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Full Length Research Paper

Fate of some heavy metals in the composting of the urban solid waste produced in Lome,Togo

Edem K. Koledzi[1], Gnon Baba[2], Sanonka Tchegueni[1], K. N. Segbeaya[2], Moursalou Koriko[1], Guy Matejka[3] and Gado Tchangbedji[1]

[1]Université de Lomé – FDS - Laboratoire GTVD BP : 1515 Lomé – Togo.
[2]Université de Kara, B.P. 404, Kara, Togo.
[3]Université de Limoges – ENSIL- Groupement de Recherche Eau, Sol et Environnement (GRESE) 87068 Limoges Cedex, Togo.

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The aim of the present work is to assess the balance of some heavy metals during the composting of urban waste in Lome. Heavy metals constitute problems in waste management because of their multiple sources and their potentially high toxicity. Wastes were sieved to eliminate the fine fraction and set in windrows for composting and after maturation the sieved-compost was chemically characterized. The fraction of the super fines, that is, with a particle size less than 10 mm, contributed 30 to 56% of the average contents of metals in compost. Sorting of wastes into various fractions such as plastics, hazardous materials, glass, miscellaneous combustible material, metals, and super fines lowered the metals content in compost by about 80%. Elimination of super fines and sorting of urban waste before composting are means to reduce the content of heavy metals in composts.

Key words: Metals, waste, composting, leaching test.

INTRODUCTION

Metals in solid waste of cities constitute a significant source of environmental pollution and threat to human health. The presence of metals in waste is mainly due to their use in the industrial manufacturing of various products (batteries, sprays, kitchenware, paints, ink, electronic components) or their presence in various packaging materials (conjoint boxes, brick packages for milk and juice, paper, cardboard, plastics). The contribution of metals in household waste varies according to the categories constituting the waste and in respect to individual metals. Tolerance limits for metals vary between countries (ADEME, 1999; Lagier, 2000).

Composting is a technique that gives values to organic waste which can be recycled in the form of humus. It transforms fermentable waste into organic matter, similar to the organic matter of the soil (Tchegueni et al., 2013). Compost is used as a measure for improving soil quality and fertility; although the presence of heavy metals can restrict its uses due to health or environmental risks. Due to these potential hazards, the maximum total concentrations for a range of heavy metals are one of the parameters used to establish compost quality standards. Studies in some developing countries as Benin, Guinea and Mali show the presence of heavy metals (Cd, Cu, Ni, Pb, Zn) in urban composts (Soclo et al., 1999; Matejka et al., 2001; Soumaré et al., 2003). In developing countries the common processes of composting do not guarantee at present a sufficiently high quality of compost in term

*Corresponding author. E-mail: edemledzi@yahoo.fr . Tel: +228 90 19 85 35.

of metals. If no regulatory standards are implemented, compost may contain metals in quantities greatly exceeding the limits established in developed countries (AFNOR, 2010).

The aim of this study is to improve the process of composting on the basis of a balance assessment of metals on the decentralized plant of a non-government organization (NGO) in Lomé, Togo.

MATERIALS AND METHODS

Physical characterization of waste

In order to estimate the global average content of metals, characterization of the waste was carried out. Sampling was realized according to the statistical law of Bernoulli. While according to the French national organization for standardization (AFNOR, 1996) 13 categories are defined, in this study the following 10 waste categories were distinguished: organic food and yard waste; paper and cardboard; textiles; plastics; miscellaneous combustible material (misc. C) including leather, rubber, and wood; glass; metals; miscellaneous inerts (misc. I) including gravel, ceramic, tile, ashes, and stones; hazardous materials; fines (20-10 mm); and super fines (<10 mm).

Sample for analysis

Samples were collected by taking several 500 g of material from different places within the waste pile. Every sample was mixed and 1 kg of each material was collected from the mixture.

Moisture content

The moisture content of a given sample (20 – 50 g) was determined by heating to 105°C in an oven for 24 h (Charnay, 2005; Garcia et al., 2005; Aloueimine et al., 2006; Yobouet et al., 2010).

Metal contents

Six aliquots of 0.5 g of each sample category were taken for analysis. They were digested in a vessel adding 30 ml of a mixture of 20 ml HCl and 10 ml HNO_3, (Bustamante et al., 2008; Belyaeva and Haynes, 2009). Metals were determined by atomic adsorption spectrometry (Koffi et al., 2010; Shokrzadeh and Saeedi Saravi, 2010).

Scheme of the process

The process often used in platforms is sorting-composting. In this study the sieving (10 mm) of the fine fraction was introduced into the process before the staking operation in windrows and after maturation (Figure 1).

Leaching test

The leaching test consisted of bringing a given mass of crushed waste in contact with a defined quantity of water and analyzing the eluate. For this study the assay was realized with a report Liquid/Solid = 10 (water: 100 ml; solid: 10 g). The leaching solution used was EDTA, 0.05 mol L^{-1} at pH 7 and the eluates were mineralized before the spectrophotometric analysis (Koledzi et al., 2011a).

Statistical analysis

Standard Errors (SE) were calculated using general statistical methods like the ones described by Salant and Dillmann (1994) and Rea and Parker (1997).

$$SE = \frac{\sqrt{\frac{\sum_{i=1}^{n}(x_i - u)^2}{n-1}}}{\sqrt{n-1}}$$

Where u: average; x_i: value number i; n: total number.

RESULTS AND DISCUSSION

Moisture content

In the dry season and wet season the moisture contents of the categories vary: organic 50-60%, paper and cardboard 16-43%, textiles 5-10%, plastics 5-18%, misc. C 3-30%, fines 15-33%, and super fines 10-28%. The moisture contents of the following categories glass, metal, misc. I, and hazardous materials were null.

Metals in the waste of Lomé

After having determined the average composition of waste dry matter and using results of analysis of metals by category, the global average content of the waste in metals was calculated (Table 1). The global average distribution of waste by category shows the high super fines content with an average rate of 39 ± 1 % dry waste. Previous studies of Koledzi et al. (2011b) showed that this category contains 9-10 % of organic matter and that the rest is only sand. This justifies the choice of the process for eliminating sand on the first table of sorting. This category is followed by the 20-10 mm fines (10 - 20 %) with an average content of 30 ± 2 % in organic matter (Koledzi et al., 2011b). Other constituents vary slightly with regard to the others with however, a minimum of 0.7 % for the fraction of metals. The categories such as plastic, glass bottles and metals generally, were got back throughout the sector of collection.

In spite of recycling, some elements as plastics still represent a part which cannot be negligible. When added to the total mass of dry waste, their proportion still remains included between 7 and 13 %. The evolution of textiles amount is few, their total degradation is supposed to be reached after 60 years according to the literature. The average content of metals is classified as followed: Cd < Ni < Cu < Zn < Pb.

According to Rahnama et al. (2010), there are two

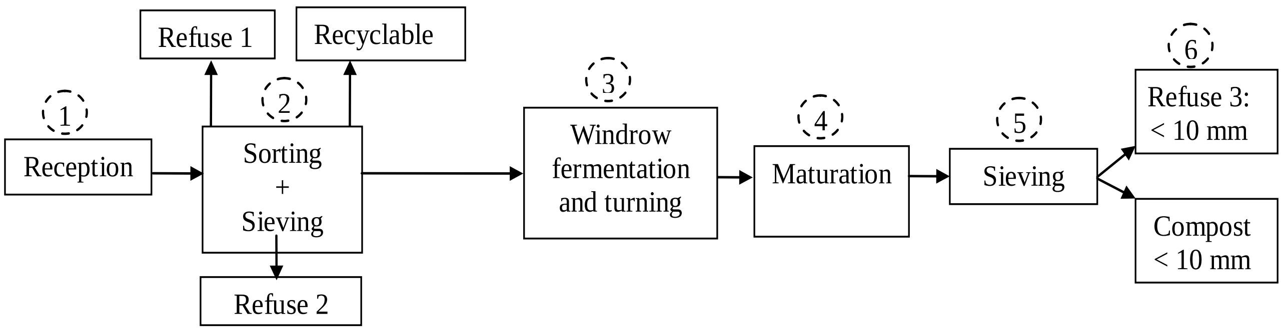

Figure 1. Plan of the line in industrial scale composting. Refuse 1: > 10 mm, no recyclable; Refuse 2: < 10 mm, 90 % of sand.

Table 1. Composition of waste (dry matter) according to category and average metal contents.

Waste category	Percentage		Metal contents (mg kg^{-1})				
	Dry season	Wet season	Ni	Cu	Zn	Pb	Cd
Organic	13.2	8.1	9.1	67.3	148	154	1.8
Paper and cardboard	4.5	8.7	11.8	38.1	112.1	26.1	1.4
Textiles	5.1	6.8	37.7	766	1220	99.2	6.8
Plastic	13.0	7.8	45.2	296	376	161	12.1
Glass	1.2	0.6	19.6	14.6	58	373	1.3
Metals	0.7	1.3	481	15540	5070	9050	7.9
Misc. C	7.3	4.2	19.6	497	867	184	14
Misc. I	3.3	2.1	23.3	21.2	558	641	1
Hazardous materials	1.7	1.8	388	21.7	2391	412	15.8
Fines - (20-10 mm)	10.9	19.6	26.8	299	441	746	3
Super fines (<10 mm)	39.0	38.9	34.1	465	553	931	4.5
	Dry season		38.3 ± 1.1	453.1± 2.1	559.5 ± 2.1	604.7± 3.2	5.7 ± 1.1
	Wet season		41.3 ± 1.2	554.9 ±2.2	595.5 ± 2.1	695.4 ± 2.1	5.0 ± 0.1
	Average		39.8 ± 1.1	504.0 ± 2.1	577.5 ± 2.1	650.0 ± 2.6	5.3 ± 0.6

/dm : /dry matter
Source: ADEME, 1999.

groups of metals: the “main things” (e.g., Cu, Zn) and the “non-main things” (e.g., Ni, Pb, Cd). The first biochemists who elaborated this research topic distinguished these metals on the basis of their ligand affinity. Cd and Pb have an affinity for sulfur which allows identification of proteins “which precipitate heavily” or easily give salts. On the other hand, both metals also have some physico-chemical characteristics:
(1) they do not destroy themselves, although they transport themselves or change their chemicals shape;
(2) they have a high electric conductivity, which explains their use in numerous industries;
(3) but especially, they present certain human toxicity, entailing in particular more or less grave neurological hurts, whereas the others have a given utility in determined biological processes;
(4) they are only toxic elements;

Proportion of metals brought by each category

The Table 2 gives the annual proportion of metals brought by every category in 1 kg of dry waste and as a consequence in a heap of waste. Super fines provide the highest metal contents varying from 33 % to 56 ± 2 %. In the case of Ni, this category evolves as the following: hazardous (17±1 %), metals, plastics, textiles. For Cu, this element is followed by some metals (32 ± 2%), textiles, fines, plastics while for Zn, the source of contamination comes from textiles (12.7 ± 3%) followed by fines, metals, Misc. C, hazardous, plastics.

In the case of Pb, super fines are followed by fines

Table 2. Annual average proportion of metals brought by every category.

Waste category	%	%proportion of metals (/dm)				
	(/dm)	Ni	Cu	Zn	Pb	Cd
Organic	10.6	2.4	1.4	2.7	2.5	3.6
Paper and cardboard	6.6	2.0	0.5	1.3	0.3	1.7
Textiles	6.0	5.6	9.1	12.6	0.9	7.6
Plastic	10.4	11.8	6.1	6.8	2.6	23.8
Verres	0.9	0.4	0.0	0.1	0.5	0.2
Metals	1.0	12.6	32.0	9.1	14.5	1.5
Misc. C	5.7	2.8	5.7	8.6	1.6	15.2
Misc. I	2.7	1.6	0.1	2.6	2.7	0.5
Hazardous	1.8	17.1	0.1	7.2	1.1	5.2
Fines - (20-10 mm)	15.3	10.3	9.1	11.7	17.5	8.7
Super fines (<10 mm)	39.0	33.4	35.9	37.3	55.8	33.1

/dm: /dry matter.

Table 3. Concentration of metals in raw compost (mg/kg.dm).

Elements	Compost 1	Compost 2	Compost 3	Compost 4	*NFU 44 051
Ni	40 ± 1	14 ± 1	20 ± 1	18 ± 1	60
Pb	460 ± 2	380 ± 2	480 ± 2	290 ± 2	180
Cd	1 ± 0.02	1± 0.01	2± 0.03	2± 0.03	3

/dm: /dry matter. Source: AFNOR 2010.

(17.5%), metals. Cd is also brought by plastics (23.8 ± 1.1%), Misc. C (15.2 ±1.2%), fines (8.7%), textiles (7.6%). The first screening does not only eliminate sand but also a very important proportion of metals. Except for the primary screening the sorting of hazardous, Misc. C, metals, plastics and textiles would also eliminate 50 ± 3 % of Ni, 53 ± 2 % of Cu, 44.3 ± 1.1% of Zn, 20.7 ± 2.1 % of Pb and 53.3 ± 2.1 % of Cd. This process of composting would thus allow the removal of around 80 ± 2 % of metals.

Metal contents in compost

Contents of three metals (Ni, Pb, Cd) were determined on raw compost without elimination of sand and on compost obtained from the process appearing in Figure 1. The Table 3 presents the contents of Ni, Pb and Cd in five composts obtained without primary screening but with the sorting of the unwanted materials (plastics, metals, hazardous, Misc. C, Misc. I, glass, textiles). Only the Pb content is above the French standard (AFNOR, 2010) because it is brought by super fines in a 55.8% ratio in the waste.

The metals contents in super fines and thus in compost could result from the layer of humus, from some steppe black soil of gardens (Nilsson, 1972; Coughtrey et al., 1979; Veeken and Bert, 2002), and therefore in households waste. The city of Lomé is located on a sandy soil and households' keepers have a few knowledge of waste management. Household wastes are put down at first on the ground before being swept thus increasing the quantity of sand found in the waste.

Table 4 shows that the contents of metals in compost obtained after the sorting and the primary screening are very low with regard to the standard. The question is to know if these small quantities could be transferred to plants after amendment of grounds by these compost and thus to food chain. The leaching test and speciation of metals were realized to determine the potential of release of the elements in compost. This parameter allows the evaluation of the easily soluble pollution.

Metals speciation: case of Pb

According to the previous works of Koledzi et al. (2011a) on methods developed for simple extractions with different solvents (water, $CaCl_2$, EDTA), only EDTA seems to have a strong effect on the release of lead. The chosen solution was thus EDTA 0,05 mol L^{-1} at pH = 7 to test the retention of Pb in compost obtained by the process. This leaching test realized on compost allowed to determine the maximal capacity of release from the solid matrix towards the solution (leachate) corresponding to

Table 4. Composition of metals in composts obtained by process (mg/kg dm).

Elements	Compost 1	Compost 2	Compost 3	Compost 4	Compost 5	*NFU 44 051
Ni	10 ± 1	5 ± 1	2 ± 0.1	LQ	14 ± 1	60
Cu	LQ	8 ± 1	10 ± 1	LQ	15 ± 1	300
Zn	50 ± 1	10 ± 1	40 ± 1	30 ± 1	30 ± 1	600
Pb	5 ± 1	LD	6 ± 1	7 ± 1	3± 0.1	180
Cd	1± 0.01	LD	LD	LD	LD	3

LD: Limit of detection; LQ: Limit of quantification; /dm: /dry matter. Source: AFNOR 2010.

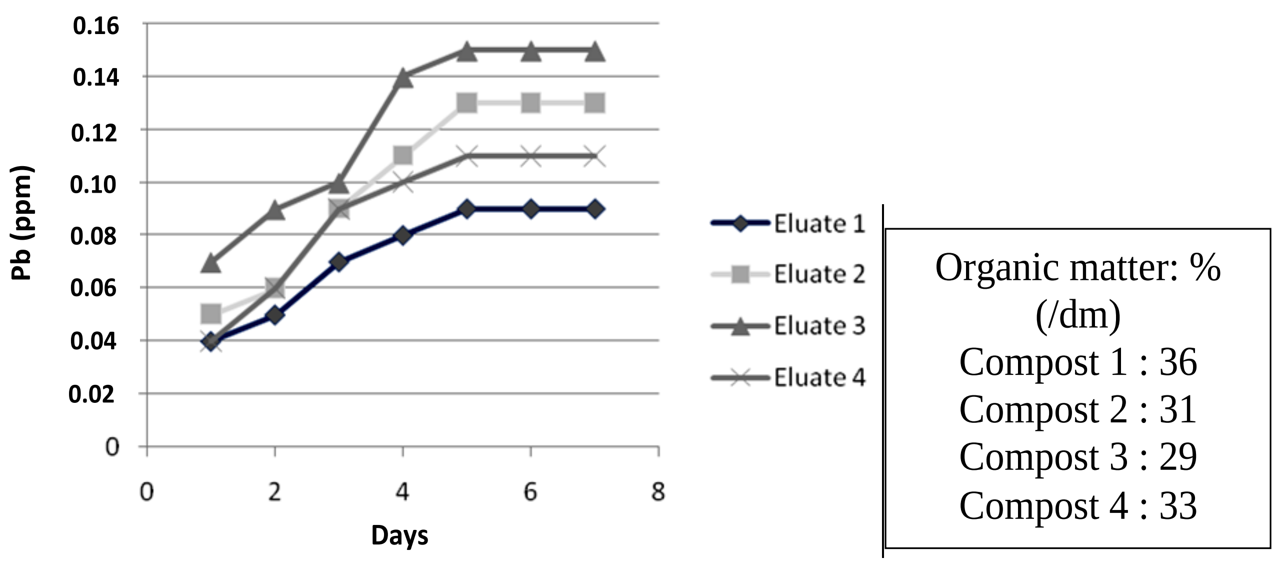

Figure 2. Extraction of Pb with EDTA (0,05M) pH=7.

the pollution susceptible to be remobilized and transferred to plants in short or medium-term. Contents of Pb in the leachate obtained with EDTA appear in Figure 2.

The classification of the retention potency appears to be: Compost 3 < Compost 2 < Compost 4 < Compost 1. Two hypotheses are possible: either the compost is rich in metallic hydroxides and thus participates in the retention of lead by cation exchange or by absorption, or it is sufficiently rich in organic matter for entrapping or retaining the metal by chemical complexes formation. The research for the content in organic matter by ignition gives 36 % for compost 1, 31 % for compost 2, 29 % for compost 3, and 33 % for compost 4. The higher the rate of organic matter is, the lower the rate of extraction. The retention of Pb is strong when the fraction of organic matter is high. The major part of Pb seems bound to the organic matter as shown by the results obtained after the fourth day of extraction (Figure 2). Complexation by organic matter would lead to a stable fixation state, leading to low mobility of Pb. The retention of Pb can occur not only on organic matter but also on metallic hydroxides, either by cation exchange or by fixation on carbonates.

In natural ecosystems, particularly in soils, chemical speciation of metals is dependent on numerous physico-chemical and/or biological parameters which can be subject to wide variations. The chemical speciation of an element is defined as including all the chemical forms / sorts of this element in a natural environment. Some ligands (inorganic or organic) are able to condition the speciation of this element by the formation of more or less stable complexes. It was shown that the toxicity of metal is dependent on its speciation and that the free ionic metal (Cu^{2+}, Pb^{2+}, etc.) speciation is one of the most reactive form, with the neutral species, because it is more easily assimilated by the live organisms (Lai et al., 2010). This metal (Ni, Cu, Zn, Pb, Cd) speciation is also dependent on a large number of physical (temperature, pressure) and chemical parameters (pH, ionic strength, concentrations in major elements, complexing ligands).

Conclusion

The implementation of data relative to the potential pollution capacities of metals by category is an essential stage in the management of waste with the aim of mitigation of the impact of these elements on the human health and the environment. This is mostly important in the developing countries where serious reflections hare to be led in this frame. So, this allows for directing surrounding areas of management, adapted to the context, by optimizing their contribution in the reduction of the specific quantities of waste intended for the final discharge.

This work allowed determining the origin of Ni, Cu, Zn, Pb and Cd in compost, to make the balance assessment quantity by metal and by category and to realize the balance assessment on these metals in the process of composting. Finally, the partial study on the basis of the previous results of Koledzi et al. (2011a) on the transfer of Pb allowed to show the possibility of retention of metals in the compost and thus in the ground enriched with organic matter.

This study on a decentralized plant will have to allow the actors implication (decision-makers, local authorities, companies etc.) in the management of household waste. It also will be helpful for and conceiving effective programs. It will provide the necessary arguments to convince the population to subscribe to programs of management of specific waste as for example, the elimination of super fines in waste, in the case of Lomé. For example, a reduction of the plastic and super fines, which are the main sources of Cd in the household waste, would appreciably contribute to the reduction of the rates in this element.

Furthermore the sorting of textiles, metals, Misc. C, would lead to a significant reduction of Ni, Cu, Zn, Pb and Cd. The sanitary and environmental stake in these toxic elements is particularly important when it is taken into account, their half-life period which can vary from a few days to some thousand years according to the matrix.

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