazulak. 2008. The effect of long-term annual application of biosolids on soil properties, phosphorrus, and metals. *Soil Sci Soc Am J* 72:73-82.

Stehouwer R, RL Day and KE Macneal. 2006. Nutrient and trace element leaching following mine reclamation with biosolids. *J Environ Qual* 35:1118-1126.

Tang WW, GM Zeng, JL Gong, J Liang, P Xu, C Zhang and B.B. Huang. 2014. Impact of humic/fulvic acid on the removal of heavy metals from aqueous solution using nanomaterials: a review. *Sci Total Environ* 468-469:1014-1027.

Tokunaga TK, J Wan, MKFiresMge, TC Hazen, KR Olson, DJ Herman, SR Sut Mg and A Lanzirotti. 2003. In situ reduction of chromium (VI) in heavily contaminated soil through organic carbon amendment. *J Environ Qual* 32:1641-1649.

Tu CL, TB He, CQ Liu and XH. Lu. 2012. Effects of land use and parent materials on trace elements accumulation in topsoil. *J Environ Qual* 42:103-110.