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Co-composting of sewage sludge and *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase plant material from a constructed wetland system treating domestic wastewater in Cameroon

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Trials were conducted at the Cité-Verte domestic wastewater treatment station (Yaoundé-Cameroon) in order to assess the effect of three sewage sludge: Macrophyte ratios on the co-composting process and compost quality. The ratios were T1: 25 kg of plant material (*Echinochloa pyramidalis*) and 75 kg sludge; T2: 50 kg of plant material and 50 kg sludge, and T3: 75 kg of plant material and 25 kg of sludge. The assessment parameters of the co-composting process included the daily evolution of temperature, the pH and water content for each month. The quality of the mature compost obtained was analysed based on their C/N ratio, Ca, Mg, P, K, trace elements and helminth eggs content. During co-composting, maximum temperatures ranged from 45.3 ± 4.7°C (T1) to 70.77 ± 2.76°C (T3). Mature co-compost was obtained after 3 months (T1), 4 months (T2) and 5 months (T3). Mean pH and C/N ratio of co-composts respectively ranged from 7.26 to 7.62 and from 10 to 15. In mature compost, the average values of organic matter, N and P respectively were 3323 ± 405 mg/kg, 165 ± 32 mg/kg and 36 ± 5 mg/kg for T1; 2945 ± 128 mg/kg, 152 ± 30 mg/kg and 27 ± 6 mg/kg for T2; and 228 ± 103 mg/kg, 105 ± 48 mg/kg and 7 ± 1 mg/kg for T3. K content was 1 mg/kg in all three co-composts. Heavy metals were found at trace levels. Helminth eggs concentration in compost was 0.2 ± 0.03 egg/g (T1), 0.1 ± 0.02 egg/g (T2) and 0.007 ± 0.01 egg/g (T3). All these co-composts did not present a significant hygienic risk with regards to WHO guidelines (2006) for safe reuse of faecal matter or faecal sewage in agriculture (less than 1 egg/g TS). For a given amount of plant harvested, it was concluded that the quickest way to produce a compost safe of parasites will be to mix them with 3/4 of sludge from the digestion tank.

Key words: Co-composting, Cameroon, compost quality, *Echinochloa pyramidalis*, hygienic risk, sewage sludge.

INTRODUCTION

All over the world, people in rural and urban areas have been using human excreta for centuries to fertilize fields and fishponds as well as to maintain or replenish the soil organic fraction, that is, the humus layer. Till date, in both agriculture and aquaculture, this practice is still common (Strauss et al., 2003; Fabián et al., 2012). Reuse activities have led to a strong economic link between urban dwellers (food consumers as well as waste producers), and urban farmers (waste recyclers and food producers). Chinese peri-urban vegetable farmers have reported that customers prefer excreta-fertilized vegetables to chemically fertilized ones (Wang, 1991). Thus, vegetables grown on excreta-conditioned soils are sold at a higher price (Wang, 1997). In developing countries, natural wastewater treatment systems in replacement of conventional systems such as activated sludge treatment systems are considered nowadays as a viable alternative (Koné et al., 2007; Kengne et al., 2008; Tanveer and Guangzhi, 2012). Meanwhile, despite their good purifying performances, these systems are most often associated to the production of important by-products (sludge scum, plants, treated water, grit refuse etc.). Some of these products such as sludge scum can constitute organic amendments for the improvement of soil fertility (Strauss et al., 2003; Whautelet, 2011). Indeed, they contain nutrients (N, P, K, etc.) required for plant growth (Olufunke et al., 2009; Luna et al., 2011; Nogueira, 2013). This particular by-product generally undergoes a finishing treatment in order to limit sanitary and environmental risks linked to its discharge and or reuse in agriculture (Blaszkow et al., 2010; Bouzid and Djadi, 2015), because the latter is generally biochemically unstable and liable to contain pathogenic organisms and heavy metals (Olufunké et al., 2009).

In Cameroon, a two stage subsurface flow (SSF) constructed wetland was set up since 2012 for the treatment of domestic wastewaters for a population equivalent of approximately 5000 at the Cite-Verte neighbourhood. The system consists of an up-flow anaerobic pre-treatment with a screen/grit removal chamber, an anaerobic settling tank, an oil removal chamber and two gravel filters. This is followed by a two-stage subsurface flow (SSF) constructed wetlands. The process produces approximately 1 ton of sludge/week, collected as scum at the level of the anaerobic settling tank, which requires careful management. Several techniques such as incineration, composting and/or co-composting have been mentioned in literature as potential procedures for sludge transformation (Moumeni and Boutekrabt, 2001; Blaszkow et al., 2010) with regards to their cost and their level of technological mastery (Olufunké et al., 2009; Koné et al., 2007). Among these techniques, composting and co-composting are the most recommended because of their low cost and easy realisation.

Many studies have reported that sewage sludge alone produces compost of poor quality due to its high moisture content and low air permeability. In addition, this sludge contains a high concentration of nitrogen. It is therefore necessary to mix with other ingredients including bulking agents such as rice straw, sawdust, grass or leaves. These bulking agents are used to adjust the C/N ratio between 25:1 to 50:1, regulate the moisture content and maintain inter-particle void dispersion, thus allowing for adequate air and water exchange within the composting mass (Petric and Selimbasic, 2008; Iqbal et al., 2010).

Maturity is an important concept that is closely related to the quality of compost. Simply put, mature compost has decomposed enough to promote plant growth. Experienced producers and users of compost often evaluate maturity using subjective indicators such as colour, smell, and feel (Kuo et al., 2004). Dark brown, earthy smelling, moist, and finely divided composts that lack sour or ammonia off-odours are expected to be of adequate maturity to promote plant growth. However, more quantitative measures are required to better enable end-users to determine the optimal rate and frequency of compost application. A good compost in terms of the physicochemical constituents include an optimal C:N ratio ranging between 10-20:1, EC (<2.0 mmo), pH (6.0-7.5), the presence or absence of contaminants like human pathogens, physical contaminants (plastics), weed seeds, heavy metals, and pesticide residues (Walker, 2001).

Besides the production of sewage sludge at the Cite-Verte station, the frequent harvesting of plant materials generate huge amounts of grass and leaves which could serve as bulking agents for the composting of sludge produced. However, the appropriate mixing ratio for the best output of the process is not yet known. Therefore, the present study was conducted to assess the effect of three plant/sludge ratios on the co-composting process and the quality of compost obtained.

MATERIALS AND METHODS

Material preparation

The experiment was conducted at the Cité-Verte wastewater treatment plant in Yaounde (Cameroon); located at latitude 3° 40'N and longitude 11°29' E, 761 m above the sea level. The treatment system is made up of a vertical flow anaerobic pre-treatment with a screen/grit removal chamber, an anaerobic settling tank, an oil removal chamber and two gravel filters. This is followed by a two-stage subsurface flow(SSF) constructed wetlands.

The study was conducted at pilot scale in order to gain scientific and technical knowledge, skills and experiences in co-composting of macrophyte *(E. pyramidalis*) and sewage sludge. Plant material

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and sewage sludge both originated from maintenance operations of the Cité- Verte wastewater treatment plant. Scum collected from pre-treatment settling tanks served as sewage sludge, while macrophytes were harvested from planted beds at the end of their life cycle (five to six months). About 2 m^3 of sewage sludge with an average total solid (TS) content of 25 to 30% was loaded on top of an unplanted drying bed and allowed to dewater for one to two weeks, depending on climatic conditions. Thereafter, harvested plant materials were manually chopped with a cutlass into small fractions of about 2 to 3 cm to increase microbial surface contact and to ease of handling.

Plant material and sludge mixing ratios for co-composting

Based on the available bulking material; three different mixing ratios (treatments) of plant material and sewage sludge were set up as follows:

1. T1: 75 kg of sludge + 25 kg of *E. pyramidalis;*
2. T2: 50 kg of sludge + 50 kg of *E. pyramidalis;*
3. T3: 25 kg of sludge + 75 kg of *E. pyramidalis*.

Three heaps were prepared per treatment by measuring a total corresponding weight of both dewatered sewage sludge and plant materials in their respective ratios. The heaps were randomly set up. These materials were thoroughly churned up with a shovel to obtain a uniform mixture. They were then heaped into windrows of about 1.10 m long, 0.7 m wide and 0.35 m high. The windrows were manually overturned periodically using shovels. Where necessary, 3 to 7 L of tap water was added when returning the heaps to adjust their moisture content to an optimum of 50 to 60% (Tiquia et al., 2002; Mckinley et al., 1986 Suler and Finstein, 1977). In order to protect the windrows from bad weather and especially favour aerobic fermentation as required by composting, they were covered with black polyethylene plastic paper on which aeration holes had been made.

Turning frequency and co-composting process

Using a shovel and a pitch fork, the heaps were turned every three days for the first 15 days. The frequency was then reduced to once a week for one month and then once every two weeks when temperature approached ambient conditions. The turning ensured that the entire compost mass was subjected to optimum conditions of aeration, temperature and moisture during composting. The high turning frequency in the early stages was to enable all parts of the heaps to be heated sufficiently for efficient pathogen inactivation and also to aerate heaps for the necessary aerobic conditions. This is because oxygen consumption is generally highest during the early stages of composting. The leaps were watered each time they were turned, except when the moisture content was enough. During each composting cycle, 2 samples were taken from the inner layer and 3 from the outer layer of the heaps and thoroughly mixed with a shovel. About 500 g of this mixture was filled into a polyethylene bag for sampling and immediately transported in an ice bag to the laboratory for analysis. The transportation time of the samples from the field to the laboratory was about 15 min. These samples were kept at -20°C before analysis.

Physicochemical and parasite characterisation of composting feedstock and compost

Assessment of co-composting process

To assess the co-composting process, samples were taken after 0, 4, 8, 12 and 16 weeks of composting and analysed in the laboratory of Biotechnology and Environment at the University of Yaoundé I. The parameters measured were temperature, moisture content and pH. The ambient temperature and specific temperatures of the different heaps were measured three times a day respectively at 8 am, 12 pm (mid-day) and 4 pm. Measurements were made at five points on the composting heaps by inserting a HANA thermometer at a depth of 40 cm into the heaps. The average temperatures of the heaps were obtained and used to verify the number of days for which the piles were subjected to temperatures above 55ºC. This served as a basis for the elimination of pathogens present in the sewage sludge (US EPA, 1984). The pH was measured in the supernatant suspension of 1:5 compost/distilled water using a Hach pH-meter model HQ11d. Moisture content was determined by weight loss upon drying 50 g of sample at 105°C in an oven for 24 h. The difference in weight was established as the water content and was used to determine the moisture fraction of the sample.

Assessment of sewage sludge, plant material and compost quality

The sewage sludge, plant material and final compost obtained were analysed in terms of their physicochemical (Carbon, TKN, Ca, Mg, P, K) and parasitological (helminth eggs) characteristics, as well as their heavy metal content (Pb, Cd, Zn, Cu, Cr and Fe). To assess the sewage sludge and compost quality, Carbon, Total Kjeldahl nitrogen (TKN), Ca, Mg, P, Na and K were analysed for their fertilizing value. TKN was assayed through wet acid digestion of 0.5 g samples followed by distillation in Bucchi K-350 distiller and back titration with H_2SO_4 0.1N. Total P was measured colorimetrically using a Hach DR. 3900 spectrophotometer. Organic matter (%) and organic carbon (%) were determined by igniting an oven dried sample overnight in a Carbolite® muffle furnace at 550°C for 6 h. Nutrient content (Ca, Mg) were determined by EDTA titration while (K, Na) were determined using a Jenway® flame photometer; these values were expressed as % dry weight.

The safety (hygienic quality) of the compost thus depended on its heavy metal and helminth eggs content. Helminth eggs were included in this safety investigation because they are extremely resistant to most of the sludge stabilization treatments. Many epidemiological studies for humans revealed a significant health risk associated to nematode eggs due to the high survival rate of helminth eggs in the environment and their low infective doses (Feachem et al., 1983). The assessment of helminth egg levels in the compost was done in compliance with the US EPA protocol (1999) modified (Schwartzbrod and Banas, 2003). Sulphuric acid extracts of the compost sample was finally used for the determination of heavy metals content (Pb, Cd, Zn, Cu, Cr and Fe) using a Hach DR. 3900 spectrophotometer.

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare mean values from different samples. The significant differences were obtained and individual means were tested using the least significance difference test ($P<0.05$).

RESULTS AND DISCUSSION

Physicochemical and microbial characteristics of composting feedstock

Chemical characteristics of sewage sludge and plant

Table 1. Nutrient, heavy metal and helminth eggs in sewage sludge and plant material (n=3).

Parameter	Sewage sludge	Plant material (*E. pyramidalis*)
Moisture (%)	63 ± 0.5	43.5 ± 0.8
TOM (%)	60.45 ± 0.11	46.22 ± 9
C (%)	30.22 ± 0.07	23.11 ± 0.001
N (%)	1.30 ± 4	0.18 ± 0.006
P (%)	0.07 ± 0.02	0.01 ± 0.001
K^+ (%)	0.02 ± 0.002	0.17 ±0,7
Ca^{2+} (%)	0.05 ± 0.003	0.01 ± 0.03
Mg^{2+}(%)	0.05 ±0.001	0.13 ± 0.009
Na^+ (%)	0.49 ±0.02	0.06 ± 0.005
C/N	23.24 ± 1.7	128.38 ± 3.8
Cd (mg/L)	5.78 ± 0.7	0
Cr (mg/L)	343.75 ± 12.4	0
Cu (mg/L)	600 ± 21	0
Fe (mg/L)	3150 ± 11	0.7 ± 0.1
Pb (mg/L)	0	0
Zn (mg/L)	175 ± 5	0
Helminth eggs (eggs /Kg) D.M.)	3770 ± 34	0

material used in the experiment are shown in Table 1. The analyses of samples (sludge, plant material) revealed average contents of essential nutrients notably organic matter, nitrogen (N), phosphorus (P), potassium (K) and exchangeable cations (Ca^{2+}, Na^+, K^+ and Mg^{2+}) which are required for plant growth. Hence, it can constitute an organic amendment for the improvement of soil fertility. Similar results were mentioned by Strauss et al*.* (2003), Olufunke et al*.* (2009) who found faecal sludge and sewage sludge to be good sources of organic matter and nutrients. The C/N ratio of sludge (23.24) was lower than suitable values for composting process, hence, do not respect the range (30-35) for required composting material as suggested by the literature (Petric and Selimbasic, 2008; Iqbal et al., 2010). It is therefore necessary to apply bulking materials with high C content like plant material. Many studies have reported that sewage sludge alone produces poor compost quality due to its high moisture content and low air permeability. It is therefore necessary to mix with other ingredients including bulking agents such as rice straw, sawdust, grass and leaves (Petric and Selimbasic, 2008; Iqbal et al., 2010).

These bulking agents are used to adjust moisture content and maintain inter-particle void dispersion, which provides adequate air and water exchange within the composting mass (Eftoda and McCartney, 2004; Petric and Selimbasic, 2008; Iqbal et al., 2010), and also provides optimal initial carbon-to-nitrogen (C/N) ratio to enhance the decomposition rate (Kalamdhad and Kazmi 2009). Hence, the plant material used in this study can constitute a good bulking agent given its high C/N ratio (128.38). The sludge-plant material mixture proved to be necessary for the reduction of the C/N ratio and the induction of biological activity in co-composting swaths. It may also result in maximum stability, highest fertilizer value, and minimum potential environmental pollution, corroborating with Ndegwa and Thomson (2000) who reported similar advantages in a C/N ratio of 25:1 for starting materials in the vermicomposting process of sewage sludge.

Heavy metal elements were also present in sludge, but their concentration was low. The concentration of helminth eggs in sewage sludge is above the French norms (NFU-44 051). Therefore, it must undergo a polishing treatment in order to limit sanitary risks linked to their discharge and or reuse in agriculture.

Effect of plant material and sludge ratio on the evolution of co-composting temperature

The evolution of temperature directly reflects the microbial activities during composting (Golueke, 1991); it may be considered as a good indicator of the bio-oxidative phase. Stentiford (1996) suggested that temperatures higher than 55°C maximised sanitation; those between 45 and 55°C maximised the biodegradation rates, and between 35 and 40°C maximised microbial diversity in the composting process. The ambient temperatures ranged from 22 to 28°C throughout the experimental period. Temperature development in the T1 and T2 piles between days 6 and 19 differed considerably from that in T3 (Figure 1). The

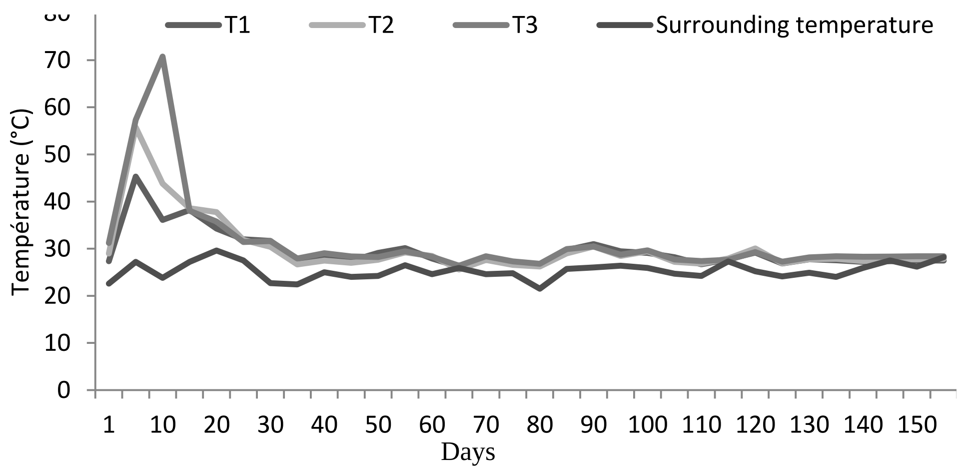

Figure 1. Temperature change of different heaps during co-composting.

piles showed an abrupt increase in temperature from day 5, with core temperature reaching 40°C in T1, 43°C in T2 and 47°C in T3 at mean ambient temperature of 23°C. The thermophilic (40 to 70°C) and mesophilic (40 to 25°C) phases could be seen as the bio-oxidative phase reported by Kuo et al. (2004). The temperature profile of the three piles had a similar pattern and the duration of the thermophilic phase was evaluated to be from about 5 days in T1, 9 days in T2 and 12 days in T3. These results are in line with the recommendation of the United States Environment Protection (USEPA) that the temperature of the compost pile should be higher than 40°C and maintained thus for at least 5 days, in order to ensure the elimination of pathogenic microorganisms (USEPA, 1984). This statement is also supported by Venglovsky et al. (2005). After the thermophilic stage, temperatures of all treatments rapidly declined until day 15, and then gradually decreased up to the ambient temperature. Subsequently from day 25 onwards, temperatures remained ambient until the end of the composting process, indicating the maturation phase in the sense of Diaz and Savage (2007) who showed that the color of composting materials changes from more intense to loose as observed in this study. The increased temperature observed in all treatments seven days after the beginning of the process may be due to delayed microbial growth stemming from pile turning and moisture content adjustment on day 6. Generally, pile turning could reactivate the composting process due to an increase in oxygen availability to microorganisms present during composting (Cayuela et al., 2006) thereby increasing the microbial metabolism and subsequent release of heat. On another hand, the evolution of temperature during the first week in the different treatments could be the result of a strong microbial activity induced by the presence of biodegradable organic matter such as mentioned by Compaoré and Nanéma (2010). The heat generated accelerates the decomposition of proteins, fats and complex sugars like cellulose and hemicelluloses contained in *E. pyramidalis*. The strong reduction in temperature observed in all treatments at the cooling phase could be explained by a slow-down of the activity of microorganisms due to the exhaustion of easily biodegradable organic matter as confirmed by Compaoré and Nanéma (2010). The stabilisation of temperature observed at the maturation period could be due to the stop of fermentation (release of gases) and the elimination of phytotoxicity (presence of ammonium ions, acetic acid, etc.) able to deteriorate soils and organisms that live therein as suggested by Fancou et al. (2008).

Effect of plant material and sludge ratio on water content of piles during co-composting

The initial moisture content of the three piles was not very similar at the beginning of the process (Figure 2).

Water content (WC) decreased progressively in all treatments during the co-composting. It changed from 58.08 ± 3.57% (T1), 63.18 ± 3.06% (T2) and 48.26 ± 0.74% (T3) at the beginning of co-composting, to 27.3 ± 3.71 % (T1), 28.81 ± 1.69 % (T2) and 29.91 ± 3.95 % (T3) at the end of the experiment. These values of WC in treatments 1 and 2 were significantly higher than those of treatment 3 within the first month of co-composting. Generally, the least values of water content were recorded in the swaths of T3, while the highest were recorded in those of T1. Nevertheless, at the 5th month of the process, water contents presented slightly higher values in T3 than in T1 and T2, even though the differences were not statistically significant (Figure 2). The decrease of moisture could be explained by the

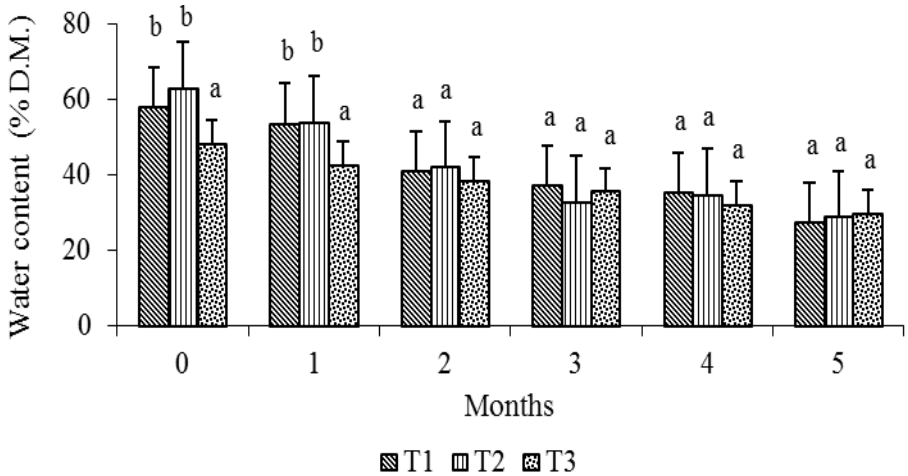

Figure 2. Water content variation of co-composts during co-composting process.

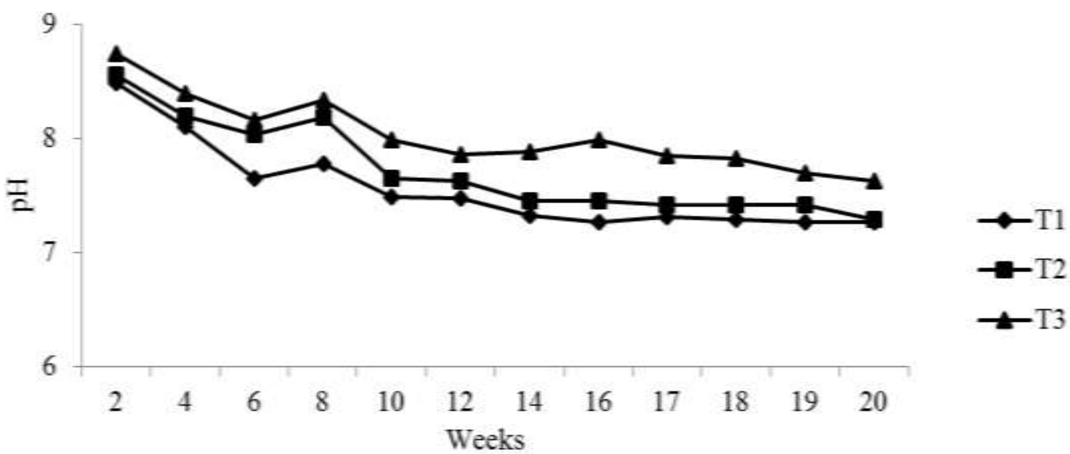

Figure 3. Changes of pH in different treatments during co-composting.

evaporation of water due to a thermal effect and by the combined action of overturning and aeration. According to Francou et al. (2008) part of the calorific energy radiated during the composting process provokes an evaporation of water leading to the drying off of matter while Compaoré and Nanéma (2010) attributed water loss in the form of vapour as a result of the different overturns carried out during composting.

Effect of plant material and sludge ratio on pH values during co-composting

The pH variation in the different treatments is presented in Figure 3. A regression of pH was noticed in the swaths of all treatments. Despite this regression, pH remained basic with values ranging from 8.49 ± 0.03 to 8.74 ± 0.10 at the beginning of co-composting to 7.26 ± 0.04 to 7.62 ± 0.04 at the end. A slight pH peak was observed between the 6^{th} and the 10^{th} week in all treatments with values of 7.78 ± 0.13 (T1), 8.18 ± 0.35 (T2) and 8.33 ± 0.27 (T3). This increase in pH of all compost piles was due likely to the metabolic degradation of organic acids and the ammonification process taking place during organic matter degradation as reported by Satisha and Devarajan (2007) as well as Mahimairaja et al. (1994).

The pH values in T3 remained higher than those in T1 and T2 throughout the process, with lowest values recorded in T1. At the end of co-composting, pH oscillated between 7 and 8 in all treatments. The increase of pH and the slight differences recorded during co-composting could be attributed to the initial composition of substrates (sewage sludge and plant material mixture). Indeed, Compaoré and Nanéma (2010) affirmed that the

Figure 4. Change of colour and physical characteristics of co-composts. a: Swath of treatment 1; b: Swath of treatment 2; c: Swath of treatment 3.

substrate could influence the evolution of pH during composting. Furthermore, the highest pH in T3 could be explained by its highest plant material quantity (*E. pyramidalis*) as compared to sludge. The decrease of pH from 8.74 to 7.26 observed at the beginning of co-composting is different from literature results. In fact, Cayuela et al*.* (2006) observed that at the beginning of composting of olive mill wastes, an increase in pH from 7 to 9 was generally recorded. These differences can be due to the type of organic matter used, the period of experimentation and the composting methods. The pH peak recorded between the 6^{th} and the 10^{th} week in all treatments should be associated to the degradation of short chain fatty in proteins and the liberation of ammonia during ammonification. Furthermore, the stabilisation of pH at the end of the process in all treatments could be attributed to the oxidation of ammonium by bacteria and the precipitation of calcium carbonate as mentioned by Chakroune et al. (2005). The final pH values (7.26, 7.29 and 7.62 respectively) obtained are in the range of those of Olufunke et al*.* (2009) in composts of different sources of organic matter (faecal sludge, animal dung, household refuse), after pH ranged from 7.1 to 8.6. After 2 weeks of composting, the pH values of all composts prepared gradually declined from 8.0, 8.3 to 6.9 and 7.3.

Effect of plant material and sewage sludge ratio on the maturity of co-composts

Co-composts were considered as ready when they had the odour of humid ground, a brown or dark colour, with a charred feel upon touch and when their temperature at the end of co-composting became stable and close to the external surrounding temperature without exceeding 30°C (Chakroune et al., 2005). However, the differences in colour only appeared at the beginning and the end of co-composting with colours that moved from black, dark brown and brown for T1, T2 and T3 respectively to deep black, black and dark brown after 150 days of co-composting (Figure 4).

The black, dark brown and brown colours respectively observed in T1, T2 and T3 at the first period of co-composting of sewage sludge and plant material could be explained by the composition of the initial mixture. Indeed at the beginning, the colour of sludge was dark and plant material was green. The black colour (T1 and T2) and dark brown (T3) of composts obtained should be due to the presence of humus contained resulting from the total mineralisation of co-compost materials, also indicating their maturity. Indeed, Mbuligwe et al. (2002), characterise mature co-compost by its deep black colour,

Table 2. Heavy metals contents and helminth eggs content of co-compost obtained (n = 3).

Parameter	Treatment			
	T1	T2	T3	French Norms (NFU-44 051)
Cd (mg/kg)	1.06 ± 0.07^{a}	1.19 ± 0.05^{a}	1.32 ± 0.08^{b}	3
Cr (mg/kg)	95 ± 5.00^{a}	84.58 ± 8.87^{a}	228.33± 11.61^{b}	120
Cu (mg/kg)	141.67 ± 19.09^{a}	237.50± 45.07^{b}	270.83± 19.09^{b}	300
Fe (mg/kg)	2237.50 ± 625.37^{a}	2166 ± 190.94^{a}	2550 ± 43.30^{a}	nd
Helmintheggs (eggs/g DM)	0.2 ± 0.03^{c}	0.1 ± 0.02^{b}	0.007 ± 0.01^{a}	Absent in 2 g of raw material

To move from milligrams per kilogramme ($mg.kg^{-1}$) to percentages (%), divide by 10^2; nd = not determined. Values followed by the same letter are not significantly different from each other following Student Newman Keul's test ($p < 0.05$).

while the World Health Organization characterizes it by it black or dark brown colour.

The nauseating odour that emanated from the various treatments during the first weeks of co-composting could be associated on one hand to the unpleasant odour of sewage sludge from the wastewater treatment plant, and on the other hand to the anaerobic conditions inside the swaths at the beginning of the experiment. Indeed, the high water contents in swaths at the beginning of co-composting should obstruct aeration interstices, creating anaerobic conditions as confirmed by Agendia et al. (1997). The rapid diminishing of these odours after the 5th week of co-composting could be explained by the drop in water content and more by the presence of plants which should have conferred a good aeration to the swaths. In fact, Francou et al. (2008) mentions that it is essential to compost sludge from waste treatment stations with a dry carbonated structuring agent because this optimisation favours the creation of gaps, which are obligatory for a good aeration.

Effect of plant material and sewage sludge ratio on compost characteristics

Heavy metals and helminth eggs content of co-composts obtained

The analyses of final composts revealed the presence of some heavy metals (Cd, Cr, Cu, and Fe) and helminth eggs in lowest quantities compare to sewage sludge (Table 2). These quantities are statistically different in treatments T1 and T2 compare to T3 for Cd, Cr, and Cu.

Heavy metals contents of the final composts were below the French norms NFU-44 051. Meanwhile, the chromium content of T3 (228.33 ±11.61 mg/kg) is largely above the limit value (120 mg/kg MS) (Table 3). The heavy metals (HM) contents of all composts are lower than those of the sludge used for co-composting, and Zn which was present in sludge (175 mg/kg) is no longer present in final composts. These results shows that these latter do not constitute any danger to be used as agricultural amendment. The HM values are weak as compared to those obtained by Agendia et al. (1997) and Compaoré and Nanéma (2010) in Yaoundé and Ouagadougou respectively. These values are high as compared to those obtained by Swati and Vikram in Burkina-Faso (2011). The differences observed could be due on one hand to the nature of wastes used and on the other hand to the co-composting technique and the methods of analyses as suggested by Compaoré and Nanéma (2010). The HM concentrations of co-composts are largely inferior to those obtained in sludge used for co-composting. Hence, co-composting should have contributed to the reduction of these concentrations in co-composts obtained. The reduction of HM could be attributed to the co-composting method and to the presence of molluscs like leeches and earthworms in swaths placed for co-composting. In fact, several authors, like Swati and Vikram (2011) confirm that molluscs are generally used as metallic pollution indicators because they are excellent bio-accumulators.

The low quantities of helminth eggs of co-composts obtained as compared to the initial sludge should be the result of the elimination of the latter during the co-composting process under the action of high temperatures. Actually, Venglovsky et al. (2005) showed that temperature higher than 55°C enable compost hygienisation. Furthermore, Venglovsky et al.(2005) mentioned that temperature maintained between 55 and 60°C during three consecutive days is require to eliminate a maximum of pathogenic elements in a compost pile. The final compost do not constitute a risk for being used as agricultural amendment because the helminth egg values present in the composts are in conformity with French norms (absence of eggs in 2 g of raw material).

The odour of humid ground, the deep black and brown colours as well as the temperatures close to the ambient temperature allow for the consideration of final composts as mature. In fact, all these parameters are taken into considerations by several authors (Olufunké et al.,

Table 3. Physical parameters of co-composts obtained (n = 3).

Parameter	Treatments			
	T1	T2	T3	Compost quality standards (WHO,1993)
Weight (Kg)	55.67 ± 3.06^{a}	66.67 ± 5.69^{a}	79 ± 7.55^{b}	nd
Conductivity (µS/cm)	639 ± 36.17^{a}	589 ± 54.25^{a}	806.33 ± 178.30^{a}	nd
'water' pH	7.26 ± 0.04^{a}	7.29 ± 0.03^{a}	7.62 ± 0.04^{b}	6-9
'KCl' pH	7.71 ± 0.02^{a}	7.68 ± 0.05^{a}	7.8 ± 0.02^{b}	6-9
Temperature	27.47 ± 0.06^{a}	27.87 ± 0.55^{a}	28.4± 0.95^{a}	nd
WC (%DM)	27.30 ± 3.71^{a}	28.81 ± 1.61^{a}	29.91 ± 3.95^{a}	nd

nd = Not determined. Values followed by the same letter are not significantly different according to Student Newman Keul's test ($p < 0.05$). Values followed by the same letter are not significantly different with each other with regards to Student Newman Keul's test ($p < 0.05$).

Table 4. Chemical parameters of co-composts obtained (n = 3).

Parameter	Treatment			
	T1	T2	T3	Compost quality standards (WHO,1993)
TOM (% DM)	33.23 ± 4.05^{b}	29.45 ± 1.28^{b}	22.8 ± 1.03^{a}	10-30
C (%DM)	16.61 ± 2.02^{b}	14.97 ± 0.21^{b}	11.4 ± 0.51^{a}	nd
N (% DM)	1.65 ± 0.32^{a}	1.52 ± 0.30^{a}	1.05 ± 0.48^{a}	0.1-1.8
P (% DM)	0.36 ± 0.05^{b}	0.27 ± 0.06^{b}	0.07 ± 0.01^{a}	0.1-1.7
K^{+} (% DM)	0.01^{a}	0.01^{a}	0.01^{a}	0.1-2.3
Ca^{2+} (% DM)	0.24 ± 0.05^{b}	0.06^{a}	0.08 ± 0.01^{a}	nd
Mg^{2+} (% DM)	0.03 ± 0.01^{a}	0.02 ± 0.01^{a}	0.04 ± 0.01^{a}	nd
Na^{+} (% DM)	0.49^{a}	0.49^{a}	0.46 ± 0.06^{a}	nd
C/N	10.20 ± 1.08^{a}	10.69 ± 0.97^{a}	10.16 ± 2.96^{a}	10-15

nd = Not determined. Values followed by the same letter are not significantly different according to Student Newman Keul's test ($p < 0.05$).

2009; Mbuligwe et al., 2002).

Physical parameters of composts obtained

The evaluation of mean weights values of the obtained composts showed that those of T3 were significantly higher than those of T1 and T2. However, temperature and water content did not follow similar pattern (Table 3). The highest conductivity values were recorded in composts T3 and the least in co-composts of T2 but they did not present significant differences. The pH values in all treatments were slightly basic both for 'water' pH and for 'KCl' pH. Globally, the physical parameters of all obtained composts were in the range of World Health Organisation (WHO, 1993) for agricultural use.

Chemical parameters of final composts obtained

The concentrations of TOM, C and P are significantly higher in final composts of T1 and T2 as compared to those of T3 (Table 4). These contents were in the range of WHO (1993). Nutrients (N, K, Mg^{2+} and Na^{+}) do not present significant differences in all composts obtained and the C/N ratios (up to 10) are in the range of compost quality standards of WHO (between 10 and 15). Exchangeable cations (K^{+}, Na^{+}, Ca^{2+} and Mg^{2+}) concentrations are low in all composts but the only difference observed was notice in composts of T1 which have a Ca^{2+} content that is significantly higher than those of T2 and T3. These results could be explained by the initial composting feedstock ratio and the composting procedure used.

Elements such as N and P are found in higher quantities in the co-composts of T1 and T2 as compared to initial sludge. However, the co-composts of T1 are on the whole richer in nutrients than those of T2 and T3. The determination of total soluble fertilizing elements permits the forecasting of the fertilizing effect of co-composts which is an important aspect of the quality of the compost.

The chemical element contents of final composts are slightly lower than those obtained by Agendia et al.

(1997) in Yaoundé, during the compost production from *Pistia stratiotes* biomass generated by a macrophytic sewage treatment system. They are also below those obtained by Compaoré and Nanéma (2010) in Ouagadougou during the composting of urban solid wastes. According to FAO norms, final composts obtained have high TOM and N contents with a low C/N ratio; but weak concentrations of P, K, Na^+, Ca^{2+} and Mg^{2+}. Meanwhile, compared to the AFNOR norms, these composts were very rich in TOM, N, P, with very low C/N ratios. The obtained results could be explained by the nature of initial organic substrates and the composting procedure used. The sludge and *E. pyramidalis* plants ratios could explain the differences in nutrient contents of the obtained composts as well as the strongest TOM and mineral elements concentrations in the T1 composts. Indeed, Raj and Antilb (2011) affirmed that mineral elements contents found in composts are depending to the nature of wastes and tributary to their major initial elements. The C/N ratios (< 13) found in obtained composts may confirmed their richness in nitrogen as confirmed by Agendia et al. (1997). The pH values (between 6 to 8) of the composts are favourable to microbial activity according to the compost quality standards of WHO (1993).

Conclusion

This study revealed that sewage sludge and plant material from wastewater treatment plant can be used to produce compost for agricultural purpose. The richness observed in organic matter, nutrients (C, N, P, and K) and exchangeable cations (Ca^{2+}, Na^+ and Mg^{2+}) in sewage sludge and plant material shows that these by-products can be used for agricultural purposes. However, the concentration of helminth eggs and heavy metals (Cd, Cu, Cr, Fe, and Zn) found in sewage sludge could limits it reuse. In other to improve the hygienic quality of sewage sludge for it safe agricultural reuse, composting process was achieved in combination with plant material. During the co-composting period, similar evolution tendencies were observed in all treatments for each monitored parameter. Temperatures, pH and WC in all piles were sufficient for the mineralisation of organic matter, change of colour and the elimination of parasites. The mixture of plant material and sewage sludge contributed to reduce heavy metal content (Pb, Zn, Cu, Cr, Cd, and Fe) and helminth eggs concentrations while increased nutrient (N, P, Ca, Mg Na and K) content of final composts. These heavy metals and helminth eggs concentrations in final co-composts are in the range of WHO, US EPA and French guidelines for compost. The concentration of nutrient were higher in Treatment 1 (75 Kg sludge and 25 Kg plant material) and it duration of co-composting was the lowest (3 moths). According to these observations, the above treatment can be recommended for the co-composting of sewage sludge and plant material coming from the wastewater treatment plant of Cité-Verte. However further researches about the effect of other different type of bulking materials and sewage sludge from this wastewater treatment plan for co-composting are recommended.

Conflict of Interests

The authors have not declared any conflict of interests.

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