Characterization of Mineral Macronutrients Kinetics During Faeces-Based Composting Process in Composting Toilets

Effebi Kokoh Rose, PhD
Kouame Bene Lucien, MSc
Kouassi Yeboua Firmin, PhD
Unité de Formation et de Recherche en Sciences et Gestion de l'Environnement (UFR-SGE), Laboratoire de Geosciences et Environnement Université Nangui Abrogoua, Abidjan, Côte d'Ivoire
Kouadio Louis, PhD
University of Southern Queensland, International Centre of Applied Climate Sciences, West Street, Toowoomba, Queensland 4350 Australia
Gone Droh Lancine, PhD
Unité de Formation et de Recherche en Sciences et Gestion de l'Environnement (UFR-SGE), Laboratoire de Geosciences et Environnement Université Nangui Abrogoua, Abidjan, Côte d'Ivoire

Doi: 10.19044/esj.2017.v13n36p177 URL:http://dx.doi.org/10.19044/esj.2017.v13n36p177

Abstract

Given the environmental concerns and public health risks that could arise, the use of composting toilets by-products requires compliance with quality standards beforehand. However, such quality assessment is often lacking for those by-products in rapidly urbanizing sub-Saharan cities. This study examines the kinetics of major mineral nutrients [i.e., nitrogen (N), phosphorus (P), and potassium (K), which are among the key indicators of a compost's stability] during a composting process of fecal matters from composting toilets. The monitoring was carried out at Abobo-Sagbé, Abidjan, Côte d'Ivoire over a 4.5-month period. Feces-based compost data collected on 6 different dates (i.e., on the 28th, 48th, 62nd, 76th, 90th, and 133nd day from the start of the composting process) were analyzed, and screened for their contents in total N, total P and K. Results showed a rapid decrease of the content of all three elements during the first 29 days, followed by a sharp increase, especially for P and K, and then a quite stable variation during the last 2 months of the monitoring. Variations of C/N ratio during the study were similar to those reported previously. Although the proportions of P and K were satisfactory at the end of the monitoring period, the final C/N ratio was relatively high compared to suitable ratios characterizing mature composts, suggesting therefore additional time may be required before any use of the compost as fertilizer in agriculture.

Keywords: Compost, composting toilet, ecological sanitation, fecal, kinetic, monitoring, nutrients

Introduction

Although significant progress has been made in achieving the Millennium Development Goals (http://www.unmillenniumproject.org/goals/) and the ongoing commitments of the United Nations led 2030 Agenda for Sustainable Development, access to adequate and improved sanitation facilities in rapidly urbanizing Sub-Saharan African (SSA) cities remains a critical issue (Mbaye et al., 2011). Indeed, in most urbanized areas of those SSA countries, excreta are collected in individual sanitation systems installed at the level of the dwellings themselves. Be it septic tanks, dry or bucket latrines, or unconnected public toilets, the sewage sludge from these systems must be regularly evacuated and managed properly. Their mismanagement can cause serious environmental nuisances and lead to significant public health issues (Klingel et al., 2002). Uncontrolled sludge discharged into the environment due to the lack of adequate disposal systems can pollute soils, surface and ground waters, can destroy the balance of ecosystems, and cause waterborne diseases (Blunier et al., 2004). A suitable sludge management system involving an adequate drainage system for sewage systems (providing a minimum risk for handling and transport), coupled to an efficient treatment system could help overcome these concerns (Defo et al., 2015).

Over the past decades the reuse of fecal sludge as fertilizer or soil conditioner has become increasingly popular, namely because this helps reduce water pollution from chemicals and could be cost saving (Brainerd and Menon, 2014). Organic wastes composts from sewage sludge (Perez-Murcia et al., 2006), municipal solid waste (Ostos et al., 2008), animal manure (Atiyeh et al. 2001; Eklind et al. 2001), green waste (Grigatti et al., 2007; Ribeiro et al., 2007), and agro-industrial waste (Papafotiou et al., 2004; Bustamante et al., 2008) can be used with very good results as growth medium instead of peat (Kala et al., 2012). Fecal sludge is a good soil conditioner and a renewable source of plant nutrients, such as nitrogen (N), phosphorus (P), potassium (K), and organic matter (Cofie et al., 2004). Composts based on such materials can be used as fertilizers in agriculture, providing the safety conditions are met. Indeed, bacteriological pollutions can occur (thereby increasing human health risks) when these composts are not adequately handled (Atidegla et Agbossou, 2010; Adjagodo et al., 2016).

In Côte d'Ivoire a regulatory and organizational framework for the management of sewage sludge has been put in place through the National Office for Sanitation and Drainage (ONAD) since 2011. One of its key targets is advocating and promoting the transformation of fecal sludge into compost for their agricultural valorization so that to encourage an ecological sanitation, particularly across the existing slums and suburbs of cities like Abidjan.

It is crucial to have clear insights on the processes (e.g., inactivation rates of microbiological organisms, kinetics of nutrient contents, etc.) involving in feces-based composting for obtaining stable and harmless composts in SSA countries such as Côte d'Ivoire. Yet only few studies (e.g., Cofie et al., 2009; Mouria et al., 2010; Anonymous, 2012) have reported on the contents of nutrients N, P, and K in faeces-based composts in regard to their agricultural value. The main objective of this paper was therefore to investigate the kinetics of the three mineral macronutrients, as well as the C/N ratio, during a composting process of fecal matters from composting toilets for the potential use of such composts in agriculture. First, the kinetics of the three elements were characterized. Then, the results were discussed according to the standard proportions suitable to further use of these by-products in agriculture.

Materials and methods

Study area and data collection

The study was carried out at Abobo-Sagbé, Abidjan, Côte d'Ivoire. Abobo-Sagbé is one of the south-western neighborhoods of Abobo. It covers an area of 430 ha, with a population of circa 100,000 inhabitants. The average annual growth rate is 3% (INS, 2001). The study was part of a project aiming at (i) offering composting toilets to people in urban slums in order to stop open-air defecations, and (ii) generating new job opportunities while ensuring the management of excreta in households and healthy use of composting toilet by-products (e.g., as fertilizer in agriculture).

In our study one pit of composting toilet (total volume = 1 m^3) was purposively selected to represent the average users involved in the project as described by Effebi et al., 2017, in Figure 1. The selected composting toilet was used by 25 individuals. Fecal matters in the composting toilet were collected directly in a pit mounted above ground (urines were channeled via a PVC and collected in a different receptacle located outside the latrine). Upon the filling of the receptacle, the pit was closed for the composting process. Note that during filling, a bulking agent (e.g., sawdust or chips) was added after each defecation to absorb moisture, and reduce the risk of odor and proliferation of flies.

The collection of feces-based compost samples was conducted over 133 days of composting, starting on February 7, 2017. The depth of the compost pit was 1 m. The sampling was performed at three vertical positions in the compost pit: at the top A (0-5 cm from top), mid-depth B (45-55 cm from top) and depth C (90 cm from top), as described by Effebi et al., (2017) in Figure 2. They were then carefully mixed manually as one content and 1-kg sample was collected and stored in sterile plastic bags for the determination of the physical chemical characteristics (organic matter, total nitrogen, total phosphorus, potassium, and the C/N ratio) in laboratory. Samples were transported to the laboratory in an ice chest on the same day (within 2 hours after collection).

Figure 1. Composting toilets monitored in the experiment. A. Front view; B. Rear view; C. Orifice for urine collection and valve covering the pit; D. Wastewater collecting orifice (wastewaters are from hand and anal washing water after each defecation), (Effebi et al., 2017)

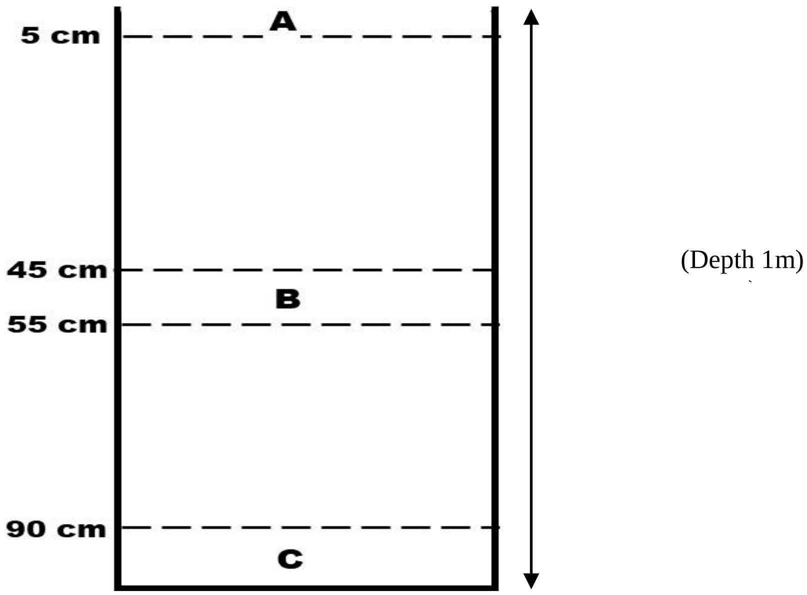

Figure 2. Schematic pit profile and sampling depths: top (A), mid-depth (B) and bottom (C), (Effebi et al., 2017)

Laboratory analysis

Organic matter: Regarding the determination of the organic matter, AFNOR, (1987), the sample was calcined in a muffle furnace at 550 °C. The residual material resulting from the combustion was the mineral matter (MM). The organic matter (OM) was determined by calculating the difference between dry matter (DM) and MM (Equation 1).

$$OM\ (\%) = \frac{DM-MM}{DM} \times 100 \qquad (1)$$

Potassium and total phosphorus: they were determined through digestion process and analysis by ICP OES according to NF, 1998. First, 30 mL of distilled water was added to a sample of 20 mg of compost and mixed. The solution obtained was then filtered through a Millipore membrane (0.45 µm diameter). Then, the membrane and the residue were treated with 4 mL of 65% nitric acid and 4 mL of hydrogen peroxide (H_2O_2) in a digestion vessel connected to a reflux condenser. The compound obtained was heated until a clear mineral was obtained, which was evaporated afterwards to 2 ml and cooled. After adding 10 mL of 0.2M hydrochloric acid, the solution was heated in a microwave oven at 175 ° C for 20 minutes in order to dissolve any residual material. After cooling and filtration, 20 mL of the solution was taken and analysed through optical spectroscopy. The spectra were dispersed by a network spectrometer and the intensity of the lines was evaluated by a detector (K: 578 nm, P: 880 nm).

Total nitrogen: the proportion of total nitrogen was determined by the Kjeldahl method as described by Black (1965).

Each of the chemical analyses was repeated four times.

Statistical analysis

All the mean values of each parameters were compared using a t-test ($\alpha = 0.05$) in order to check for the statistical significance of their difference. Data analysis was performed using software R version 3.3.2 (Team, 2016). Prior to the comparison, normality tests (i.e., Shapiro test) were performed for each parameter. Whenever the normality test had a p-value < 0.05 a non-parametric test was used (a parametric test being used for $p > 0.05$).

Results

Organic matter

The evolution of organic matter proportion during the composting process in the composting toilets from Abobo Sagbé is shown in Figure 3. Unsurprisingly, there was a decrease of OM percentage during the monitoring period, mainly due to bacterial activities. The average values of OM decreased from 83.15% to 64.93% over 4.5-months composting process. The difference in OM percentage was not statistically different over the study period ($p = 0.61$).

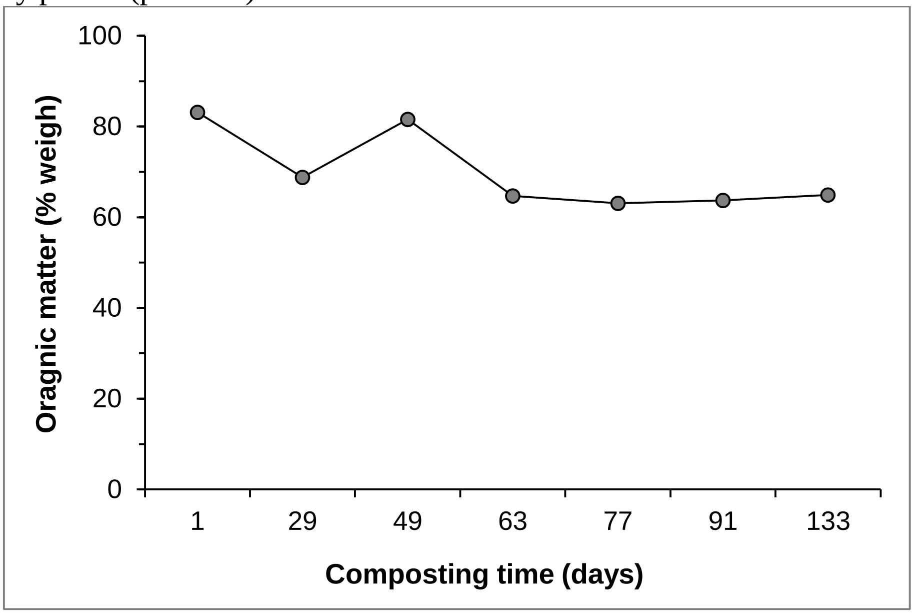

Figure 3: Evolution of organic matter during the faeces-based composting process

Total nitrogen, total phosphorus and potassium

The contents in total nitrogen, total phosphorus and potassium during the composting process in the composting toilets from Abobo Sagbé are presented in Figure 4. A quite similar pattern was observed for the three elements: a sharp drop from day 1 to 29 (particularly noticeable for N), followed by an increase from day 29 to 63. Then the proportions of P and K remained practically stable up to the end of the monitoring period, to reach 0.96% and 0.76%, respectively. Whereas the proportion of N dropped gradually to reach 0.54% over the same period.

The differences in the means of P and K over the composting period were statistically different ($p = 0.03$); whilst that in the means of N was not statistically different ($p = 0.07$).

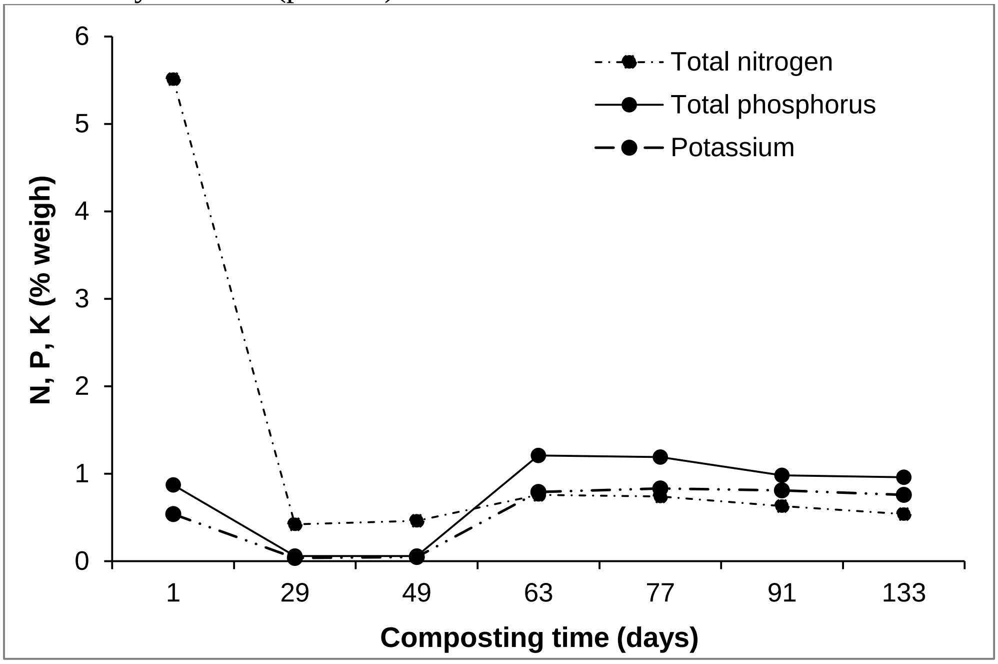

Figure 4: Evolution of total nitrogen, total phosphorus and potassium during the faeces-based composting process

C/N ratio

The evolution of the C/N ratio is shown in Figure 5. Three distinct phases were observed: a strong growth from 7.54 to 88.69 during the 49 first days of composting; then, a decrease of >50% from the 49th to 63rd day; and finally a progressive growth from the 73rd day when the C/N ratio varied from 42.6 to 60.12.

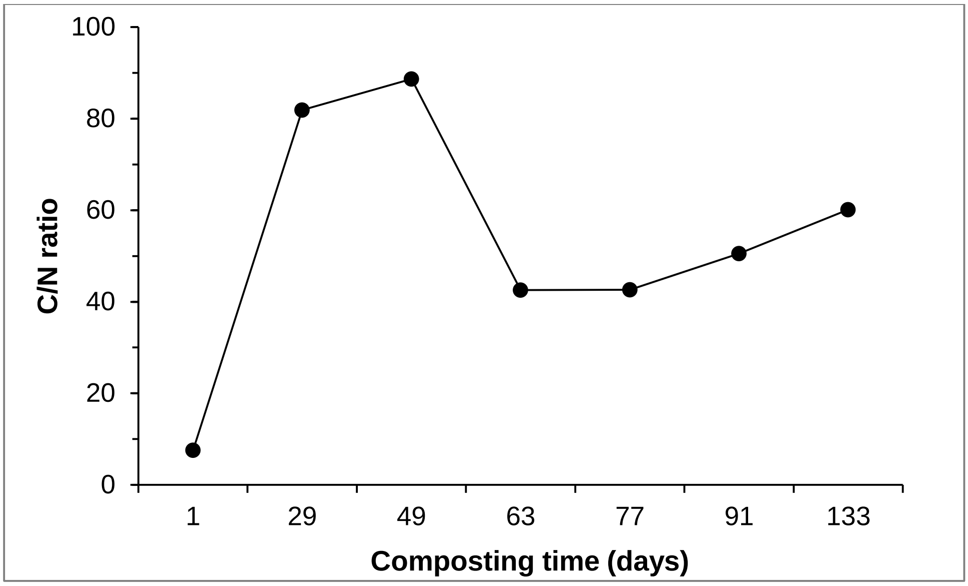

Figure 5: Evolution of the C/N ratio during the faeces-based composting process

Discussion

Organic matter

Organic matter refers to all organic compounds that may be degraded during the composting process. The decrease observed in our study is in line with Calvet et al. (2011) and Albrecht (2015). Such decrease is related to the bacterial activity since microorganisms use the organic substances necessary for their metabolism, and the mineralization of the compost during the biological degradation of the substrate. However, this decrease is variable and depends on the conditions and duration of the composting process. The losses of OM during the process can reach 20 to 60% by weight of the total OM initially available (Ukondalemba, 2016).

Total nitrogen

Total N is the summation of organic and inorganic N. The evolution of the different forms of N (e.g., ammonium, ammonia) during a composting process depends on the content of the residues and the rate of decomposition of the organic matter (Sànchez-Monedero et al., 2001). The high nitrogen loss during the first 29 days in our experiment could be attributed to the evaporation of nitrogen in the form of ammonia. According to Fanny (2007) and Sanchez-Monedero et al. (2001) the presence of ammonia combined to elevated temperatures and acid pH are conducive to the removal of nitrogen in ammonia form. The rate and proportion of such removal vary according to other various factors including aeration, moisture content, and the frequency of turning (Bishop and Godfrey 1983). These losses can range from 10 to 50% of the initial amount.

The slight increase observed from the 29th to 63rd day can be related to the mineralization of composting products, and suggests therefore a composting material rich in fermentable nitrogen. Similar observations were reported by Znaidi (2002) who estimates that part of the increase in nitrogen comes from the residues of microbes and bacteria, which have multiplied especially during the first phase of the composting process. Hence, the nitrogen fertilizing value of organic products depends on their initial richness in ammoniacal nitrogen, but also and above all, on the ability of the organic nitrogen they contain to be mineralized (Verdun, 2012). The degradation of proteins under the effect of heat and the action of microorganisms can also justify such increase in total N (Mustin, 1987). However, nitrogen value from 0.54% at the end of the composting process remains lower than the recommended level (i.e. 0.81%) in compost (Council of the European Communities, 1986).

Total phosphorus and Potassium

K and P are highly available provided, they have not been leached during or after the composting process (EcoSanRes, 2004). Relatively stable contents of P and K were observed during the last 2 months of the monitoring. This stability can be related to the drop in humidity in the compost. Phosphorus is not volatile and less leachable than nitrogen because of its low mobility. Moreover, some "phosphorus-solubilizing" microorganisms can transform the insoluble mineral phosphorus into soluble phosphorus and organic phosphate after assimilation into their cells. Thus, some of the soluble phosphorus can still remain in the medium (Mustin, 1987). However, phosphorus value (0.96%) at the end of the composting process remains higher than the recommended level (i.e. 0.67%) in compost (Council of the European Communities, 1986).

In the plant, potassium is the most absorbed element after nitrogen (Sparks et Huang, 1985). The percentage margin of K obtained in our study (0.03 to 0.83%) is quite similar to that of Gbenatey et al. (2017) (0.7 to 1.0%). However, it remains higher than the recommended level (i.e. 0.3%) in compost (Council of the European Communities, 1986).

Ratio C/N

The C/N ratio has frequently been used to describe organic waste decomposition and it is widely accepted that a high substrate C/N ratio implies a low mineralization rate due to N deficiency. Furthermore, composts with high C/N ratio can cause nitrogen immobilization upon amendment to soil, whereas those with low C/N ratio can cause ammonium toxicity (Epstein et al., 1992). Various studies suggest ideal C/N ratios ranging from 12 to 25 for a mature (i.e., ready to be used) compost (Rosen et al., 1993, Hue and Liu, 1995; Benny, 1996, Namkoong, 1999; Tiquia, 2010).

The sharp increase of C/N during the first 49 days of composting in our study can be explained by the mixing of faeces with sawdust during the use of toilets, which is an important source of carbon (Mustin, 1987). The decrease that occurred during the following 15 days is evidenced by the degradation of materials caused by bacteria activities, with loss of carbon in the form of carbon dioxide (CO_2). Indeed, carbon constitutes a source of energy for bacteria (Ukondalemba, 2016). Similarly, nitrogen is used as their protein source. This consumption of nitrogen supports the progressive growth observed the last 2 months of the monitoring.

All the variations observed during the monitoring period are similar to those reported by Sall (2014) when co-composting agri-food residues on farm. However, the final C/N ratio of 60.12 was higher than those recorded by Heerden et al. (2002) and Gbenatey et al. (2017) (C/N = 20 and $12 \leq$ C/N ≤ 20, respectively). According to Ukondalemba (2016), this ratio expresses the proportion between carbon and bio-available nitrogen. It generally depends on the intrinsic composition of the substrate to be composted. There are exceptional cases. For example, Charest and Beauchamp (2002) demonstrated that a C/N ratio of 65 was adequate for a composting process involving a residue rich in cellulose and lignin with a small increase in temperature and a long thermophilic phase, while preventing losses of nitrogen in the environment. In contrast, Huang et al. (2004) showed that a C/N ratio of 15 gives a compost with high pH and electrical conductivity, with a low temperature rise, a short thermophilic phase, and a high content of NH_4 -N and volatile solids.

Conclusion

The kinetics of the three mineral macronutrients (N, P and K), as well as the organic matter content and C/N ratio, were characterized during a composting process of fecal matters from composting toilets. Our findings showed quite similar patterns on the course of all three elements (NPK) throughout the monitoring period, with varying proportions. The final C/N ratio recorded was still high compared to standards. Based on the available proportions of P, K and organic matter, the compost could serve as amendment for soils in order to increase their contents in these elements and contributing to the sequestration of carbon. However, the final C/N ratio needs to be lowered through additional composting time so to improve the quality of the feces-based compost and increase its value in agriculture.

Acknowledgements

We are grateful to the laboratory personnel of the Ivoirian Anti-Pollution Center (CIAPOL) for their technical assistance in data analysis.

References:

1. Adjagodo, A., Agassounon, M.D.T., Kelome, N.C., Lawani, R. 2016. Flux des polluants liés aux activités anthropiques, risques sur les ressources en eau de surface et la chaine trophique à travers le monde : synthèse bibliographique. Int. J. Biol. Chem. Sci., 10(3) : 1459-1472. DOI : http://dx.doi.org/10.4314/ijbcs.v10i3.43
2. AFNOR. 1987. Qualité des sols et méthodes d'analyse. 1 édition, 133 P.
3. Albrecht, R., Verrecchia, E., Pfeifer, H.R. 2015. The use of solid-phase fluorescence spectroscopy in the characterization of organic matter transformations. Talanta, 134: 453–459. doi: 10.1016/j.talanta.2014.11.056
4. Anonyme. 2012. Le compostage. Chambre d'agriculture de Lozère, 4 p.
5. Atidegla, C., Séraphin, K., Agbossou, E. 2010. Pollutions chimique et bactériologique des eaux souterraines des exploitations maraîchères irriguées de la commune de Grand-Popo : cas des nitrates et bactéries fécales. Int. J. Biol. Chem. Sci., 4(2) : 327-337.
6. Atiyeh, R.M., Edwards, C.A., Subler, S., Metzger, J.D. 2001. Pig manure vermicompost as a component of a horticultural bedding plant medium : effects on physicochemical properties and plant growth. Bioresour. Technol., 78 :11–20.
7. Benny, C. 1996. Chemical and biological characterization of organic matter during composting of municipal solid waste. J Environ Qual., 25(4), 760 :776. doi: 10.2134/jeq1996.254776x.36.
8. Bishop, P.L., Godfrey, C. 1983. Nitrogen transformations during sludge composting. Biocycle., 24:34–39.
9. Black, C.A. 1965. Methods of soils analysis, Part 2 - chemical and microbiological properties, Agronomy monograph No.9. American society of Agronomy, Madison, Wisconsin USA.
10. Blunier, P., Koanda, H., Strauss, M., Klutse, A. et Tarradellas, J. 2004. Quantification des boues de vidange, Exemple de la ville d'Ouahigouya, Burkina Faso. EAWAG/SANDEC, Lausanne, 8 p.
11. Brainerd, E., Menon, N. 2014. Seasonal effects of water quality: The hidden costs of the green revolution to infant and child health in India. J. Devel. Econ., 107: 49–64. DOI: http://dx.doi.org/10.1016/j.jdeveco.2013.11.004.

12. Bustamante, M.A, Paredes, C., Moral, R., Agullo, E., Perez-Murcia, M.D., Abad, M. 2008. Composts from distillery wastes as peat substitutes for transplant production. Resource Conserv. Recycle, 52 :792–799
13. Calvet, R., Chenu, C., Houot, S. 2011. Les matières organiques des sols. Rôles agronomiques et environnementaux. Editions France Agricole.
14. Cantin, S. 1998. Caractérisation de l'évolution de composts et de lixiviats: relations avec le processus de compostage et la qualité des eaux. Mémoire. Université du Québec, Institut national de la recherche scientifique, Maîtrise en sciences de l'eau, 206 p.
15. Charest, M. H., Beauchamp, C. J. 2002. Composting of de inking paper sludge with poultry manure at three nitrogen levels using mechanical turning behavior of physico chemical parameters. Biores. Technol., 81 (1), 7-17.
16. Cofie, O., Kone, D., Rothenberger, S., Moser, S., Zubruegg, C. 2009. Cocomposting of faecal sludge and organic solid waste for agriculture : process dynamics. Water Res (Oxf) 43(18) :4665–4675.
17. Council of the European Communities (CEC).1986. Council directive on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/ EEC). Official Journal of the European Communities No. L 181/16-27.
18. Defo, C., Fonkou, T., Mabou, P.B., Nana, P. et Manjeli, Y. 2015. Collecte et évacuation des boues de vidange dans la ville de Bafoussam, Cameroun (Afrique centrale). Vertigo, 15 (1).
19. EcoSanRes. 2004. Directives pour une Utilisation des Urines et des Fèces dans la Production Agricole ; rapport 2004-2 de la collection de volume EcoSanRes, 53 P.
20. Effebi, K. R., Ouattara, I., Ouattara, K. N., Kouadio, L. (october 2017). Ecological Sanitation in Tropical Environments: Quantifying the Inactivation Rates of Microbiological Parameters During a Feces-Based Composting Process. European Scientific Journal, Vol.13, No.29, pp. 1-16.
21. Eklind, Y., Ramert, B., Wivstad, M. 2001. Evaluation of growing media containing farmyard manure compost, household waste compost or chicken manure for the propagation of lettuce (Lactuca sativa L.) transplants. Biol Agric Hortic, 19 :157–181
22. Epstein, E., Chaney, R.L., Henry, C., Logan, T.J. 1992. Trace elements in municipal solid waste compost. Biomass Bioenergy, 3(3-4):227–38. doi: 10.1016/0961-9534(92)90028-o

23. Fanny, M. 2007. Etude des possibilités de valorisation des produits issus de traitement des boues de vidange ; cas de Yaoundé, Cameroun, étude CREPA, 142 P.
24. Gbenatey, E. N., Amoah, P., Ofosu-Budu, K. G., Muspratt, A., Pradhan, S.k. 2017. Effects of co-composting of faecal sludge and agricultural wastes on tomato transplant and growth. Int J Recycl Org Waste Agricult, 6 :23–36. DOI 10.1007/s40093-016-0149-z
25. Grigatti, M., Giorgioni, M.E, Ciavatta, C. 2007. Compost-based growing media : influence on growth and nutrient use of bedding plants. Bioresour Technol., 98 :3526–3534
26. Hue, N.V., Liu, J. 1995. Predicting Compost Stability. Compost Sci Utiliz., 3(2) :8–15. doi: 10.1080/1065657x.1995.10701777.38.
27. Huang, G.F., Wong, J.W.C, Wu, Q.T., Nagar, B.B. 2004. Effect of C/N on composting of pig manure with sawdust. Waste Manag., 24 :805–813. doi:10.1016/j.wasman.2004.03.011
28. INS. 2001. Recensement Général de la Population et de l'Habitat (RGPH); Données sociodémographiques et économiques des localités, résultats définis par localités, région des lagunes, Abidjan, Côte d'Ivoire, 3, tome 1, 43 p.
29. Kala, D.R., Rosenani, A.B., Thohirah, L.A., Fauziah, I., Ahmad, S.H. 2012. Oil palm waste – sewage sludge compost as a peat substitute in a soilless potting medium for Chrysanthemum. Glob J Sci Front Res Agric Biol 12(2): Version 1.
30. Khalil, M., Hossain, M., Schmidhalter, U. 2005. Carbon and nitrogen mineralizationindifferentuplandsoilsofthesubtropicstreatedwith organic materials. Soil Biol Biochem., 37 :1507–1518. doi:10.1016/j. soilbio.2005.01.014
31. Klingel, F., Montangero, A., Kone, D. et Strauss, M. 2002. Gestion des boues de vidange dans les pays en développement, SANDEC/EAWAG Dübendorf: Suisse, 63 p.
32. Kouassi, F.K. 2008. Impacts du système de réseau d'égout à faible diamètre sur la ressource en eau: le cas du réseau d'Abobo-Sagbé un quartier précaire de la ville d'Abidjan (Côte d'Ivoire), Master spécialisé; 33 P.
33. Mbaye, M.N., Niang, K., Sarr, A., Mbaye, A., Diedhiou, D., Ndao, M.D. 2011. Aspects épidémiologiques du diabète au Sénégal: Résultats d'une enquête sur les facteurs de risque cardiovasculaire dans la ville de Saint-Louis. Médecine des Maladies Métaboliques, 5, 659-664. https://doi.org/10.1016/S1957-2557(11)70343-1
34. Mouria, B., Ouazzani-Touhami, A. et Douira, A. 2010. Valorisation agronomique du compost et de ses extraits sur la culture de la tomate. Rev. Ivoir. Sci. Technol., 16, pp. 165 – 190.

35. Mustin, M. 1987. Le compost-Gestion de la matière organique. Éditions François Dubusc. Paris, 954 P.
36. Namkoong, W., Hwang, E.Y., Cheong, J.G., Choi, J.Y. 1999. A Comparative Evaluation of Maturity Parameters for Food Waste Composting. Compost Sci Utiliz., 7(2) :55–62. doi: 10.1080/1065657x.1999.10701964.37.
37. NF EN ISO 11885. 1998. ICP│ Qualité de l'eau - Dosage de 33 éléments par spectrométrie d'émission atomique avec plasma couplé par induction, code 251.
38. ONU-Habitat. 2012. Côte d'Ivoire; Profil urbain d'Abobo. Nairobi, Editions UNON; 32 p.
39. Ostos, J.C., Lopez-Garrido, R., Murillo, J.M., Lopez, R. 2008. Substitution of peat for municipal solid waste and sewage sludge-based composts in nursery growing media : effects on growth and nutrition of the native shrub Pistacia lentiscus L. Bioresour Technol 99 :1793–1800.
40. Papafotiou, M., Phsyhalou, M., Kargas, G., Chatzipavlidis, I., Chronopoulos, J. 2004. Olive-mill wastes compost as growing medium component for the production of poinsettia. Sci Hortic 102 :167–175.
41. Perez-Murcia, M.D., Moral, R., Moreno-Caselles, J., Perez-Espinosa, A. 2006. Use of composted sewage sludge in growth media for broccoli. Bioresour Technol., 97 :123–130.
42. RGPH. 2014. Quatrième recensement général de la population et de l'habitat. Résultats globaux par Sous-Préfecture ou commune (Côte d'Ivoire), p.2
43. Ribeiro, H.M., Romero, A.M., Pereira, H., Borges, P., Cabral, F., Vasconcelos, E. 2007. Evaluation of a compost obtained from forestry wastes and solid phase of pig slurry as a substrate for seedlings production. Bioresour Technol., 98(17):3294-7.
44. Rosen, C.J., Halbach, T.R., Swanson, B.T. 1993. Horticultural uses of municipal solid waste composts. Hort Technol., 3(2):167–73.
45. Sall, P.M. 2014. Étude du compost et du lixiviat obtenus par co-compostage des résidus agroalimentaires à la ferme. Maitrise en biologie végétale; Québec (Canada), 125 P.
46. Sánchez-Monedero, M.A., Roig, A., Paredes, C., Bernal, M.P. 2001. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresour. Technol., 78(3):301-308.
47. Sparks, D.L. and Huang, P.M. 1985. Physical chemistry of soil potassium. p. 201-276. In R.D. Munson (ed.) Potassium in agriculture. American Society of Agronomy, Madison, WI.

48. Team, R.C. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/
49. Tiquia, S.M. 2010. Reduction of compost phytotoxicity during the process of decomposition. Chemosphere, 79(5):506–12. doi: 10.1016/j.chemosphere.2010.02.040.
50. Ukondalemba, L.M. 2016. Caractérisation et tests de traitement des déchets ménagers et boues de vidange par voie anaérobie et compostage pour la ville de Kinshasa. Thèse de doctorat, faculté des Sciences ; Département des Sciences et Gestion de l'Environnement, Unité Assainissement et Environnement, 313 P.
51. Verdum. 2012. Les produits organiques utilisables en agriculture en Languedoc-Roussillon - Tome 1 ; chapitre 5 : Les critères analytiques des produits organiques, 14 P.
52. Znaidi, A., El Akram, I. 2002. Etude et évaluation du compostage de différents types de matières organiques et des effets des jus de composts biologiques sur les maladies des plantes ; (Tunisie) ; Master en science organique et agriculture méditerranéen, 104 P.