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AGRONOMIC POTENTIAL VALUE OF HOUSEHOLD URBAN SOLID WASTES BY COMPOSTING AND COMPOSTS QUALITY ASSESSMENT

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Abstract

Using composting technology, the biodegradable fraction of solid wastes collected from Agbalepedogan district in Lomé (Togo) was transformed into composts with no phytotoxicity suitable for use in agriculture. The household urban solid wastes were mixed with poultry manure and *Mucuna pruriens* leaves in appropriate percentages and transformed into composts. The composting process was monitored by temperature, pH and C/N ratio controlling. The composts quality was appreciated by phytotoxicity test, particle size distribution, contents of nitrogen, phosphorus, potassium, organic matter and trace elements. The results showed that composts particle size distribution presented four fractions (>10 mm, 5-10 mm, 2-5 mm and ≤2 mm) whose average percentages are respectively 9.04±0.2%; 10.71±0.2%; 12.68±0.4% and 67.53±0.6%, respectively. Composts produced contained 1.02±0.1% - 2.72±0.2% of nitrogen, 1.35±0.3% - 2.70±0.4% of phosphorus, 1.31±0.2% - 1.72±0.3% of potassium and 23.50±0.4% - 37.75±0.5% of organic matter. The pH in final composts were between 8.50±0.2 and 9.00±0.3 while C/N ratio varying from 8.06±0.2 to 13.13±0.2. The concentrations of some heavy metals in final products were 79.8±1.7 - 140.2±1.6 mg/kg.dm of zinc, 27.1±1.01 - 76.6±1.03 mg/kg.dm of copper, 2.07±0.33 - 9.19±0.22 mg/kg.dm of lead, 4.13±0.16 - 11.05±0.36 mg/kg.dm of nickel and 0.79±0.02 - 2.15±0.03 mg/kg.dm of cadmium. These concentrations were lower than the limited value for heavy metals prescribed by French and US EPA regulation for organic and organic-mineral fertilizers.

Keywords: Household Solid Waste, Poultry Manure, *Mucuna pruriens*, Composting, Composts Quality.

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Introduction

The production of urban solid waste is increasing in quantity and diversity in African developing countries and generates huge risks on the environment and the health of populations. The generation of household solid waste has been increasing in Lome, capital of Togo in West Africa, mainly driven by growing global population, urbanization and economic growth, coupled with changing activities and consumption behavior (Koledzi, 2011). A household urban waste is defined as a material whose economic value is zero or negative. In order to secure the ecological balance and an adequate living quality for the human society also in the future, it is more than ever before necessary to manage these wastes, utilize them to the extent possible to save primary resources. Waste management is a major challenge for any society. It contributes to sustained economic activity and enhances public welfare. In recent years, the research showed that, many wastes produced in important quantities may be transformed into an organic fertilizer by composting. Land application of compost obtained from municipal waste is one of the most economical and attractive methods of solving two problems in the developing countries: waste disposal and soil infertility. Therefore, composting is more suitable technology for waste management in developing countries. Compost consists of the relatively stable decomposed organic materials resulting from the accelerated biological degradation of organic materials under controlled and aerobic conditions. Many studies (Ouédraogo *et al.*, 2001; Caravaca *et al.*, 2003; Gamal, 2009) have shown that application of mature composts at reasonable rates improves soil physical properties, increases available soil nutrient levels and plant growth.

The aim of this study is to assess the agronomic potential value of biodegradable fraction of household urban solid waste collected from Agbalepedogan district in Lome (Togo) by composting, as well as to evaluate the quality of the final product composts.

Materials and Methods

The composting took place at a large-scale composting platform of the Non Governmental Organization: Clean Natural Ecosystem (ENPRO) situated in Lome (6°10'N, 1°11'E; with altitude comprises between 19 and 60 m). The household urban solid wastes collected from one district of Lome called Agbalepedogan were transferred to clean area and physically segregated into different inorganic and organic components (Fig. 1). They were sorted by the following categories: biodegradable fraction (wood and wood products, pulp, paper and cardboard, food, food waste, textiles, garden, yard and park waste) and no biodegradable fraction (glass, plastic, metal and other inert waste; fine and sand).

Fig. 1. Physical segregation of household urban solid wastes into different inorganic and organic components.

The urban solid waste biodegradable fraction characterized by high organic carbon and low nitrogen contents, is co-composted with poultry manure and *Mucuna pruriens* leaves. Four combinations of waste with poultry manure and *M. pruriens* leaves were formulated. In fact, five constructed windrows were carried out in five replicates, one for each combination and a control set with only household urban solid waste as follow:

- Windrow 1: control set composed only household urban solid waste (100%),
- Windrow 2: mixture of household urban solid waste (85%) and poultry manure (15%),
- Windrow 3: mixture of household urban solid waste (70%) and poultry manure (30%),
- Windrow 4: mixture of household urban solid waste (85%) and *M. pruriens* leaves (15%),
- Windrow 5: mixture of household urban solid waste (70%) and *M. pruriens* leaves (30%).

The windrows produced respectively compost C_{W100}, compost C_{W85P15}, compost C_{W70P30}, compost C_{W85M15} and compost C_{W70M30}.

Composting operation

The windrows had triangular shape with 1.5 m wide of the base and 1.0 - 1.5 m high (Fig. 2). The windrows were turned using a loading shovel twice a week for the first 10 weeks (Fig. 3) and then, the material was allowed to mature for a period of 3 weeks with no turning. A representative sample of approximately 500 g was taken once a week after turning. The sample was a composite made up from 10 grab subsamples taken along the length on the windrow. The samples were screened through a 10 mm sieve and kept refrigerated for physico-chemical analysis. The moisture was kept at 45 - 50% by adding water. The temperature was monitored daily using mercury thermometers placed near the centre of the pile at six different points along its length and the average of all measurements was recorded. Other parameters controlling are pH and C/N ratio. The composting process involved three phases: pilling (Fig. 2), compost maturation (Fig. 3) and compost screening (Fig. 4).

Fig. 2. Triangular shape of windrows with 1.5 m wide of the base and 1.0 - 1.5 m high.

Fig. 3. Aeration of windrow by turning.

Fig. 4. Matured compost screening.

Composts quality characterization

Physical characterization of compost: determination of particle size distribution

The distribution of compost particle size was measured. The compost samples were dried at 40°C up to one hour and sieved to >10 mm, 5-10 mm, 2-5 mm, and ≤ 2 mm.

Chemical characterization of composts

Composts obtained were analyzed in laboratory. The pH was determined at the start until end of composting process. The sample was taken from control and experimental windrows. Each sample was mixed with water in 1:10 to make solution. The prepared solutions were left for 2 hours so that the maximum salts can be dissolved. The pH electrode was dipped in each sample prepared solution and readings were recorded when it was stabilized (Ameen *et al.*, 2016). The amount of organic carbon content was determined following the wet oxidation method of Walkley and Black (Schnitzer, 1982) while organic matter was obtained using a conversion factor by multiplying the organic carbon content by 1.724 (Sleutel *et al.*, 2007; Luske and Van der Kamp, 2009). The dried material was analyzed to assess nitrogen, phosphorus and potassium contents. The total nitrogen content was determined by distillation of the Kjeldahl method (Bremner and Mulvaney, 1982) after mineralization. The available phosphorus content was analyzed using 0.5 M sodium bicarbonate extraction solution (pH = 8.5) following the method of Olsen *et al.* (1954). Exchangeable potassium was extracted using ammonium acetate and thereafter determined by flame photometer (Agbede *et al.*, 2008). The heavy metals: zinc (Zn), copper (Cu), lead (Pb), nickel (Ni) and cadmium (Cd) were determined by Atomic Absorption Spectrophotometer (AAS) after extracting in acid conditions (HCl/HNO = 3:1) (Meller *et al.*, 2015; Khan *et al.*, 2016).

Phytotoxicity test of compost

The phytotoxicity test through germination bioassay test is a simple and reliable indicator of compost maturity. The germination test in this study was conducted on *Zea mays* and *Vigna unguiculata* using 100% sand, 100% compost and their mixture at mixing ratios of 75% sand + 25% compost and 25% sand + 75% compost. These crops were selected for their biological standardization in highly sensitive seeds, rapid and easy germination (Koledzi, 2011). Three seeds of each culture were sowed in jugs filled each with 2 kg of sand, 2 kg of compost and 2 kg of each mixture. Four jugs filled with 100% sand were tested as a control. Germination bioassay was conducted in a complete randomized design with four replications and the mean values were separated on the basis of Duncan Multiple Range Test (DMRT) at a probability level of 0.05. The number of germinated seeds was evaluated during 4 to 7 days after sowing. The phytotoxicity of composts was assessed through germination rate (GR) calculated based on the following equation:

$$GR(\%) = \frac{ANGS}{NSS} \times 100$$

Where,

ANGS represents the average number of germinated seeds and NSS is number of seeds sowed.

Data handling

The results were statistically subjected to Analysis of Variance (ANOVA) using SAS software version 9.2, 2nd edition of 2010. The means separation was performed using the Duncan significance test at $P<0.05$ level.

Results and Discussion

Physical characteristics of composts

Five different composts were obtained. They presented brown color and soil odor (Fig. 5). Their particle size varied between ≤ 2 mm and >10 mm (Table 1).

Table 1. Composts particle size distribution (%).

Fractions	Cw100	Cw85P15	Cw70P30	Cw85M15	Cw70M30	Average
> 10 mm	10.98±0.03	11.02±0.2	8.20±0.2	8.00±0.2	7.00±0.1	9.04±0.2
5-10 mm	10.10±0.02	10.25±0.3	10.00±0.4	11.28±0.5	11.92±0.3	10.71±0.2
2 - 5 mm	13.40±0.03	10.62±0.4	12.60±0.5	13.71±0.5	13.09±0.4	12.68±0.4
≤ 2 mm	65.50±0.06	68.09±0.6	69.10±0.7	67.00±0.5	67.98±0.4	67.53±0.6

The composts obtained have four particle size fractions (> 10 mm, 5-10 mm, 2-5 mm and ≤ 2 mm) (Table 1). It is observed that the particles of size ≤ 2 mm constitute the important fraction (67.53%) regardless of the type of composts. The high content of fine particles can be explained by the high levels of fine municipal solid waste and the decomposition process. The similar results was observed by Compaoré *et al.* (2010) and Charnay (2005) on compost of solid municipal wastes.

Different types of composts enriched some with poultry manure and others with leaves of *M. pruriens* had the highest proportions in fine elements because of the nature of these substrates quickly decomposable into fine elements. In general, all the composts obtained have of better quality because the average refusal part is around 9% and the proportions of fine particles are higher than 60% (Compaoré and Nanéma, 2010).

Fig. 5. a. Standard Compost C_{W100} (produced by 100% household waste); b. compost C_{W85M15} (produced by 85% household waste and 15% *M. pruriens* leaves); c. compost C_{W85P15} (produced by 85% household wastes and 15% poultry manure); d. compost C_{W70P30} (produced by 70% household waste and 30% poultry manure); e. compost C_{W70M30} (produced by 70% household waste 30% and *M. pruriens* leaves).

Daily temperature recorded during composting process showed clearly two commonly-seen composting phases: the mesophilic phase with temperature below 45°C and the thermophilic phase where temperature increases more than 45°C. Present results were similar to those reported by (Koledzi *et al.*, 2011; Bazrafshan *et al.*, 2016). A possible reason for this effect may be that: when composting begins, the mesophilic flora (microorganisms able to grow in the 25° to 45°C temperature range) predominate and are responsible for most of the metabolic activity that occurs. This increases the temperature of the composting materials and the mesophilic populations are replaced by thermophilic species, those that thrive at temperatures above 45°C. This rise in temperature is influenced to a great extent by oxygen availability. Windrows kept for the most part aerobic reach temperatures up to 70°C and produce few objectionable odors. The data related to the effect of temperature on the composting process indicate that optimum decomposition takes place between 55 and 70°C.
The presence of more easily biodegradable compounds in windrows of *M. pruriens* leaves and poultry manure could explain the difference showed in the thermophilic phase during. In fact, organic matter degradation was greater in windrows in the mixture with *M. pruriens* leaves and poultry manure which may be explained by the longer thermophilic phase for these windrows. The temperature was maintained between 60 and 70°C for about 60 days, which will contribute to the transformation of highly polymerized substrate (lignin and cellulose) by thermophilic microorganisms and to the hygienization of the end product (compost) due to pathogen, weed and seed reduction. When the temperature started to decrease, the windrows were turned in order to improve the homogeneity of the fermentation process. The thermophilic phase lasted approximately 80 days for mixtures waste + *M. pruriens* leaves and waste + poultry manure, respectively. The bio-oxidative phase of composting was considered finished when the temperature of the windrows was stable and close to that of the atmosphere. This occurred after 120 and 130 days in waste + *M. pruriens* leaves and waste + poultry manure, respectively.

Chemical characteristics of composts

Composts analyzed shown nitrogen content varying from 1.02 to 2.72%, phosphorus content varying from 1.35 to 2.70%, potassium content varying from 1.31 to 1.72%, organic carbon content varying from 13.40 to 21.95% and organic matter content varying from 23.5 to 37.75% (Table 2). The nutrient contents of studied composts were comparable to those determined by Compaoré *et al.* (2010) and can be used as fertilizer. Composts maturity is often assessed by the C/N ratio. It has been established that a C/N ratio between 10 and 15 corresponds to mature compost (Namkoong *et al.*, 1999). The averages C/N ratios determined in this study were comprised between 8.06 and 13.13 indicating that the composts would be mature (Table 2).

Maturity is a term used to specify the level of phytotoxic substance in compost samples and compost appropriateness for plant growth (Brewer and Sullivan, 2003; Aslam *et al.*, 2008). The pH in final products were between 8.50 and 9.00 (Table 2).

Table 2. Compost chemical characteristics.

Types of composts	pH-H_2O	% OM	% C. Org.	% N tot.	C/N	% P_2O_5	% K_2O
C_{W100}	8.50±0.2b	23.50±0.4	13.40±0.5c	1.02±0.1c	13.13±0.2a	1.35±0.3b	1.40±0.6a
C_{W85P15}	8.84±0.2ab	30.10±0.3	17.50±0.3b	1.90±0.2b	9.21±0.3b	2.31±0.1a	1.31±0.2a
C_{W70P30}	8.98±0.3a	34.19±0.3	19.88±0.3b	2.51±0.3a	8.28±0.3c	2.60±0.3a	1.72±0.3a
C_{W85M15}	8.90±0.2ab	34.17±0.4	19.87±0.2b	2.00±0.3b	9.93±0.2b	2.50±0.2a	1.60±0.3a
C_{W70M30}	9.00±0.3a	37.75±0.5	21.95±0.3a	2.72±0.2a	8.06±0.2c	2.70±0.4a	1.65±0.2a
CV (%)	3.00	-	2.10	15.20	3.70	8.40	22.90
PPDS $_{5\%}$	0.43	-	0.62	0.53	0.59	0.43	0.64

The values of the same column assigned to the same index of letters are statistically identical to the threshold of 5%.

Organic matter evolution

The organic matter content in windrows decreased during the composting process, showing the removal of organic matter through microbial activity. The loss of organic matter in the finished product is a result of the biodegradation by microorganisms during the fermentation process. At the beginning of composting, the C/N ratio increased. This increase would be the consequence of the leaching of nitrogen through the liquid phase. Organic matter degradation was more important in the mixtures: waste (70%) + poultry manure (30%) and waste (70%) + *M. pruriens* leaves (30%), which may be due to the longer thermophilic phase for these windrows. According to Paredes *et al.* (2000), this fact can be explained by the higher content of easily degradable organic compounds provided by poultry manure and *M. pruriens* leaves.

The difference between composts can be attributed to the higher content of easily degradable organic compounds provided by poultry manure and *M. pruriens* leaves. Organic matter decomposition bring about an increase in pH, as recorded by Paredes *et al.* (2000), which was explained as a consequence of the degradation of acid-type compounds, such as carboxylic and phenolic groups, the mineralization of compounds, such as proteins, amino acids and peptides, to ammonia and the relative increased concentration of ions, due to the loss of windrows weight. This fact was observed in the higher pH of composts.

Evolution of pH values during the composting process

At the beginning of the composting process, the samples of composts showed (Fig. 6) an acidic pH as a result of organic acids being released from biodegradation of polycarbohydrates (Iglesias and Perez, 1991). During the composting process all samples showed (Fig. 6) continuous increase of pH values as a result of biodegradation of organic acids (Iglesias and Perez, 1991) and biodegradation of organic matter containing nitrogen (proteins, amino acids etc.) leading to formation of amines and ammonia salts through mineralization of organic nitrogen (Dumitrescu *et al.*, 2009). Changes in the pH through time are a function of the fluctuating alkalinity during the composting process (Komilis and Ham, 2006). All composts recorded a pH above 8.5 which can induce the volatilization loss of ammonia as the acid/base equilibrium shifts from NH_4^+ to NH_3 (pKa = 9.2) (Fadiran and Dube, 2009). A pH of 6.3 - 9.0 supports good microbial activity during composting. Usually pH is a factor which is very relevant for controlling N-losses by ammonia volatilization, which can be particularly high at pH >7.5 (De Bertoldi *et al.*, 1983). The results of control and experimental windrows in term of pH value were almost same. All windrows showed alkaline pH throughout the composting process, in the range of 8.5 to 9.0. The alkaline pH is important parameter to evaluate compost maturity and stability. The acidic pH affects the rate of respiration of microbes and decreases the rate of degradation. The pH of the compost should be alkaline throughout and end of the composting process. The high activity of microbes at thermophilic stage is because of the alkaline pH (Sundberg *et al.*, 2004).

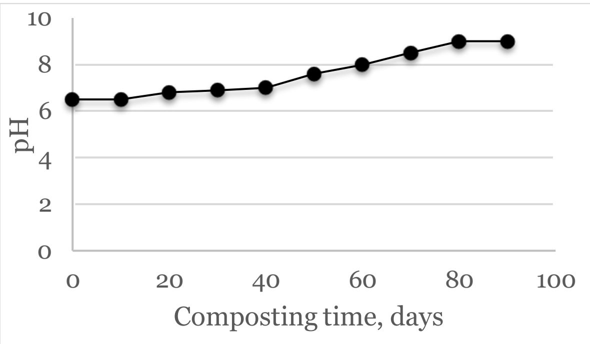

Fig. 6. pH evolution during the composting process.

Heavy metal content in final product

The concentrations of the selected heavy metals: zinc (Zn), copper (Cu), lead (Pb), nickel (Ni) and cadmium (Cd) in the compost samples are presented in Table 3. As shown in Table 3, the heavy metal contents in the final products were lower than the regulation limits prescribed by the US EPA (Bazrafshan *et al.*, 2016) for exceptional quality compost and did not exceed admissible values listed in the French Regulation (AFNOR, 2005) for organic and organic-mineral fertilizers. The zinc and copper concentrations were relatively higher than other heavy metals. Comparing the obtained results for heavy metal concentrations with those, our results were in agreement with the findings of other researchers. Many authors' papers confirm a substantial content of heavy metal in composts produced from municipal solid waste (Koledzi *et al.*, 2014; Meller *et al.*, 2015).

Table 3. Means concentrations of heavy metals in composts and standard deviations (n=5) (mg/kg.dm).

Heavy metal	C_{W100}	C_{W85P15}	C_{W70P30}	C_{W85M15}	C_{W70M30}	Limited values*	Regulation limits**
Zn	140.20±1.60	96.90±1.90	89.70±1.60	94.60±1.80	79.80±1.70	600	2800
Cu	76.60±1.03	67.40±1.10	39.20±1.02	59.80±1.03	27.10±1.01	300	1500
Pb	9.19±0.22	4.52±0.12	3.09±0.32	7.05±0.26	2.07±0.33	180	300
Ni	11.05±0.36	6.70±0.22	4.13±0.16	9.34±0.32	5.63±0.06	60	420
Cd	2.15±0.03	1.10±0.01	0.79±0.02	1.09±0.01	0.93±0.01	3	39

* *Limited value for heavy metals prescribed by French regulation (AFNOR, 2005)*
** *Regulation limits for heavy metals prescribed by the US EPA (Bazrafshan et al., 2016)*

Germination rate of maize and cowpea seeds on different composts

The five types of composts elaborated were subjected to the germination test on two crops: cowpea and maize. Table 4 shows the results of the germination test. These results show that the mixture of 25% of compost and 75% of sand provides best germination rates of 100% for maize and 93.4% for cowpea. From the mixture of 75% compost and 25% sand, resulted the germination rates of 100% for maize and 86.80% for cowpea. The germination rates of maize and cowpea seed with pure compost are respectively 59.8% and 51.2% compared to 100% for pure sand (Table 4). These germination rates comprised between 51.2% and 100% allowed to conclude that the composts studied are mature and have no phytotoxicity (Zucconi *et al.*, 1981; Toundou, 2016). In general, it is observed that germination rates of maize are slightly higher than those of cowpea (Table 4). It can be deduced that the germination rate is a function of the crop. Similar findings were made by Compaoré *et al.* (2010) with a germination test on maize and groundnuts.

According to these authors, the cereal seems to be more sensitive to high compost doses compared to the vegetables and would not be better recommendable for evaluating the phytotoxicity of composts. Compost enriched with poultry manure has germination rates ranging from 57 to 100% for maize and 45.5 to 100% for cowpea.

Table 4. Average germination rate (%) of maize (*Zea mays*) and cowpea seed (*Vigna unguiculata*) on sand, compost and mixture sand + compost.

Type of compost	Crop seed	100% Sand	75% Sand + 25% compost	25% Sand + 75% compost	100% compost
C_{W100}	Cowpea	100	100.00	100.00	54.00
	Maize	100	100.00	100.00	57.00
C_{W85P15}	Cowpea	100	100.00	67.00	34.00
	Maize	100	100.00	100.00	57.00
C_{W70P30}	Cowpea	100	67.00	100.00	57.00
	Maize	100	100.00	67.00	57.00
Average Poultry	Cowpea	100	83.50	83.50	45.50
	Maize	100	100.00	83.50	57.00
C_{W85M15}	Cowpea	100	100.00	100.00	54.00
	Maize	100	100.00	100.00	74.00
C_{W70M30}	Cowpea	100	100.00	67.00	57.00
	Maize	100	100.00	100.00	54.00
Average Mucuna	Cowpea	100	100.00	83.50	55.50
	Maize	100	100.00	100.00	64.00
Average rate	Cowpea	100	93.4.00	86.80	51.20
	Maize	100	100.00	93.40	59.8.00

On the other hand, compost enriched with leaves of *M. pruriens* has germination rates ranging from 64.00 to 100.00% for maize and 55.50 to 100.00% for cowpea (Table 4). Considering the nature of the substrates incorporated in composts, it is noted that the germination rates observed with composts containing poultry manure are slightly lower than those of composts containing the leaves of *M. pruriens*. This difference can be explained by the fact that the poultry manure contains ammoniac which would reduce the seed germination rate as already reported by Jimenez and Garcia (1989) and Tang *et al.* (2006).

Agronomic quality of the composts

The laboratory analysis to determine the agronomic quality of the final products showed mature composts with C/N ratio comprises between 8 and 13, and pH between 8.5 and 9.0 (Table 2). The pH and Electrical conductivity values for the samples of composts at the end of composting process are optimal for agricultural purposes. This is comparable to pH and electrical conductivity mean values in municipal solid waste compost reported in the literature (Mathur *et al.*, 1993; Kaseva *et al.*, 2002; Barje *et al.*, 2016). The ideal C/N ratio of mature compost is about 10, which approaches that of humus. This is the case of our products (composts). However, this value is almost never achieved because of differences in bioavailability of compost mixtures (Mathur *et al.*, 1993). This study shows that all organic fraction waste was favorable to produce a good fertilizer with no phytotoxicity, this refers to the basic elements (nitrogen, potassium, phosphorus, and organic matter) and to the rates of germination test, which should not vary in the finished product if the leaching is avoided.

Conclusion

This study has shown that, by using composting technology, it is possible to transform household urban solid wastes generated in district of Agbalepedogan in Lome mixed with poultry manure and *Mucuna pruriens* leaves in appropriate percentages into composts (organic fertilizers) with no phytotoxicity useful to improve soil fertility. It can be deduced that composting is a suitable alternative for the recycling urban solid wastes into organic fertilizers. This technology constitutes household wastes management to obtain added-value composts with future potential uses in agriculture.

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