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Composting of urban solid waste in Lomé, Togo: fate of some heavy metals (Ni, Cu, Zn, Pb and Cd)

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ABSTRACT

Metals may constitute problems in waste management because of their multiple sources and potentially high toxicity of some constituents. Processes of composting do not always guarantee acceptable quality of the compost in terms of hazardous metals. The aim of this article is to assess the balance of some heavy metals during the composting of different categories of urban waste. The fraction of the super fines, i.e. with a particle size of less than 10 mm, contributes 30 to 56% of the total, average contents of metals in compost. Sorting of waste into various fractions such as plastics, hazardous materials, glass, miscellaneous combustible material, metals, and super fines lowers the metal contents in finished compost by about 80%. The remaining 20% can be washed during the fermentation of windrows or, still better, can be reduced by chemical complex formation in the compost as shown by the leaching adequate test.

Keywords: Heavy metals, composting, leaching test.

INTRODUCTION

Metals in solid waste of cities constitute a significant source of environmental pollution and may be a 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). In developing countries the common processes of composting do not guarantee at present a sufficiently high quality of compost in terms of metals. If no regulatory

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standards are implemented, compost may contain metals in quantities greatly exceeding the limits established in developed countries (AFNOR, 2010).

The aim of this study was to improve the process of composting on the basis of a balance assessment of metals on the decentralized plant of a non-governmental 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 in the 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, and stones; hazardous materials; fines (20-10 mm); and super fines (<10 mm).

Sample collection

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; Yobouet et al., 2010).

Metal contents

Six aliquots of 0.5 g of each sample category were taken for analysis. They were digested in 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 of Measure (SEM) were calculated using general statistical methods like the ones described by Salant and Dillmann (1994) and Rea and Parker (1997).

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

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

For each result, the SEM is calculated to assess the distribution and differences in values.

RESULTS

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).

Proportion of metals brought by each category

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.

Metals contents in compost

Contents in three metals (Ni, Pb, Cd) were determined on raw compost without elimination of sand and on compost obtained from the process appearing at Figure 1.

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).

Metals speciation: case of Pb

Contents of Pb in the leachate obtained with EDTA appear in Figure 2.

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

Waste Category	**%**		***Metal contents (mg / kg. dm)**				
	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	1554	507	905	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; *ADEME 1999.

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

Waste Category	**% (/ dm)**	**Proportion of metals, % (/ 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
Glass	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 ; *AFNOR 2010.

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; *AFNOR 2010.

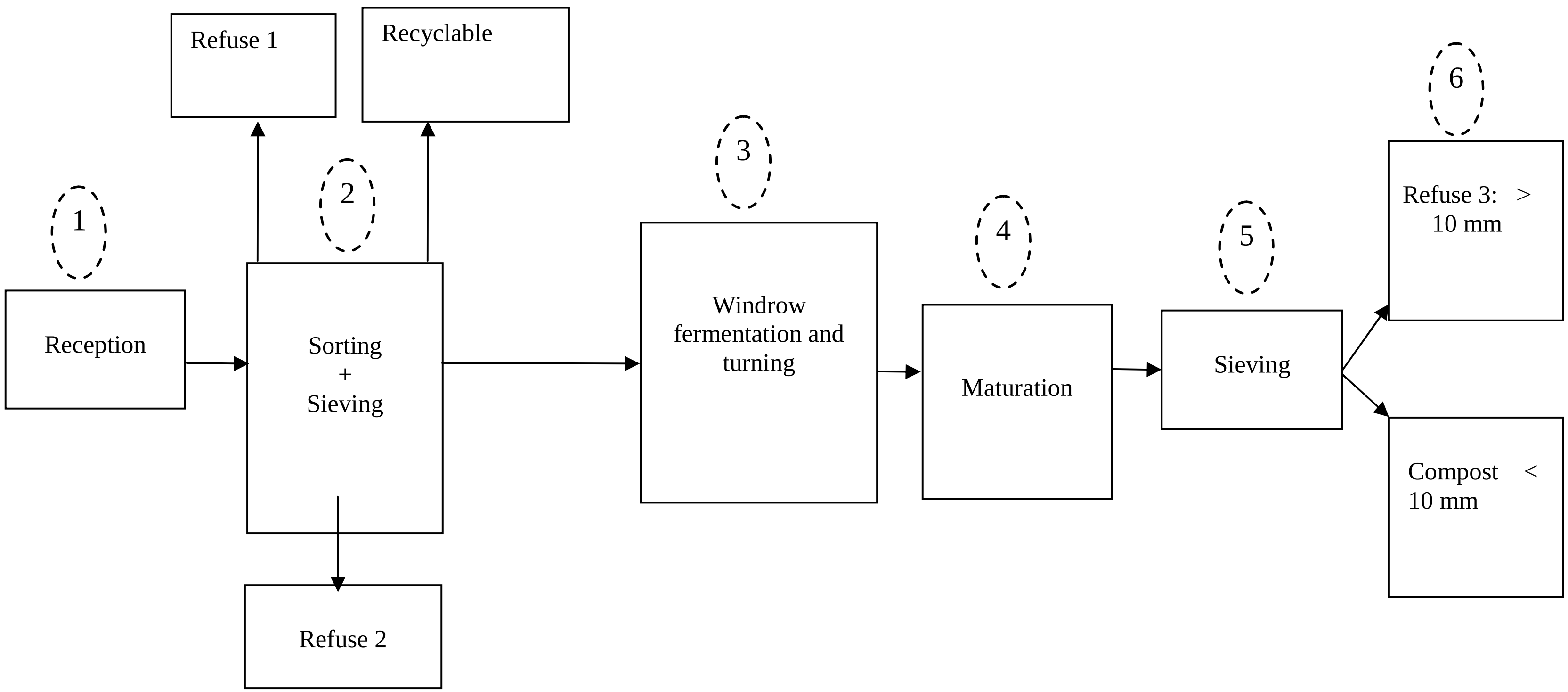

Figure 1: Plan of the line in industrial scale composting. Refuse 1: > 10 mm, no recyclable; Refuse 2: < 10 mm, 90 % of sand.

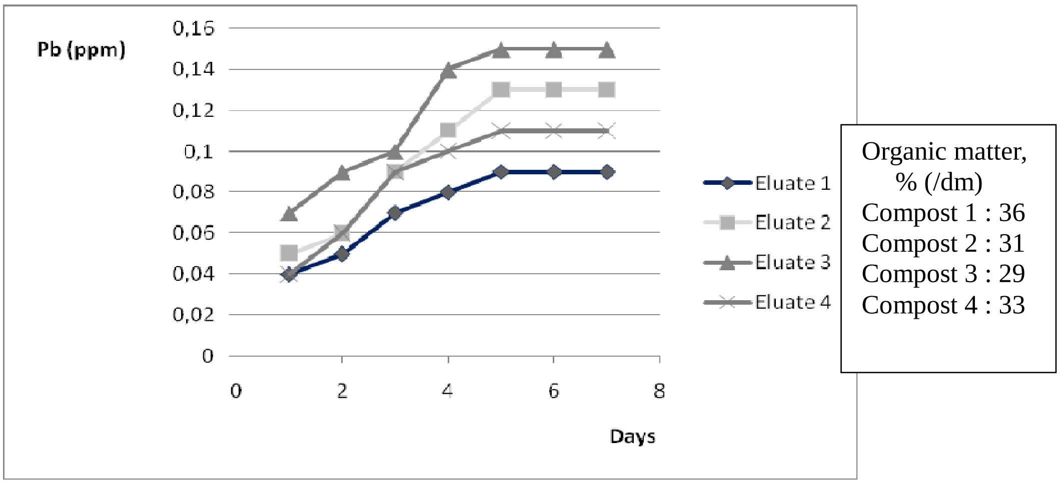

Figure 2: Extraction of Pb with EDTA (0,05M) pH=7.

DISCUSSION

Moisture content

The moisture content varies according to the category. Water is necessary for the microorganisms. Its content determines the start of the composting process and the creation of a favorable course of biological processes biotope. The decomposition of organic matter is not inhibited in dry and rainy season due to the high moisture content.

Metals in the waste of Lomé

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 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 the sulfur which allowed to identify proteins “which precipitate heavily” or easily give salts. On the other hand, both metals also have some physico-chemical characteristics:

- they do not destroy themselves, although they transport themselves or change their chemicals shape;

- they have a high electric conductivity, which explains their use in numerous industries;
- but especially, they present certain human toxicity, entailing in particular more or less grave neurological hurts, whereas all the others have a given utility in determined biological process;
- they are only toxic elements;

Proportion of metals brought by each category

The superfine and fine fractions represent an average of 50% in the dry season against 59% in the wet season. The rate of organics decreases during the wet season, possibly due to a change in food and to onset of waste degradation in the transfer site into fine elements. Informal waste recycling is carried out in order to generate income and at times contributing towards everyday survival. Waste collectors often go from door to door to collect sorted dry recyclable materials, such as metals, from householders. The Misc. C component is constituted for the greater part by charcoal, as the majority of households use only wood or charcoal as a source of heat for cooking.

Super fines provide the highest metals contents varying from 33% to 56 ± 2%. In the case of Ni, this category evolves as 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 (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.

The valorization of raw waste through composting directly on the dumping site features a considerable drawback: the high percentage of minerals (sand and gravel). Mixed municipal solid waste may contain heavy metals, although featuring a low content in the organic fraction. Thus, contamination can largely be avoided by separating the organic waste from other residues prior to composting.

Metals contents in compost

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; Koledzi et al., 2011c), and therefore in households waste. The city of Lomé is located on a sandy soil and households’ keepers have a few knowledge of the waste management. Household wastes are put down at first on the ground before being swept thus bringing 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 thus the speciation of metals were realized to determine the potential of release of the element 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 the pollution susceptible to be remobilized and transferred to plants in short or medium-term.

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 is 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 soil, chemical speciation of metals is depending 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 the most reactive form, with the neutral species, because more easily assimilated by the alive organisms (Lai et al., 2010). This metal (Ni, Cu, Zn, Pb, Cd) speciation is also dependent on a large number of physical parameters (temperature, pressure) and chemical ones (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 have to be led in this frame. So, that allows 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. 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 will also be helpful for and conceiving effective programs. It will provide the necessary arguments to convince the populations to subscribe to programs of management of specific waste as for example, the elimination of super fines in the waste in the case of Lomé.

So, 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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The French associations Gevalor and GoodPlanet are carrying out a project called "Africompost", which started in 2011. It is founded by the French AFD and FFEM and aims at supporting the development of already operational composting units to generate good quality compost and selling carbon credits thus generated by reduction of methane emissions from landfill disposed waste. Another target is to empower the local project partners. The project shall provide environmental and economic as well as social benefits by generating around one hundred new workplaces for persons with a low education level.

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