Municipal household waste used as complement material for composting chicken manure and crop residues

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Abstract

There are few organic materials available as agricultural soil amendment because their low chemical content means that large quantities are required. In order to improve the availability of raw materials for composting, as well as the quality of the compost produced, municipal solid waste (MW) was added to cotton-seed residue (CSR) and to the association of CSR with chicken manure (M) in different weight/weight (MW/added materials) ratios of 5:1 and 2:1. Aerobic composting was processed and compost yield was determined, as well as compost particle size and pH. Also, the compost bulk density and its water holding capacity were determined as well as contents of total nitrogen, carbon, phosphorus, calcium (Ca), magnesium and heavy metals. According to its pH and carbon/nitrogen ratio values, the municipal waste of Cotonou was judged to be a good raw material for composting in order to improve availability of the organic source of nutrients. The composts produced with MW+M+CSR had the highest potential for amending Ferralsols, especially with a mixture of 2:1 (200 kg MW+100 kg M+100 kg CSR) that could be applied at 10 t ha^{-1}. However, further improvement in composting methods was suggested to increase Ca^{++} and reduce mercury contents, respectively. Moreover, potassium balance should be improved in the produced compost.

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Introduction

By 2020, the population of sub-Saharan Africa will be more than 1.1 billion people (Rose-grant *et al*., 1995). It is suspected that food insecurity, malnutrition, and resource degradation may increase. By 2020, Africa will import 50-70 million tonnes of cereals per year to meet the demands of the population (Dyson, 1996).

In the region, the growth rate in agricultural production is slower than that of the population as a consequence of a poor economic and agricultural policy (Cleaver and Donovan, 1995) as well as traditional agricultural practices that resulted in mining soils with plant nutrients (Smaling *et al.,* 1997). The loss of approximately 54 kg nitrogen (N), 20 kg phosphorus pentoxide (P_2O_5) and 56 kg potassium oxide (K_2O)/ha/year was also reported in agricultural soil of Africa (Stoorvogel and Smaling, 1990). Moreover, because of the reduction in the fallow duration induced by population growth pressure, soil fertility is no longer restored. The use of fertilizers is, therefore, recommended to ensure adequate crop production. However, most of the African farmers cannot afford mineral fertiliser, thus the use of organic fertiliser is considered as an alternative.

However, the exclusive use of organic fertiliser mainly composed of farm residues has been reported to increase food production by a maximum of 2% per year (Hiyami and Ruttan, 1985), well below the population growth rate, requiring a 5-6% increase in food production. This is due to the limited availability and to the low content of nutrients of organic fertilisers (Bekunda *et al.*, 1997). Meanwhile, there is an important quantity of municipal wastes (liquid and solid) produced in Africa (Parrot *et al.*, 2009) that is polluting the urban environment. These wastes could be used to improve agricultural soil fertility if processed through an accurate composting strategy. Adding municipal wastes to a small amount of crop residues and/or animal manures can improve the availability of organic sources of nutrients and their potential for soil amendment. In fact, crop residues and animal manure are known to be the best compost materials (Inoko, 1984) but they are not available in sufficient quantities. However, the ratio of raw materials in the mixture should be determined for the production of good compost.

The present study, conducted in Benin, West Africa, tried to use municipal waste of the city of Cotonou where only 32% of this waste is collected (Direction des Services Techniques, 2003). The objective was to increase nutrient content of the compost obtained from mixing municipal waste with farm residues and/or animal manures in different ratios in order to increase availability and efficiency of this organic source of nutrients for agricultural soil amendment.

Materials and methods

Site location

The study was carried out in Hêvié (06°26'37'' N, 02°13'50.3'' E, 35 m asl) located at 30 km north-west of Cotonou (Benin, West Africa). During the trial period (2003-2004), there was a moderate variation in air temperature of between 33°C and 23°C. The soil is a Ferralsol, with a sandy loam texture and low organic matter content. The region is located in the Sudano-Guinean climate region with two rainy seasons (from end of March to July and from late September to November) alternating with two dry seasons (from December to early March and from late July to early September).

Compost components

The compost was composed of three raw materials: i) municipal waste (MW) collected in the city of Cotonou (Benin, West Africa). It was mainly composed of household waste, domestic animal dejections, tree leaves and non-degradable materials (glasses, metals and plastic); ii) chicken manure (M) collected from the surrounding poultry farms where the chickens are essentially fed with corn flour, fish meal, oyster shell and salt; iii) cotton-seed residue (CSR) collected from the factory as a dry mixture of fibres remaining after transformation.

Compost characterisation

The composts chemical [pH, organic carbon (C), nitrogen ($_{tot}N$), phosphorus ($_{tot}P$), potassium ($_{tot}K$), sodium (Na), heavy metals] characteristics were measured at the maturity of compost. A glass pH meter was used for pH measurement in a solution at a 1:5 (compost:water) ratio. The same tool was use to determine electrical conductivity (EC) in a solution at a 1:10 (sample:water) ratio. The gravimetric moisture content was obtained by weighing a sample before and after drying in an oven at 105°C during 24 h. Compost total nitrogen (micro-Kjeldahl method), cations [Ca^{2+}, magnesium (Mg^{2+})] and heavy metal contents were determined with a spectrometer (by atomic absorption) as well as K^+ and Na^+ (by flame emission). Organic matter content in the compost was also determined by loss on ignition at 450°C as well as total phosphorus content (Duval, 1964). Water holding capacity was also estimated using 0.01 MPa, as described by Cassel and Nielsen (1982).

Composting techniques

Two strategies were used to associate the materials for composting: i) MW combined to M at the W-weight/M-weight ratios of 5:1 (C1) and 2:1 (C2); and ii) wastes MW was associated to CSR and M at the weight:weight ratios [MW/(CSR+M)] of 5:1 (C'1) and 2:1 (C'2). The 400 kg piles of compost were built on oilcloth with the raw materials in a pyramid shape, and protected from rainfall with plastic sheets. The piles for compost-C1 were composed of 220 kg and 80 kg of MW and M, respectively, while they accounted for 50% in compost-C2. In composts C'1 and C'2, equal weights (40 kg and 100 kg) of M and CSR were, respectively, mixed to MW. Each mixture of materials was randomly replicated 3 times. The mixtures are composed of alternative layers of dry organic matters (municipal wastes and chicken manure) with municipal wastes making up the top layer. These initial heaps of composts were sprayed with water up to 60% of water holding capacity of the municipal wastes during composting. The moisture of the piles was adjusted by adding approximately 10 litres of water every two weeks during periodical (weekly) turning.

Compost characterisation

Compost temperature was recorded with a thermometer that was placed toward the central part of each pile every two days during the 86 days of the process; 500 g of compost was sampled periodically (0, 2, 4, 6, 8, 10 weeks) from each pile for laboratory analysis during the compost processing time (14 weeks). At maturity, the total quantity of compost from each pile was weighed.

The relative variation in chemical parameters (pH, $_{org}C$, $_{tot}N$, C/N) during the composting process was calculated using the following equations:

$$Y = 100\,(X_{2weeks} - X_{14weeks})\,/\,X_{2weeks} \quad (1)$$

where

$$X = (pH,\ _{org}C,\ _{tot}N \text{ or } C/N) \quad (2)$$

Statistical analysis

The compost chemical characteristics were subjected to analysis of variance and means were compared using Student-Newman-Keuls test. The statistical analyses were performed using the SAS package (SAS Institute Inc., Cary, NC, USA).

Results

Chemical characteristics of raw materials for composting

The municipal waste had significantly ($P<0.05$) lower content of organic-C, total-N, Mg, K, total-P and moderate content of Ca than the other materials (Table 1). In contrast, chicken manure had the signifi-

Table 1. Chemical characteristics of raw materials used for composting.

Raw materials	Chemical characteristics							
	Water pH	C (%)	N (%)	Ca (%)	Mg (%)	K (%)	P (%)	C/N
Municipal waste	7.50[b]	20.37[c]	0.84[c]	3.76[b]	0.49[c]	0.75[c]	0.15[c]	24.3
Chicken manure	8.86[a]	23.68[b]	2.11[a]	6.75[a]	1.37[a]	2.47[a]	2.00[a]	11.2
Cotton seed residue	6.91[c]	55.21[a]	1.73[b]	1.43[c]	0.85[b]	1.89[b]	1.09[b]	31.9
CV (%)	0.46	0.45	8.00	4.00	2.60	3.50	2.92	
Pr>F	<0.001	<0.001	<0.001	<0.001	<0.002	<0.003	<0.001	

C, carbon; N, nitrogen; Ca, calcium; Mg, magnesium; K, potassium; P, phosphorus; C/N, carbon/nitrogen ratio; CV, coefficient of variation; Pr, probability; F, Fisher. [a,b,c]Means within each column followed by the same letters are not significantly different (Student-Newman-Keuls test).

cantly (P<0.05) highest contents in all the studied nutrients except for organic-C (23.68%) that was at a moderate level.

The lowest Ca (1.43%) content was observed in cotton-seed residue which had shown the highest organic-C (55.21%) content whereas moderate levels of N (1.73%), Mg (0.86%), K (1.89%) and P (1.09%) were seen compared to their respective contents in the other studied materials. Municipal waste and cotton-seed residue had almost neutral pH while chicken manure had a pH of 8.9 with the lowest ratio of C/N (11.2) compared to the high values of C/N recorded for municipal waste (24.3) and cotton-seed residue (31.9).

Effect of composting process

Sinusoidal trend of pH was observed for each of the composts (C1, C2, C'1 and C'2) whatever the mixture materials (MW, M, and CSR) and respective ratios (Figure 1). Two maximum values of pH were observed for each compost type at the 4th and 8th week of composting, respectively. All pH values fell to approximately 7-8 at the end of the process (14th week). The concentrations of organic-C was significantly higher in composts-C' (MW+M+CSR) than in the mixture of municipal waste and chicken manure (C1 and C2). But the biggest decrease in organic-C content was observed for composts-C'. It remained almost stable for composts-C, particularly from the 8th week of composting. Similar trends were observed for Total-N with no significant difference between the concentrations determined in C1 and C2 after the 8th week of composting. Two periods were observed for C/N dynamic: from study start up to the 5th week of composting and from the 5th week to the end of the process. They were characterised by significant lowest and highest values of C/N in C2, respectively. A significant decrease (negative balance) in pH values, organic-C and C/N were observed for each mixture during composting (Table 2). The highest pH values were observed for C1 (-13.94) and C'2 (-13.73). However, a positive balance of total-N could be observed for C1 (+9.40) and C'2 (+12.17).

Physical and chemical characteristics of the compost

There was a significant difference in sand and ash contents according to compost natures and ratios. The composts had similar yields, and no significant difference was observed in bulk density or water holding capacity between the different ratios for the same material (Table 3). However, the significant (P<0.05) highest bulk densities were observed for compost-C (C1 and C2) regardless of the mixture ratio while C'1 and C'2 had the significant (P<0.05) highest water holding capacity. Most of the studied chemical elements [Mg, K, C, N, Na, manganese (Mn), zinc (Zn) and iron (Fe)] including lead (Pb) (186.4 ppm) had the significant highest concentration in C'1 (Table 4). On the contrary, this compost had low contents of mercury (Hg) and cadmium (Cd) contrasting with C'2 which had the highest content of Cd (0.4 ppm).

Table 2. Relative variation in chemical parameters during composting process.

Treatment	Relative variation (%)			
	Water pH	$_{org}$C	$_{tot}$N	C/N
C1	-13.94	-15.01	+9.40	-22.46
C2	-10.99	-15.84	-8.43	-8.17
C'1	-8.21	-32.81	-3.34	-30.49
C'2	-13.73	-23.81	+12.17	-32.08
	Initial (2 weeks) values (%)			
C1	7.6	15.15	13.04	11.70
C2	7.64	16.85	13.58	12.48
C'1	7.79	25.12	23.76	10.60
C'2	7.98	27.33	25.65	10.82

$_{org}$C, organic carbon; $_{tot}$N, total nitrogen; C/N, carbon/nitrogen ratio; C1, municipal solid waste+chicken manure; C2, municipal solid waste+chicken manure; C'1, municipal solid waste+cotton seed residue+chicken manure; C'2, municipal solid waste+cotton seed residue+chicken manure.

Table 3. Effect of component's ratio on the physical characteristics of the compost.

Compost	Ratio	Physical characteristics				
		Bulk density (t/m^{-3})	Compost yield (%)	Water holding capacity (%)	Sand (%)	Ash (%)
C	C1:5/1	0.84^{a}	45.33^{a}	68.63^{c}	70.90^{a}	2.5^{b}
	C2:2/1	0.82^{a}	51.17^{a}	85.97^{bc}	63.28^{c}	4.83^{a}
C'	C'1:5/1	0.69^{b}	50.67^{a}	133ba	66.37^{b}	3.10^{b}
	C'2:2/1	0.62^{b}	49.67^{a}	178.07^{a}	61.45^{d}	5.40^{a}
CV	4.94	9.46	20.32	1.21	8.70	
Pr>F	0.009	0.462	0.004	<0.001	<0.001	

C, carbon; C1, municipal solid waste+chicken manure; waste/manure (W/M) ratio of 5/1; C2, municipal solid waste+chicken manure; W/M ratio of 2/1; C'1, municipal solid waste+cotton seed residue+chicken manure; waste+cotton seed/manure (W+C/M) ratio of 5/1; C'2, municipal solid waste+cotton seed residue+chicken manure; (W+C/M) ratio of 2/1; CV, coefficient of variation; Pr, probability; F, Fisher. [a,b,c,d]Means within each column followed by the same letters are not significantly different (P<0.05).

Discussion

Choice of suitable material for composting

In addition to the obvious physical difference of the raw materials used, they also differed in chemical element composition. Although MW had a lower organic content (20.73%), its pH (7.5) and C/N (24.3) ratio appear to be suitable for compost production (Saskatchewa, 2008) when compared to chicken manure. But chicken manure was richer in chemical elements (Table 1) and is considered to be the best raw material for composting according to many studies, including that of Inoko (1984). This comparison supports our arguments for recommending municipal wastes collected in Cotonou for compost production as justified by its pH and C:N ratio values. Food wastes (*i.e.* corn, cassava, yam, cowpea, rice), which are the components of household wastes, are among the most biodegradable materials possessing large amounts of heterogeneous organic substrates, including sugars (as sucrose), fats, proteins, hemicelluloses, celluloses, and lignin (Eklind *et al.,* 1997; Ryckeboer *et al.,* 2003) contributing to raising the C/N ratio.

On the other hand, the municipal waste had poor (C, N, Mg, K and P) and moderate (Ca^{++}) nutrient contents compared to M and CSR. The content of organic-C was further reduced in the mixture (compost-C) of municipal waste and chicken manure whereas it significantly increased as a result of the addition of CSR (compost-C’), especially for C’2. The highest initial contents of Ca^{++} in raw materials of compost-C associated to carbohydrate mineralisation (Inoko, 1984) could have induced the significant increase in Ca^{++} content in this compost.

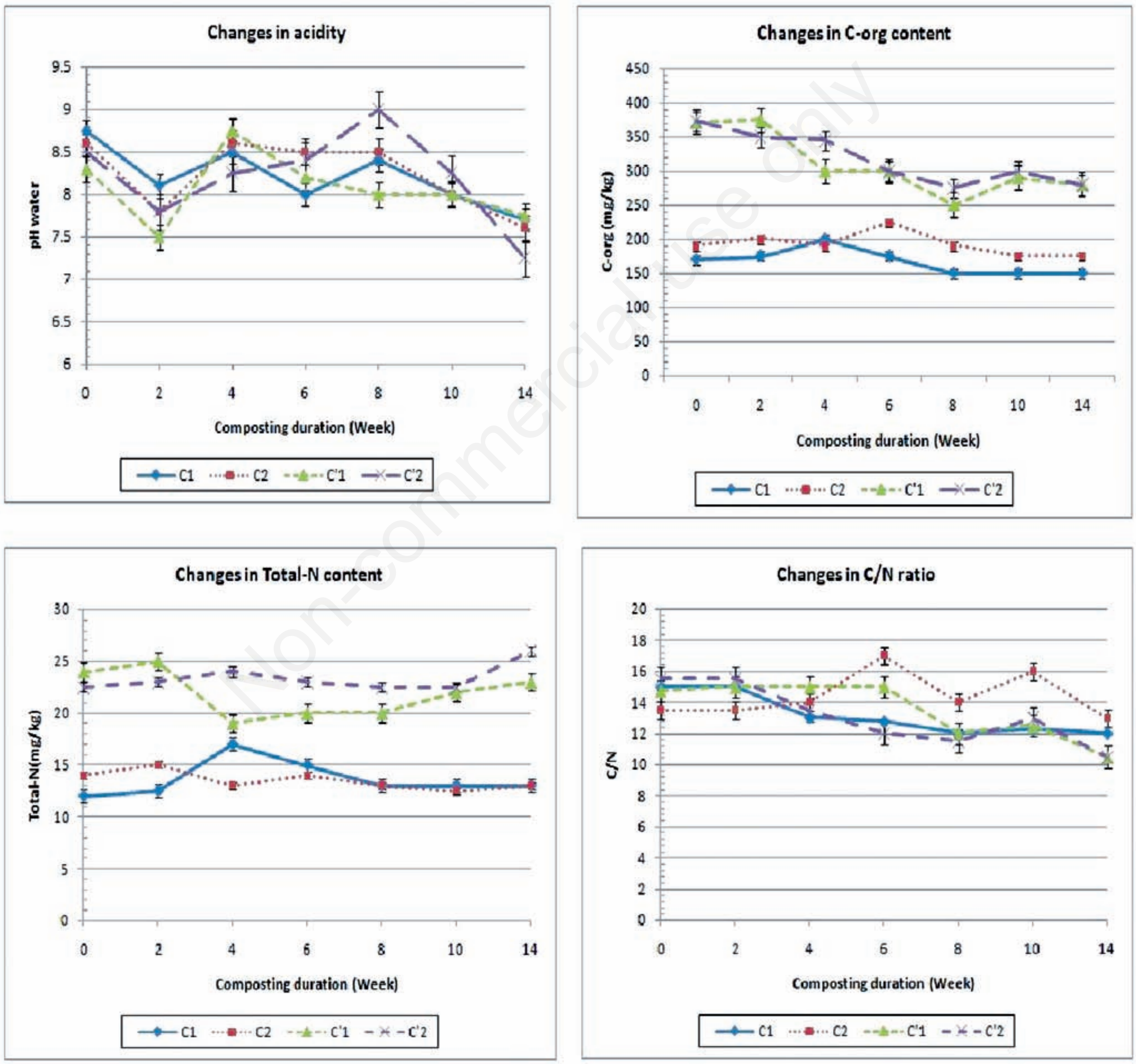

Figure 1. Changes in composts [municipal solid waste+chicken manure (C1), municipal solid waste+chicken manure (C2), municipal solid waste+cotton seed residue+chicken manure (C’1), and municipal solid waste+cotton seed residue+chicken manure (C’2)] pH and carbon/nitrogen (C/N) ratio as well as their contents of C and total-N.

Table 4. Influence of component's ratios on nutrients and trace elements contents of municipal sewage compost.

Parameters	Composts				CV	Pr>F
	W+M (C)		W+M+CSR (C')			
	C1: 5/1	C2: 2/1	C'1: 5/1	C'2: 2/1		
Characteristics						
pH water (1:10)	7.47^a	7.54^a	7.71^a	7.35^a	3.52	0.47
EC1:5 (mS/cm)	2.48^b	2.70^b	2.89^b	4.53^a	7.35	<0.001
C (‰)	150.6^b	167^b	248.2^b	271.4^a	12.31	0.003
C/N	11.5	12.4	10.5	10.5	-	-
Macronutrients						
Ca (%)	17.67^b	25.39^a	13.81^c	14.70^c	7.31	0.001
Mg (%)	1.18^c	1.84^b	2.65^a	1.43^{bc}	12.51	0.009
K (%)	7.0^b	8.6^b	15.1^a	14.5^a	18.50	0.007
P (‰)	4.14^b	6.02^a	5.65^{ab}	5.04^{ab}	12.17	0.044
N (‰)	13.13^b	13.50^b	23.73^a	25.77^a	19.32	0.010
Na (ppm)	1070^b	1070^b	2970^a	2400^a	26.35	0.007
Heavy metals						
Mn (ppm)	912.7^a	908.3^a	1367^a	1244^a	24.41	0.185
Zn (ppm)	118.6^b	122.3^b	229.6^a	156.1^b	21.23	0.021
Fe (ppm)	2273.8^a	1606.6^a	2230.7^a	1953.9^a	19.05	0.227
Hg (ppm)	1.26^a	0^b	0^b	0^b	8.71	<0.001
Pb (ppm)	38.15^b	49.6^b	186.4	43.5^b	30.36	<0.007
Cd (ppm)	0^b	0^b	0^b	0.4^a	9.38	<0.001

CV, coefficient of variation; Pr, probability; F, Fisher; W, municipal solid waste; M, chicken manure; C, carbon; CSR, cotton seed residue; C1, municipal solid waste+chicken manure; W/M ratio of 5/1; C2, municipal solid waste+chicken manure; W/M ratio of 2/1; C'1, municipal solid waste+cotton seed residue+chicken manure; W+C/M ratio of 5/1; C'2, municipal solid waste+cotton seed residue+chicken manure; W+C/M ratio of 2/1; EC, electrical conductivity; C/N, carbon/nitrogen ratio; Ca, calcium; Mg, magnesium; K, potassium; P, phosphorus; N, nitrogen; Na, sodium; Mn, manganese; Zn, zinc; Fe, iron; Hg, mercury; Pb, lead; Cd, cadmium. [a,b,c]Means within each line followed by the same letters are not significantly different (α=0.05).

Meanwhile, the significant highest values of Mg^{++}, K^+, N, and Na^+ in compost-C' were mainly consecutive to organic matter decomposition by the activity of microorganisms and humid mineralisation occurring during the composting process (Chabbey, 1993). This is supported by the highest values of negative organic-C balance observed for compost C' (Table 2). Therefore, the intensity of the microorganisms' activity and mineralisation process in respective mixtures are presumed to have induced a significant difference between mean values of chemical components of composts.

The characteristics determined for matured composts-C'1 and C'2 confirmed that municipal wastes can be used to improve soil water holding capacity and its nutrient contents when associated with M and CSR. But they have limited potential to improve soil Ca^{++} balance as required in highly weathered acid Ferralsols (Sawyer, 2004) when compared to composts-C (C1 and C2). Further improvement in composts-C' content of Ca^{++}, N and P contents may be obtained by adding Ca-fertiliser to the mixture, as has been reported by Arifin *et al.* (2006).

Changes induced by composting

The highest loss of carbon during the composting process was observed when adding CSR to the other raw material (C'1 and C'2) (Table 2 and Figure 1). This can be explained by the increase in the microorganism population utilising organic compound for their feed and energy. Predominance of fungi and actinomycetes during the thermophilic phase of composting will produce hydrolytic enzymes, depolymerising numerous resistant organic compounds (*i.e.* lignin, cellulose and hemicellulose) to smaller fragments that are water-soluble (Tiquia *et al.,* 2002). Thereafter, these compounds will be rapidly oxidised to CO_2 that can be lost (volatilisation). The loss of organic-C during composting (Figure 1) has resulted in the compost's enrichment in inorganic elements (nutrients and heavy metals) (Table 4). The mineralisation process that could have occurred at the end of the thermophilic (45-70°C) phase (Baca *et al.,* 1992) can also significantly contribute to this at the expense of the humification process. The intensity of this process could have increased during the subsequent mesophilic (30-45°C) phase because of high density and diversity of the microbial population (Taiwo and Oso, 2003). Similar processes can also explain the reduction in total-N during composting. The hydrolysation of the organic-N into ammonium further oxidised into nitrate which is susceptible to volatilisation has been regularly reported (He *et al.,* 2000; Veeken *et al.,* 2002, Bognonkpe, 2009). However, an increase in total-N content was also observed (C1 and C'2) as a result of the immobilisation process that has previously been documented for CSR (Huang *et al.,* 2004). Our results show that this process can also occur in a compost of chicken manure depending on the ratios of mixed raw material (Table 2). In fact, the scenario of total-N increasing was observed for C1 (W+M) at 5/1 and C'2 (W+M+CSR) at 2/1. From these analyses, we recommend these composts as nitrogen sources in agricultural soils of Africa that are deficient in this nutrient for crop production (Oikeh *et al.,* 2008). Compost-C'2 had the higher potential for this purpose (Table 2) but its composting process should be longer than 14 weeks to reach the end curry stage for more maturity; this was not completed during our study of C/N dynamic (Figure 1). Meanwhile, composts-C composed of W+M had reached maturity from the 8th week of the process as shown by the stability of organic-C and total-N contents as well as C/N ratio.

Except for Ca content, composts-C' (MW+M+CSR) had the highest content of the major nutrients studied, including total-K and P, but the two types of this compost had a different organic-C content: compost-C'2 had the highest organic-C content (Table 4). Three and 10 tonnes of this compost applied *per* hectare may supply 80 kg N ha^{-1} and 50 kg P ha^{-1} to soil, respectively, while only 690 kg of compost-C' can cover 100 kg of K requirement in soil. Therefore, 10 t/ha of compost-C'2 can compensate the annual loss of N, P and K (54 kg N, 20 kg P_2O_5 and 56 kg K_2O/ha/year) in the soil of sub-Saharan Africa including the Ferralsols as determined by Stoorvogel and Smaling (1990). Furthermore, this rate of compost-C'2 can supply enough P and K for cereal crop production during 2-3 cropping periods. However, the high content of K can affect nutrient balance inducing some antagonistic effects, especially with Mg and N (Gibson *et al.,* 2001). This threat can probably be averted by reducing the amount (< 200 kg) of CSR in compost-C'2. All the composts produced had an acceptable heavy metal content according to the standard levels recommended by the United States Environment Protection Agency (US EPA, 1993). However, the concentration of Hg was 10 times higher than some reported data (Kessler and Helbig, 2002). Therefore, we suspect a harmful effect of long-term application of compost-C'2 because of an accumulation of Hg, as pointed out by Saidi *et al*. (2008). In a Zn deficiency environment, applying compost-C'1 rather than C'2 would be preferable.

These analyses show that we can produce valuable compost using a limited quantity of farm residues (CSR) and chicken manure that can be completed by a relatively high amount of municipal waste. Nevertheless, further research is needed to reduce Hg content and to improve nutrient balance, especially with K.

Conclusions

Study of the potential of municipal wastes of Cotonou for composting according to their pH and C/N ratio justify the use of these materials as supplemental available raw materials for composting. The highest contents of organic-C, total-N, total-K and P were found in the composts produced by mixing MW, M and CSR. Ten tons per hectare of such compost was recommended to improve water holding capacity and nutrient contents (N, P and K) in a Ferralsols of Africa. However, further improvements in the process are still required to increase the content of Ca with improved K-balance and to reduce Hg concentration.

Therefore, our study has identified a recycling strategy for municipal wastes of Cotonou to improve soil health, crop production, and reduce farming costs and environmental pollution.

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