Global Journal of Environmental Research 2 (3): 133-139, 2008
ISSN 1990-925X

Assessment of Heavy Metal Contamination and Macro-nutrient Content of Composts for Environmental Pollution Control in Ghana

[1]J.N. Hogarh, [5]J.N. Fobil, [2]G.K. Ofosu-Budu, [3]D. Carboo, [4]N.A. Ankrah and [4]A. Nyarko

[1]Department of Environmental Science,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[2]University of Ghana Agricultural Research Station, Kade, Ghana
[3]Chemistry Department, University of Ghana, P.O. Box LG 56, Legon, Ghana
[4]Noguchi Memorial Institute for Medical Research, College of Health Sciences,
University of Ghana, P. O. Box LG 581, Legon, Ghana
[5]Department of Biol. Env'tal and Occupational Health Sciences, University of Ghana School of Public Health,
College of Health Sciences, P. O. Box LG 13, Legon, Ghana

Abstract: This study examined macro-nutrient content of solid waste compost to determine the potential of the compost for soil fertility amelioration in Ghana. Heavy metal concentrations in the compost were also examined to assess the potential health implication of compost application in urban and peri-urban agriculture. It was observed that the overall NPK concentration was low in the different compost types, but generally, total N and K were greater in agricultural waste compost compared to municipal solid waste (MSW) composts. The agricultural waste compost was also richer in organic carbon. In terms of toxicity concerns, heavy metals concentrations (Ni, Zn, Cu and Cd) were generally low in the different types of composts and within permissible Australian standards for compost products. However, lead (Pb) concentration in mixed MSW composts was significantly high in the dry season, exceeding the Australian limit of 150 mg/kg Pb, required for unrestricted compost use. There was considerable seasonal variation in the heavy metal levels in the composts made from open windrows process, with reduced levels in the rainy season. It appeared that seasons affected mixed waste characteristics, which affected compost quality. It was therefore concluded that seasons and composting processes, to some extent, were important determinants of the levels of toxic metal concentrations in final compost products in Ghana.

Key words: Solid waste · Compost · Plant macro-nutrients · Heavy metals · Ghana

INTRODUCTION

Organic waste constitutes about 60-70% of the materials in waste stream in Ghana [1, 2] and it is increasingly becoming a major source of environmental pollution in urban areas in Ghana [3]. Primarily, organic waste (through copious discharge of leachates), is a major source of contamination in urban water supply and environmental pollution when left unattended [4-6]. It putrefies easily under the hot tropical temperatures and generates considerable quantities of leachates and obnoxious odour [4, 5, 7, 8]. Under such circumstances, organic waste may also act an important breeding site for disease causing vermin including flies, insects and rodents, which are vectors of diseases such as cholera, diarrhoea, dysentery and typhoid fever [3-5, 9-11]. Therefore, the management of organic waste in Ghana is a key strategy for urban environmental health promotion and disease control effort [3, 7-9, 12].

Currently, composting presents one of the best opportunities for managing organic wastes [13-16]. It is an important option for both sustainable waste management and sustainable agriculture [14, 17]. Compost has numerous benefits and nearly all crop farmers like to apply good-quality compost to their fields. Its benefits include improving soil properties, maintaining stable soil moisture content, preventing soil-borne diseases and acting as buffer to facilitate gradual release of plant nutrients

Corresponding Author: J.N. Hogarh, Department of Environmental Science,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[7, 11, 13-15, 17-19]. In urban and peri-urban areas in Ghana, composts are produced at household, local community and large-scale municipal levels [1-3]. Composts are widely applied in both urban and peri-urban agricultural production of vegetables for the consumption of urban populations in Ghana [7, 12, 19-22]. This is because composts are cheaper compared to chemical fertilizers for use in urban agriculture for soil fertility improvement.

However, despite the huge benefits from compost application in urban and peri-urban agriculture in Ghana, there are serious doubts about public health safety of this process and whether the application of the composts in urban agriculture is safe and does not present excess significant risk to human health [1, 7, 23-25]. First, many composts produced locally are marketed and applied without adequate knowledge on their nutrient (NPK) content [2, 3]. This means appropriate compost application rates are unavailable as yet and which also means incorrect soil-specific application amount cannot be avoided. This has huge implications for urban water quality as over-dosage of compost may lead to excess nutrient loading into ground water and seepage into urban water supply system [4, 26-28]. Other problems associated with the use of compost in urban agriculture have to do with the possibility of introduction of contaminants such as heavy metals into the natural food chain and food web [5, 8-10, 12, 20, 22, 24, 26-32]. Once these toxic trace elements are introduced into the food chain, they bio-accumulate and/or bio-magnify at higher trophic levels where humans occupy in the ecological food chain and thereby creating heavy metal induced health problems in humans. Heavy metals, such as lead (Pb), cadmium (Cd) and mercury (Hg) above some threshold levels become toxic to living organisms and are major problems in composts derived from mixed materials in the waste streams [10, 12, 16, 26, 31, 33, 34]. In this respect, this study investigated the macro-nutrient value and heavy metal contamination of composts derived from solid wastes in Ghana. The study sought to find out the suitability of the composts for soil fertility improvement and whether the heavy metal levels were within acceptable limits for safe application of the composts, in view of the fact that such composts were widely applied by local farmers in urban agriculture in Ghana.

MATERIALS AND METHODS

Composting Sites: Three different solid waste derived composts were sampled. The samples were categorized according to the sources of production, described as follows: (i) residential composting, directly from household waste (referred to as Household compost) (ii) decentralised community composting, with solid waste feedstock from Asiedu-Keteke community (referred to as Asiedu-Keteke compost) and (iii) centralised large-scale composting, with solid waste feedstock from Teshie-Nungua and its environs (referred to as Teshie compost). Compost from the University of Ghana Agricultural Research Station at Kade, produced from crop residues and poultry waste (referred to as Kade compost) was analysed to serve as a control with minimal contaminants compared to the composts produced from the municipal solid wastes.

Compost Samples: The composting process at each of the sites took approximately ten months. The Teshie compost and Asiedu-Keteke composts were each produced from mixed materials, which included biodegradable fractions such as food left-over, fruits, animal wastes, leaves, other plant trimmings/parts and papers. These compostable fractions were co-mingled with non-compostable materials such as metals, plastics and rubbers and bottles, which were only removed after the composting process. Whereas the Household compost was produced from materials mainly of kitchen wastes and yard trimmings, the Kade compost was produced from materials largely comprising chicken manure, cocoa husk, rice straw and sawdust.

Sampling Procedure: Freshly produced composts, considered mature by producers, were sampled directly from the windrows. Samples were taken in the dry season (January and February) and in the rainy season (June and July). Ten replicates of each compost type were sampled and analyzed for each season. Compost samples were air-dried, ground and sieved (particle size < 0.5 mm) for physico-chemical analyses.

Physico-chemical Analyses: For the determination of pH and electrical conductivity, one part of compost was extracted with 10 parts water (that is, 1:10 w/v). The pH, electrical conductivity (EC), total nitrogen (N), nitrate nitrogen (NO_3^-), ammonium nitrogen (NH_4^+), total phosphorous (P), total potassium (K) and total organic carbon (C) were determined using standard Test Methods for the Examination of Composting and Compost reported in literature [16, 21, 27, 34-36].

One gram of compost was wet digested in 5 ml of ternary mixture [20ml (60-62%) $HClO_4$: 500ml conc. HNO_3:

50ml conc. H_2SO_4]. The digest was appropriately diluted to 100 ml and the levels of Cd, Pb, Cu, Zn and Ni were determined using atomic absorption spectrometry (AAS).

Statistical Analysis: One way ANOVA was used to make comparisons among the different compost types at 95% confidence limit.

RESULTS AND DISCUSSION

The pH of the composts ranged between 6 and 7.73 (Table 1). pH generally gives an approximate index of compost maturation. Mature composts tend to have near neutral pH values while composts under maturation tend to be more acidic. Averagely, mature composts have pH between 6 and 8 [17, 21], suggesting that probably the composts under study might be mature. The Electrical Conductivity (EC) value of the Kade (agricultural waste) compost was significantly greater than that of the three MSW composts ($p<0.05$) (Table 1), which may indicate greater degree of mineralization of the former.

The C/N ratio of the composts examined ranged between 11.37 and 14.32 (Table 1). This is consistent with C/N ratios reported for mature composts as usually below 20 [34-38]. The C/N ratio is traditionally used to determine the degree of maturity and define the agronomic quality of compost. The total nitrogen content of the Kade compost (13.3 g/kg) was significantly different from all the other composts ($p<0.05$) (Fig. 1). This marked difference could be attributed to differences in the type of materials that were used as the feedstock to produce the compost. The relatively high total nitrogen content in the Kade compost was probably due to the large amount of chicken manure (a rich nitrogen source), which was part of the feedstock for the Kade composting. The Kade compost had the highest concentration of nitrates, the form in which nitrogen is available for uptake by plants. Essentially, compost stability increases with the appearance of more nitrates and disappearance of ammonia in the composting medium [6, 11, 21]. Although the NH_4/NO_3 ratio is not sufficient to predict absolute compost maturity, it gives relative stability indications [21, 34-36, 38]. Composts with lower NH_4/NO_3 ratio tend to be comparatively more stable. This suggests relative stability of the composts studied in the following other: Kade compost > Household compost > Teshie compost > Asiedu-Keteke compost (Table 1). In general, the composts from municipal solid wastes (MSW) (Household, Asiedu-Keteke and Teshie) were found to be of low organic carbon, ranging between 5.30% and 8.37%,

Table 1: Some physico-chemical properties of marketed composts in Ghana

Solid waste compost	pH	Electrical conductivity (EC) (dS/m)	C/N	NH_4^+/NO_3	Organic C(%)
Asiedu-Keteke	6.04	3.9	11.37	0.65	8.53
Teshie	7.32	1.5	14.32	0.44	5.30
Household	7.29	0.9	12.68	0.33	8.37
Kade	7.73	7.2	13.62	0.30	18.11

in comparison to the Kade (agricultural waste) compost of 18.11% (Table 1). The difference between total organic carbon in the agricultural waste compost and the MSW composts is statistically significant ($p<0.05$).

The Kade compost, thus, presented a better product for soil organic matter content improvement. Its rich organic carbon content is a reflection of the high organic carbon value in saw dust, cocoa husk and rice straw, which were part of the component composting feedstock materials. Total potassium concentration was significantly greater in the Kade (agricultural waste) compost compared to the MSW composts ($p<0.05$) (Fig. 1). This was attributed to the cocoa husk component of the crop residues that were used to produce the Kade compost. Cocoa husk is reportedly high in potassium and known to contain 3 to 4% potassium as dry mass [40].

Generally concentrations of nitrogen and potassium in the MSW (Household, Asiedu-Keteke and Teshie) composts were lower than the levels in the Kade (agricultural waste) compost (Fig. 1). Within the three MSW composts types (household, community or municipal) however, concentrations of nitrogen and potassium were independent of the compost types. Marginal concentrations of total phosphorus were recorded in all the composts (Fig. 1). Contrary to the observed trends of greater levels of nitrogen and potassium in the Kade compost, phosphorous concentration was relatively greater in the Asiedu-Keteke compost compared to the Kade compost (Fig. 1). This marginal difference was attributed to possibilities of cross contaminations from traces of detergents in discarded paper and plastic detergent packages at the Asiedu-Keteke composting site (Fig. 2).

The feedstock materials for the Household and Kade composts were relatively devoid of contaminants such as plastics, printed materials and metals. This may have accounted for the much lower concentrations of toxic heavy metals, Cd and Pb, in the Kade and Household composts compared to the Asiedu-Keteke and Teshie composts, which were produced from mixed waste stream

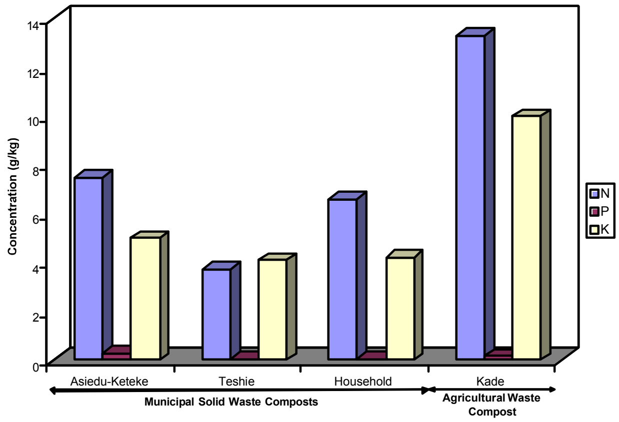

Fig. 1: Total NPK in some marketed composts in Ghana

Fig. 2: MSW compost windrow at Asiedu-Keteke using mixed waste

Fig. 3: Mature compost at Asiedu-Keteke composting site after separation of contaminants

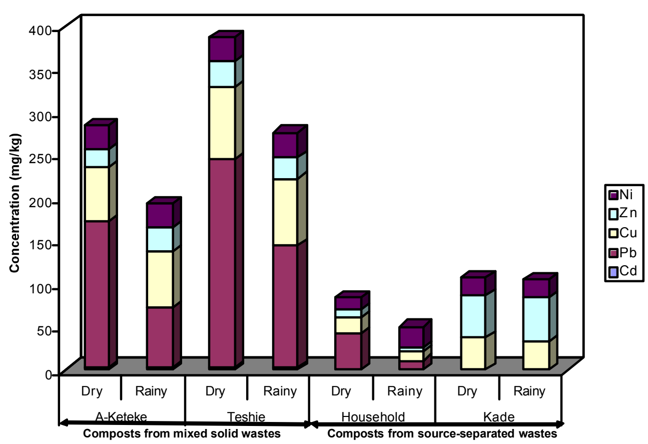

Fig. 4: Seasonal variation of heavy metals in some marketed composts in Ghana

(Fig. 4). It is well known that most of heavy metals are intrusions from contaminated materials in the compost feedstock [6, 22, 26, 32, 33].

Cadmium concentrations were below detection limit of 0.01 mg/kg in the Kade compost and very negligible in the Household compost. The highest cadmium concentration, 2.1 mg/kg, was observed in the Teshie compost, but this was within the Australian standard of 3.0 mg/kg Cd in compost [35]. Lead in the Kade compost was below detection limit of 0.01 mg/kg whiles the Household compost had the lowest Pb concentration which ranged between 10.5 and 49.5 mg/kg (Fig. 4). However, the Pb contents of the Teshie and Asiedu-Keteke composts were higher, reaching concentrations of 171.4 and 210.1 mg/kg respectively (Fig. 4), both of which exceeded the Australian compost quality standard of 150 mg/kg Pb [35]. The high concentrations of Pb in the Teshie and Asiedu-Keteke composts may have been as a result of contaminants in the mixed feedstock from which the composts were produced. On the average, mixed municipal solid waste in Accra contains 8% paper (including discarded printed materials), 8% plastic and rubber materials, 3% metals (including discarded dry and wet cells), 2% glass, 11% residue and 2% miscellaneous or other waste [2]; all of which could have introduced Pb into the composts, hence, the high concentrations of Pb in the Teshie and Asiedu-Keteke composts. Generally concentrations of heavy metals in the open MSW compost windrows decreased in the rainy season (Fig. 4). The decrease was most pronounced for Pb. Substantial leaching of metals from open compost windrows or washing away of metal-bound particles from the windrows in rainstorm water was thought to have possibly occurred, which might have contributed to the decreased levels of heavy metals in the composts in the rainy season. This theory is further strengthened by the fact that the Kade composting windrows, which were protected from rains, did not show significant difference in heavy metal concentrations between the dry and rainy seasons (Fig. 4). On the other hand, the lower levels of heavy metals in the MSW composts produced during the rainy season could also have been a reflection of a shift in consumption pattern, generating mixed waste fractions with relatively less heavy metals compared to the waste generated in the dry season. The high zinc concentration in the Kade composts (Fig. 4) might have been a contribution from residual poultry manure in the waste feedstock from which the Kade compost was produced. Poultry manure is a rich source of zinc [11, 18, 33, 39], which is attributed to antibiotics and other zinc containing chemicals used in the poultry industry. Zinc, copper and nickel concentrations in the composts (Fig. 4) were within the Australian compost quality standards of 200 mg/kg, 100 mg/kg and 60 mg/kg respectively [35].

CONCLUSION

Agricultural waste compost in Ghana appeared richer in plant macro-nutrients, especially nitrogen, potassium and organic carbon, compared to compost from MSW sources. Additionally, composts from source separated wastes (Kade and Household composts) had lower concentrations of heavy metals compared to composts from mixed waste (Asiedu-Keteke and Teshie composts). There was seasonal variation in the levels of the heavy metals in the compost produced by open windrow process, with reduced levels in the rainy season. It was concluded that composts were safe for use in urban and peri-urban agriculture without excess risk to human health. However, the composts produced during dry season from mixed waste fractions in Ghana, given the high lead content, might not be suitable for unrestricted applications.

REFERENCES

1. Carboo, D. and J.N. Fobil, 2006. Physico-chemical analysis of municipal solid waste (MSW) in the Accra metropolis. West Africa J. Applied Ecol.
2. Fobil, J.N., D. Carboo and C. Clement, 2002. Defining options for integrated management of municipal solid waste in large cities in low income economies: The case of the Accra metropolis in Ghana. J. Solid Waste Technol. Manage., 28(2): 106-117.
3. Fobil, J.N. *et al.*, 2007. The influence of institutions and organizations on urban waste collection systems: An analysis of waste collection system in Ghana (1985-2000). J. Environ. Manage., 86(2008): 262-271.
4. Everett, M., 1992. The sacred and the profane. Earthwatch, pp: 11-13.
5. Knoll, K.H., 1983. [Hygienic problems in dumping, composting and incineration of urban refuse]. Zentralbl Bakteriol Mikrobiol Hyg [B], 178(1-2): 166-73.
6. Mikhnovs'ka, A.D. and G. Lugova Zh, 1972. Microbiological processes during composting of urban sewage. Mikrobiol Zh, 34(1): 68-70.
7. Adhikari, B.K., S. Barrington and J. Martinez, 2006. Predicted growth of world urban food waste and methane production. Waste Manag. Res, 24(5): 421-33.

8. Amoah, P., *et al*., 2007. Irrigated urban vegetable production in Ghana: microbiological contamination in farms and markets and associated consumer risk groups. J. Water Health, 5(3): 455-466.
9. Afrane, Y.A., *et al*., 2004. Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana? Acta Trop, 89(2): 125-134.
10. Krajewski, J.A., *et al*., 2001. Assessment of exposure to bioaerosols in workplace ambient air during municipal waste collection and disposal. Med. Pr., 52(6): 417-422.
11. Musmeci, L. and P.M. Gucci, 1997. Health and hygiene aspects of the production of high-quality compost. Ann. Ist Super Sanita, 33(4): 595-603.
12. Amoah, P., *et al*., 2006. Pesticide and pathogen contamination of vegetables in Ghana's urban markets. Arch Environ. Contam Toxicol., 50 (1): 1-6.
13. Chanakya, H.N., et al., 2007. Micro-treatment options for components of organic fraction of MSW in residential areas. Environ. Monit. Assess, 135(1-3): 129-139.
14. Chang, N.B. and E. Davila, 2007. Minimax regret optimization analysis for a regional solid waste management system. Waste Manag, 27(6): 820-832.
15. Harel, K., 1997. Egyptian girls acquire skills, jobs and new identities. Popul Briefs, 3(3): 3.
16. McGarry, M.G., 1980. Appropriate technologies for environmental hygiene. Proc. R. Soc. Lond B Biol. Sci., 209(1174): 37-46.
17. Dick, W.A. and E.L. McCoy, 1993. Enhancing soil fertility by addition of compost, in Science and Engineering of Composting: Design, Environmental, Microbial and Utilization Aspects, Hoitink and Keener, Editors. Wooster, Ohio, pp: 622-633.
18. Franke, M., 1980. Migration in North Ghana: A study of labour migration and its effects on food production. Dritte Welt, 8(2): 186-202.
19. Shiralipour, A., D.B. McConnell and W.H. Smith, 1992. Uses and benefits of municipal solid waste compost. Biomass and Bioenergy, 3(3-4): 281-299.
20. Keraita, B., *et al*., Effect of low-cost irrigation methods on microbial contamination of lettuce irrigated with untreated wastewater. Trop Med. Int. Health, 12 Suppl 2: 15-22.
21. Poprasert, C., 1996. Organic waste recycling: Technology and Management. London: John Wiley and Sons.
22. Singh, K.P., *et al*., 2004. Impact assessment of treated/untreated wastewater toxicants discharged by sewage treatment plants on health, agricultural and environmental quality in the wastewater disposal area. Chemosphere, 55(2): 227-255.
23. Ghana, 1988. Results from the Demographic and Health Survey. Stud. Fam. Plann, 21(4): 236-240.
24. Deportes, I., J.L. Benoit-Guyod and D. Zmirou, 1995. Hazard to man and the environment posed by the use of urban waste compost: a review. Sci. Total Environ., 172(2-3): 197-122.
25. Kekovole, J., 1985. Demographic levels and trends in sub-Saharan Africa. IPPF Med Bull, 19(2): 2-4.
26. Woodbury, P.B., 1992. Trace elements in municipal solid waste compost: A review of potential detrimental effects on plants, soil biota and water quality. Biomass and Bioenergy, 3: 239-259.
27. Watts, C.D., *et al*., 1993. Application of a regional procedure to assess the risk to fish from high sediment concentrations. Sci. Total Environ., 314-316: 551-65.
28. Keraita, B., *et al*., 2007. Reducing microbial contamination on wastewater-irrigated lettuce by cessation of irrigation before harvesting. Trop Med. Int. Health, 12 Suppl 2: 8-14.
29. Diarra, S., 1991. A cutting obstacle to the harmonious development of the country. The migratory phenomenon in Mali. Pop Sahel, (16): 9-12.
30. Hachicha, R., N. Jedidi and A. Hassen, 1993. Hygienic aspects of aerobic fermentation of urban waste in the Tunisian context. Arch. Inst. Pasteur Tunis, 70(1-2): 13-20.
31. Kock, M., *et al*., 1998. Air-borne microorganisms in the metropolitan area of Graz, Austria. Cent. Eur. J. Public Health, 6(1): 25-28.
32. Krajewski, J.A., *et al*., Occupational exposure to organic dust associated with municipal waste collection and management. Int. J. Occup. Med. Environ. Health, 15(3): 289-301.
33. Richard, T.L. and P.B. Woodbury, 1992. The impact of separation on heavy metal contaminants in municipal solid waste composts. Biomass and Bioenergy, 3: 195-211.
34. TMECC, Test methods for examination of composting and compost. 2000: United States Composting Council.

35. Environment Australia, 2003. On-Farm Composting of Municipal and Commercial Organics as an Environmentally and Socially Sustainable Resource Recovery Scheme for Rural Communities. Australian Department of the Environment, Water, Heritage and the Art. GPO Box 787, Canberra ACT 2601, Australia.
36. Brinton, W.F., 2000. Compost quality standards and guidelines. WoodsEnd Research Laboratory, Inc. USA.
37. Golueke, C.G., 1981. Principles of biological resources recovery. Biocycle, 22: 36-40.
38. Jiminez, E.E. and P.V. Garcia, 1989. Evaluation of city refuse compost maturity: A review. Biological waste, 27: 115-142.
39. Kardos, L.T., C.E. Scarsbrook and V.V. Volk, Recycling elements in wastes through soil-plant systems, in Soils for management of organic wastes and waste waters, S. M. and R.C. Dnauer, Editors. 1977, Soil Society of America, American Society of Agronomy and Crop Science Society of America: USA, pp: 302-311.
40. Figueira, A., J. Janick and J.N. BeMiller, 1993. New products from Theobroma cacao: Seed pulp and pod gum. In: Janick, J. and J.E. Simon (Eds.), New crops. Wiley, New York, pp: 475-478.