Los Angeles, London, New Delhi
and Singapore
http://www.sagepub.com

wm&r

ISSN 0734–242X
Waste Management & Research
2010: 28: 177–184
DOI: 10.1177/0734242X09335699

Characterization of MSW and related waste-derived compost in Zanzibar municipality

Said Ali Hamad Vuai
Department of Physical Sciences, School of Natural Sciences and Mathematics, The University of Dodoma, Dodoma, Tanzania

The spread of municipal solid waste (MSW) in Zanzibar municipality has been associated with environmental pollution, unpleasant city conditions, contamination of water sources and coastal areas together with harbouring of malaria vectors. The contamination has a close relationship with eruption of diarrhoea, cholera and typhoid which claim the lives of the residents. Most of the wastes are of domestic and market origin and have the potential for compost production. This study examined the possibility of composting MSW from Zanzibar municipality as an alternative way of SW management and assessed the nutrient contents of the compost for application in agricultural production. Two major classes of SW were selected for the study: municipal solid waste and rice milling by-products. The samples were composted aerobically and anaerobically. The results showed that aerobic composting reduced about 60% of the waste volume. This volume reduction suggests that composting can be a promising SW management technique by reducing the large demand of space for landfilling. Municipal solid waste composted under anaerobic conditions produced compost with relatively higher concentrations of dissolved species than that produced under aerobic conditions. The trace metal contents were higher in MSW than in rice milling by-products. It was found that the unmanaged compost collected from the dumping site had low nutrient contents and was enriched with trace metals. Generally, physico-chemical characteristics, nutrients and trace metal levels suggest that Zanzibar municipal solid waste can produce high-quality compost for application to a wide range of soil types to improve their fertility, under proper management.

Keywords: municipal solid waste, compost, composting microbial community, MSW-derived compost, trace metals, Zanzibar

Introduction

Municipal solid waste (MSW) refers to materials that have no value to the concerned person and that cannot be discharged through a drainage pipe. Municipal solid waste is generated domestically, commercially and industrially and through health care, agricultural and mineral extraction activities. It often accumulates in streets and public places. The waste cannot be utilized and is costly to remove and dispose. Frequently, the failure of under-resourced authorities to collect the waste leads to unpleasant city conditions and the decomposing waste may pose a serious health hazard. Waste management is associated with controlling the generation, storage, collection, processing and disposal of municipal solid waste in a manner that is in accordance with the best principles of public health, economy, engineering and other environmental concerns. Poor management practices may lead to serious problems such as contamination of ground water and air pollution.

International experience has demonstrated that urban waste can be profitably processed into quality compost. Composting can be defined as the controlled biological decomposition of organic substrates carried out by successive microbial populations, combining both mesophilic and thermophilic activities, leading to the production of a final product which is sufficiently stable for storage and application to land without adverse environmental effects. Composting of municipal solid waste serves as the most environmentally safe and economically sound method of waste disposal.

The decomposition can be carried out naturally or enhanced using effective micro-oganisms (EM). EM refers to the specific mixed cultures of known, beneficial microorganisms that are being used effectively as microbial inoculants. EM contain selected species of micro-organisms, including a predominant population of lactic acid bacteria,

Corresponding author: Department of Physical Sciences, School of Natural Sciences and Mathematics, The University of Dodoma, P. O. Box 259 Dodoma, Tanzania.
Email: said@udom.ac.tz
Received 17 September 2008; accepted in revised form 13 March 2009

yeasts and smaller numbers of photosynthetic bacteria, actinomycetes and other types of micro-organisms. They have a high ability to decompose organic matters into the finished product (compost) within a short range of time (Zurbrugg *et al.* 2004). EM has been used by farmers and demonstrated beneficial effects. Microbes can also be used for hygiene management and municipal solid waste composting. Effective micro-organisms hasten the process of composting biodegradable waste, as well as preventing development of foul odours and fly nuisance. The use of EM technology also results in high-quality compost beneficial to crop yield and quality by increasing soil microbial population density.

The problem of municipal solid waste in Zanzibar municipality

The accumulation of municipal solid waste in Zanzibar is influenced by various factors including poor management, lack of health education and advanced tools. In 2001, the production of municipal solid waste in Zanzibar municipality was estimated to be 120 tonnes/day (Environmental Report 2004/2005). Due to the rapid increase in urbanization, the production of municipal solid waste has increased steadily. Currently, the daily production is estimated to be 200 tonnes (Zanzibar Municipal Council (ZMC) report 2005, unpublished) which correspond to SW production of 0.97 kg per capita. The production rate is higher than that reported in major cites (Hernandez-Berriel *et al.* 2008). The ZMC report (2005) revealed that 45% of the produced waste is collected and transported to the dumping sites. This has been made possible through a government subsidy, because records show that revenue collected by ZMC for municipal solid waste disposal covers only 3% of the generated waste. As a result, the collection of waste does not cover the entire area. The collection is made in priority areas such as Stone Town, where ZMC provides house-to-house collection and street cleaning services. Several strategies have been implemented to increase the financial capacity of the council. The polluter-pay policy is now being practiced in which every business contributes about 6 USD per month. However, until now, the municipal council depends financially and technically on foreign aid.

Uncollected waste is associated with environmental pollution, unpleasant city conditions, contamination of water sources and coastal areas, together with harbouring of malaria vectors. Contamination of water sources by municipal solid waste is associated with outbreaks of communicable diseases such as cholera, typhoid and bilharzia. The diseases claim the lives of residents, affect the labour force and cost Zanzibar Government a lot of money. The diseases also discourage tourists from coming to Zanzibar Islands. This situation calls for effective SW management intervention to avoid a negative impact on Zanzibar Government plans to reduce poverty, improve human capabilities, survival and social wellbeing as indicated in Zanzibar vision 2020, Millennium Development Goal and Zanzibar Strategy for Economic Growth and Reduction of Poverty.

At present, the types of municipal solid waste management practiced in Zanzibar are through disposal to decay naturally and burning. The former needs a large area and longer time to realize the significant volume reduction. This has led to shifting of the disposal sites. In 1980s, the municipal solid waste was dumped at Mwanakwerekwe (4 km from Zanzibar town) and then shifted to Jumbi, about 20 km from Zanzibar town; it is now being shifted to Kisakasaka. These dumping sites are not well protected; there is therefore the potential to contaminate nearby surface and ground waters. Burning of municipal solid waste as practiced in Zanzibar is carried out by individual persons in their own localities. Burning of unsorted waste containing plastic and toxic materials may cause air pollution and toxicity. Moreover, burning municipal solid waste at low temperature may produce dioxin and furans that have been implicated with birth defects and several kinds of cancers.

The objective of this study was to examine the possibility of composting municipal municipal solid waste as an alternative way of municipal solid waste management. Specifically, the study examines the effect of raw materials, aerobic and anaerobic processes and the influence of EM on the quality of the produced compost for application to improve agricultural productivity.

Material and methods

Study site

The area of Zanzibar municipality was selected because of higher municipal solid waste generation. Zanzibar municipality is situated in the Urban District in Urban West Region. It is located between latitude 4° to 6°30 south of the equator and from 39° to 40° east of Greenwich Meridian. It shares boundaries with the West District in the east, south and north and the Indian Ocean on the west. Zanzibar Municipality includes the old Stone Town, which is situated on the western part of Creek Road. Being an old part of Zanzibar, rich in history, Stone Town has unique architectural features and it is also the cultural heritage of Zanzibar. Zanzibar Stone Town is a fascinating living monument of the culture and history of its curious mix of Africans, Arabs, Indians, Persians and Europeans, traders and seafarers. Due to its physical features, the Stone Town is a major tourist attraction, contributing to the government income. For its national and international significance, the Stone Town was declared as a world heritage site in 2002 (UNESCO). Therefore, the proper management of municipal solid waste is necessary to keep the environment more tourist-friendly.

The Municipality covers about 16 km^2 with a population of 206,292. The Tanzania General Housing Census Report (2003) shows that 106,784 were female and 99,508 were male. The population density of Zanzibar municipality is about 350 people per km^2, with a population growth rate of about 4% per year.

Sampling

A survey was carried out in Zanzibar municipality to identify the municipal solid waste collection centres. Two types of solid wastes (municipal solid waste and rice milling by-products) were selected and composted under different conditions. The criteria for selection were their availability and environmental concern. Sampling for MSW was done from four different areas in the municipality to obtain representative samples of waste produced in the municipality. These include Darajani, Mwembetanga, Malindi dump and Stone Town. Darajani collection point receives domestic, market and commercial solid wastes while Malindi dump receives commercial and domestic waste from Mchangani and Malindi. Mwembetanga receives domestic waste from Michezani and Mwembetanga residential areas, while Stone Town receives domestic and commercial wastes mainly related to tourism activities. These are areas where municipal solid waste is kept before being taken to the Jumbi dumping site.

Municipal solid waste samples from the sampling sites were sorted into biodegradable and non-biodegradable. Non-biodegradable materials such as metals, plastic bottles, plastic bags, nylon and other materials were excluded. Pure biodegradable materials were cut into small pieces of about three 3–4 cm long using a sharp knife. The very small pieces of the raw materials help to increase surface area for microbial colonization.

Municipal solid waste (MSW) was composted aerobically and anaerobically, while the rice milling by-products (RMB) was composted anaerobically only, because of its nature of compactness which makes the supply of oxygen to the composting system very difficult.

Anaerobic composting was enhanced by EM. 1 L of molasses was mixed with 1 L of EM stock solution and then 18 L of water were added. The content was homogeneously mixed to form a total amount of 20 L of the solution. The solution was thoroughly mixed with MSW or RMB raw materials to yield a moisture content of about 40%. The mixture was placed in plastic containers of 100 L capacity and 1 m height, filled and pressed to remove air. The containers were tightly closed and compost samples were collected after 3 weeks.

For aerobic composting, the MSW was mixed with tap water to a moisture content of about 50–60%. The mixture was put into a plastic container and exposed to the air. The surface of municipal solid waste was occasionally moisturized to ensure that it did not dry out due to evaporation. The MSW was turned after the temperature decreased to almost ambient, in order to increase the amount of oxygen required by microbes to facilitate the decomposition process of the raw materials. In addition, a sample of naturally decomposed MSW from Jumbi dumping site was collected and analysed for comparison.

Analytical procedure

The temperature was monitored daily, using a mercury thermometer placed at the top (10 cm), middle (50 cm) and bottom (80 cm). The electrical conductivity and pH were measured in the suspension ratio of 1:2.5 (compost to water) by using a conductivity meter and pH meter, respectively. The organic carbon (OC) of the compost was analysed using the Walkely-Black method, in which the samples were oxidized at a temperature of approximately 120°C with a mixture of potassium dichromate and concentrated sulphuric acid (wet digestion). Nitrogen was determined using the Kijeldah method after digestion with concentrated sulphuric acid in the presence of selenium catalyst. Total phosphorous present in the samples was analysed by ashing, followed by calorimetric determination by the blue ammonium-molybdate method with ascorbic acid as reducing agent. The available phosphorous was determined using the Bray and Kurtz method. The easy acid soluble forms of phosphorous were extracted by 0.025 M HCl and 0.03 M NH_4F and then determined calorimetrically by the ammonium molybdate blue method. Potassium, calcium, copper, zinc and lead were determined after samples were ashed and digested with 1% HNO_3. Soluble fractions were obtained by extracting samples with distilled water. The extracts were then analysed by atomic absorption spectrophotometer.

Results

Temperature evolution

The temperature variations during the aerobic composting process at the top, middle and bottom of the composting bin are depicted in Figure 1. At the top of the composting bin, the temperature rose quickly to 47°C within 7 days. The maximum temperature remained for only one day. After that period, the temperature decreased gradually to 35°C, close to ambient. After this cycle, the compost was turned manually on the 25th day to increase oxygen circulation required for microbial decomposition. This resulted into a steady increase in temperature to 56°C, followed by another reduction to ambient within 7 days. The second turning did not have a significant effect on temperature variation, indicating that the organic matters had become stable. The middle and bottom of the composting bin did not show a big rise in temperature. This was attributed to a deficiency of oxygen at the bottom of the container. Thermophilic temperature (45–55°C) was reached in almost 4 days. This temperature showed that most of the thermosphilic activities occurred during com-

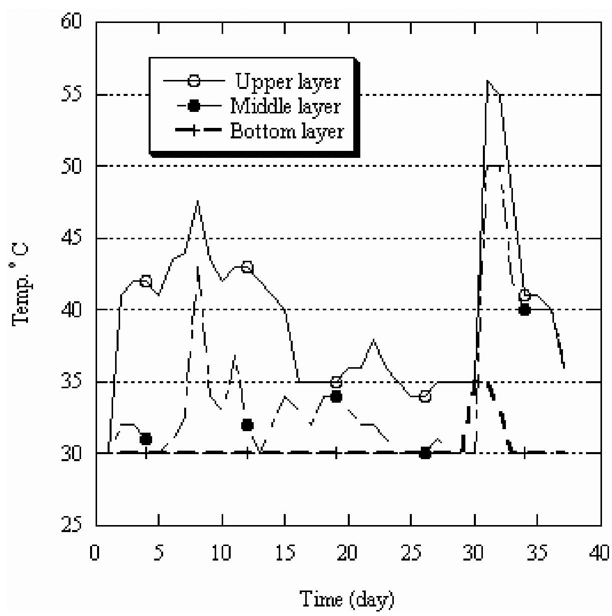

Fig. 1: Temperature variation during aerobic composting process.

Table 1: Physico-chemical characteristics of raw materials and final compost (where A: available and T: total).

Sample	pH	EC (mS cm^{-1})	OC (%)	TN (%)	AP (mg kg^{-1})	TP (%)	AK (%)	TK (%)	ACa (%)	TCa (%)
SWRM	9.3	15.7	23.12	1.39	38	0.26	1.26	3	0.65	6.1
SWRMB	9.3	14.9	22.62	1.39	54	0.26	1.26	2.7	0.61	6
SWANC	7.9	19.35	26.39	1.29	10	0.26	1.24	2.8	0.61	6.2
SWAC	9.4	14.4	16.45	1.73	183	0.24	1.2	2.5	0.49	6.6
RMBRM	5.6	3.71	40.87	1.88	19	0.24	0.76	0.9	0.002	0.01
RMBC	6.4	6.95	38.17	1.78	113	0.25	0.75	0.91	0.002	0.01
SWCJ	8.5	0.83	4.9	0.69	74	0.25	0.12	0.3	0.83	6.2

SWRM: Solid waste raw materials; SWAC: solid waste aerobic compost; RMBRM: Rice milling by-product raw materials; RMBC: Rice milling by-products anaerobic compost; SWCJ: unmanaged solid waste compost from Jumbi damping site

posting process, where most of the pathogens were killed (Rynk *et al.* 1992).

Physico-chemical properties of the compost

Physico-chemical characteristics of raw materials and final compost are listed in Table 1. The pH of MSW raw materials was alkaline. The pH remained almost the same after aerobic decomposition (SWAC). However, it decreased towards neutral (7.9) during anaerobic decomposition (SWANC). The rice milling by-products were acidic with pH 5.6, and the pH increased slightly to 6.4 after fermentation. The pH of compost sample collected from dumping site was also alkaline (pH 8.5).

The electrical conductivity (EC) of MSW raw materials was generally high (1.57 mS cm^{-1}) and decreased slightly (1.44 mS cm^{-1}) over raw materials during aerobic composting. The EC increased to 1.93mScm^{-1} for anaerobically composted MSW (SWANC). A similar trend was found for anaerobically composted rice milling by-products. The raw materials (RMBRM) had EC value of 0.37 mS cm^{-1} and increased to 0.70 mS cm^{-1} for RMBC. The EC for the compost from Jumbi (SWCJ) was 0.083 mS cm^{-1}.

Nutrient content

The total organic carbon of the MSW raw materials was 23% which was lower than for rice milling by-products (40.9%). The organic matters (OC) significantly decreased during aerobic composting to 16.5%, due to evolution of CO_2 and volatile organic matters. Under anaerobic condition, the variation was slight in both MSW and the rice milling by-products. Nitrogen contents in the raw materials were 1.39% and 1.88% for municipal solid waste and rice milling by-products, respectively. The values decreased slightly during anaerobic composting. The aerobic compost showed an increase in total nitrogen to 1.73%. This may be explained by the reduction in total organic carbon. The total nitrogen (TN) content in the compost from Jumbi dumping site was only 0.69%. The consequence of OC and TN trends was the reduction in carbon–nitrogen ratio under aerobic conditions and maintaining almost the same ratio for anaerobic composting.

Total phosphorous contents were 0.26% for MSW raw materials and 0.24% for rice milling by-products and did not vary during composting. However, the available phosphorous was only 54 ppm and 38 ppm for municipal solid waste with and without mixing with EM solution, respectively. For raw materials of rice milling by-products, the concentration was 19 ppm. The aerobic composting process increased the availability of phosphorous to 183 ppm, while anaerobic process increased to 113 ppm for rice milling by-products and decreased to 10 ppm for MSW compost. The compost collected from Jumbi had 74 ppm of available phosphorous.

The potassium contents of the raw materials were 3% for municipal solid waste and 0.9% for rice milling by-products. The available K was 1.2 and 0.76% for MSW and the rice milling by-products, respectively, and did not change significantly with the composting process. The sample collected from the dumping site which decomposed with no management had a total K of 3% while the available form was 0.12%. Total and available calcium contents were 6% and 0.65%, respectively, for municipal solid waste raw materials. The percentage did not significantly change during the composting process. However, composting under aerobic condition decreased slightly (0.48%) the available calcium. For the rice milling by-products, total calcium was only 0.01% and available Ca was 22 ppm only. Similar to the municipal solid waste, the composting process did not change the concentration. The sample of municipal solid waste from Jumbi dumping site was 6.1% and 0.8% for total and available calcium, respectively.

Trace metal content

The municipal solid waste and their corresponding compost were analysed to examine the presence of copper, zinc and lead as micro-nutrients and contaminants. The analysed results are listed in Table 2. The total concentration of copper in MSW was the same (about 45 ppm) before and after composting. The composting process did not significantly change the available copper. It was 2.3 ppm for raw materials for the aerobic process and 4.5 ppm after mixing with EM standard solution. The sample collected from the dumping site had a total copper content of 206 ppm. The rice milling by-products had even lower concentrations. The total Cu was 22 ppm and only 2 ppm was available. The Zn concentration in MSW was almost 5 times higher than that of Cu with rela-

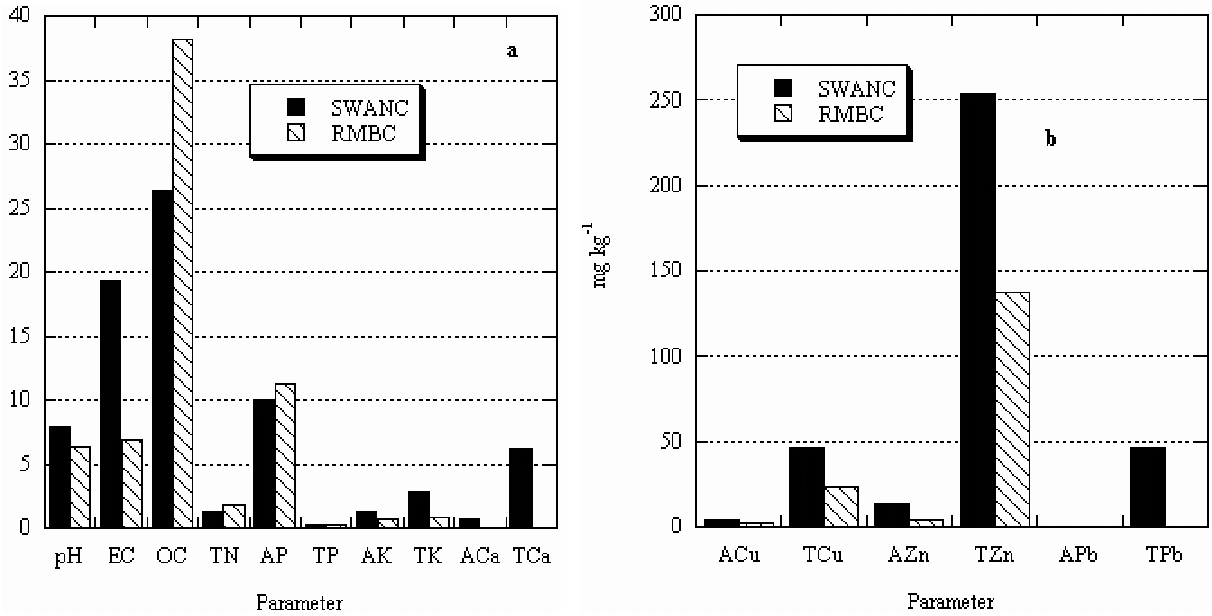

Fig. 2: Chemical composition of final compost from different raw materials (A: available: T: total) Unit of parameters are: EC = $mScm^{-1}$, AP in RMBPC = centigram kg^{-1} and OC, TN, TP, ACa and TCa are in %.

Table 2: Trace metal content (mg kg^{-1}) in the raw materials and compost (A, T as defined in Table 1).

Sample	ACu	TCu	AZn	TZn	APb	TPb
SWRM	2.3	45.3	11.3	249	ND	45.3
SWRMB	4.5	45.1	11.3	248	ND	45.1
SWANC	4.6	46.2	13.9	254	ND	46.2
SWAC	2.2	44.1	15.4	331	ND	66.1
RMBRM	2.2	22.4	11.2	112	ND	0
RMBC	2.3	22.8	4.55	137	ND	0
SWCJ	2.1	206	20.6	351	ND	103

tively constant concentration (248 ppm) for total Cu and 11 ppm for available Cu. The concentration of Zn was 351 ppm as total and 11 ppm as available in the compost collected from Jumbi dumping site. The rice milling by-products had a total Zn of 113 ppm and increased to 137 ppm after fermentation. The available Zn was only 11 ppm in raw materials and decreased to almost half (4.5 ppm) in the compost. This may be associated with the increase in pH, which precipitates most of the soluble Zn. The concentration of Pb was about 45 ppm in Municipal solid waste before and after anaerobic composting. The concentration increased slightly to 66 ppm in aerobic composting. The sample of compost collected from Jumbi dumping site had Pb concentration of 103 ppm. The total and available lead concentrations in the rice milling by-products were under the detection limit.

Discussion

Physical changes

The MSW showed that it was dominated with organic fractions and the constituents of non-decomposable fraction were mostly plastic. The composting process under aerobic conditions demonstrated a decrease in volume of almost 60% of the original municipal solid waste and appeared to be dark brown and of coarse texture. These results demonstrate that if ZMC can separate plastic materials at source and avoid mixing them with other waste, composting can be a promising way of SW management and, therefore, reduce the spread of waste in the environment. MSW spread has been a major concern to the public health sector because of its connection with outbreaks of cholera, typhoid and malaria, as well as contaminating water sources (Water Policy 2004). In addition to that, the blocking of the sewerage system which resulted in occasional flooding is also associated with draining of municipal solid waste. Health reports documented that in Jambiani village, there has been a significant decrease in malaria cases and other communicable diseases such as cholera and diarrhoea since 1998. This is attributed to municipal solid waste collection program conducted in the village (personal communication with Jambiani health officer 2007). Municipal solid waste and rice milling by-products composted anaerobically after mixing with effective micro-organisms demonstrated the presence of white filamentous fungi and a fermented smell: an indication of good composting process. The anaerobic process also decreases the volume to about 10% of the original volume.

Effect of raw materials

The MSW and the rice milling by-products were composted anaerobically under the same conditions. This provided an opportunity to study the quality of compost produced from these two major types of solid waste available in Zanzibar. The summary of the results is presented in Table 1 and Figure 2. The pH of MSW was generally higher (7.9) than that of rice milling by-products (6.5). This is attributed to large cation con-

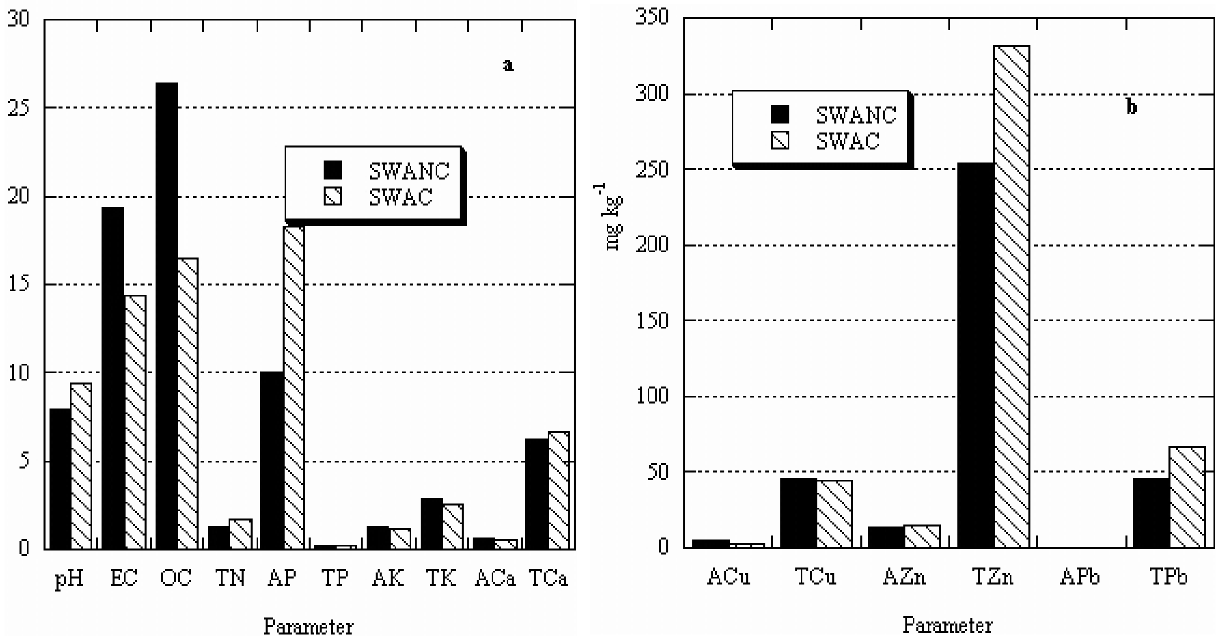

Fig. 3: Chemical composition of municipal solid waste composted under different conditions. Unit of parameters are defined in Fig. 2. Unit of parameters are: EC = $mScm^{-1}$, AP in RMBPC = centigram kg^{-1} and OC, TN, TP, ACa and TCa are in %.

tents, especially Ca^{2+}. The total Ca^{2+} concentration in MSW was almost 50 times higher and that available was 200 times higher than for the rice milling by-products. Zhang and He (2006) also found a higher pH value in the compost with large cations. The organic carbon and nitrogen contents were higher for rice milling by-products than MSW compost. This was the reflection of the nature of raw materials in which MSWRM have higher metal content and lower organic carbon and nitrogen content. The total phosphorous was almost the same for both raw materials. However, the available phosphorous was very low for MSW. This might be due to the presence of high Ca^{2+} content, leading to the precipitation of calcium phosphate. Potassium ion was also higher in municipal solid waste than in the rice milling by-products. In the case of trace metals (Cu and Zn), there were almost double in MSW than in the rice milling by-products, whereas lead was not detected at all in the rice milling by-products. This is associated with contamination by other waste products dumped together with MSW. This result suggests that in low cationic acidic soil, MSW compost can work well as a soil conditioner.

Effect of composting process

MSW was composted aerobically and anaerobically to investigate physico-chemical changes associated with composting process. The summarized results are presented in Table 1 and Figure 3. It is worth noting that anaerobic compost was enhanced by effective micro-organisms. The discussion will, therefore, present the synchronized effects of EM and anaerobic condition. The pH of anaerobic compost was slightly lower than that of aerobic, while EC was higher for anaerobic compost. The pH of compost is a function of the balance between produced organic acid and ammonia. The results suggest that the composition of organic matters present in the final compost might not be exactly the same. The anaerobic process is mainly dominated by fermentation, which involves partial decomposition of complex organic compounds into simple compounds, while aerobic involves complete decomposition of organic matters into CO_2 and water. The total decomposition was reflected by the decrease in total volume by ~60% and TOC by 10% and by the increasing the concentration of total nitrogen from 1.39% to 1.73%. The available phosphorous was highly affected by composting process. Anaerobic conditions demonstrated a significant decrease of phosphorous, which may be attributed to microbial utilization which fixes the phosphorous during new cell formation (Huang *et al.* 2004). The trace metals (Zn and Pb) were higher in aerobic compost, probably as a result of the decrease (23–16%) in organic carbon.

Effect of compost management

The majority SW treatment process practised by ZMC is landfill, in which SW collected from Zanzibar municipality is dumped and left to decompose naturally at Jumbi dumping site. It has been proposed to use the remains as compost. The decomposed SW is also subject to leaching during the rain. The leachate has been associated with contamination of well water around the site, where two wells have been declared unfit for domestic use (personal communication with Jumbi dumping site authority). The decomposed municipal solid waste from Jumbi dumping site (unmanaged compost) was collected for comparison with aerobic MSW compost (managed compost) and the results are presented in Table 1 and Figure 4. The results show that both samples were alkaline. However, the dissolved species as indicated by EC was very low in the unmanaged decomposing municipal

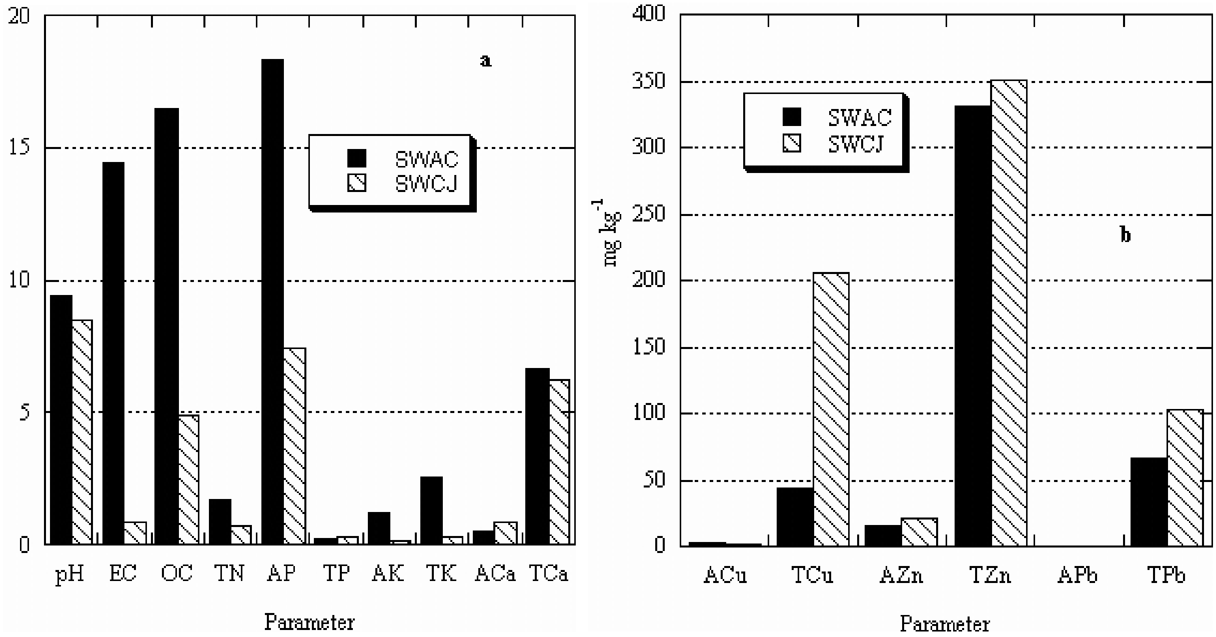

Fig. 4: Chemical composition of municipal solid waste composted under different conditions. Unit of parameters are: EC = mScm^{-1}, AP in RMBPC = centigram kg^{-1} and OC, TN, TP, ACa and TCa are in %.

solid waste. The total organic carbon, nitrogen, potassium and Ca and available phosphorous and potassium and Ca were lower in unmanaged compost from the dumping site. This is attributed to the leaching of soluble species during the rain. There is no significant difference in total phosphorous between controlled and uncontrolled compost, presumably due to low mobility of phosphorous as a result of formation of phosphate ligand in metallic oxide, as well as phophohumic complex (Iglesias-Jimenez *et al.* 1993). Soluble calcium concentration was higher for the Jumbi sample, probably due to contamination with soil. Trace metal contamination, specifically copper and lead, were significantly higher in the unmanaged compost from Jumbi dumping site (Figure 4). In general, the chemical composition of MSW compost has a similar trend in controlled and uncontrolled composting because of similar raw materials. However, the unmanaged compost was deprived of nutrients and enriched with trace metals when compared to managed compost.

Compost quality

Compost quality is affected by a number of different factors, including initial C:N ratio, management process and composting time. These ultimately determine the physico-chemical characteristics and availability of nutrients and trace elements. Good compost can support plant growth and minimize environmental damage. Some countries such as the US, Canada and European countries set limits for certain compositions in the compost. However, in Tanzania specifically Zanzibar there is no regulatory body. The quality of compost prepared in this study is, therefore, compared with other reported studies. The pH and EC values observed in this study are higher than those reported by Brady and Weil (1996) but within the reference values reported by Xing (2002). Organic carbon content, total nitrogen and phosphorous were comparable to those reported by Xing (2002) and Hargreaves *et al.* (2008).

The trace metal contents found in the Zanzibar municipal solid waste compost are within the range of those reported by other authors (Lasaridi *et al.* 2006, Zhang *et al.* 2007) and far below the limit set by the Canadian Council of the Ministers of the Environment (CCME) and Environmental Protection Agency (EPA) guideline for Cu (400, 1500 ppm), Zn (700–2800 ppm) and Pb (150, 300 ppm) for CCME and EPA, respectively. The quality of compost produced by Zanzibar municipal solid wastes can support healthy plant growth by providing adequate required nutrients (CCME 2005).

Summary and conclusion

This study examined the possibility of composting municipal solid waste from Zanzibar municipality as an alternative way of SW management and assessed nutrient contents of the compost for application to soil to improve agricultural production.

The results showed that municipal solid waste generated in Zanzibar municipality have a significant proportion of organic matters, ranging from 40–70%. Aerobic composting reduced about 60% of the volume of waste. This volume reduction suggests that composting can be a promising SW management technique and, therefore, reduces the large demand for space for landfilling, the method currently used by ZMC. Physico-chemical characteristics of final compost showed that MSW produced a compost with higher pH (~9) and higher dissolved salt content (EC 1.44–1.93 mS cm^{-1}) compared to the rice milling by-products (pH 6.5 and EC 0.34 mS cm^{-1}). Total nitrogen (1.73%) and phosphorous (0.25%) were similar in both solid waste composts. However, the trace metal contents were significantly higher (38–248 ppm) in MSW than in rice milling by-products (0–113 ppm).

Municipal solid waste composted under anaerobic conditions produced compost with a relatively higher concentration of dissolved species than that produced under aerobic conditions. The trace metal content was mainly determined by the type of raw materials used; the composting process had little effect on their presence. A proper compost management process was found to be very important for conserving nutrients. It was found that the unmanaged compost collected from Jumbi dumping site was deprived of nutrients and contaminated with trace metals.

Generally, physico-chemical characteristics, nutrient and trace metal levels suggest that MSW, under proper management, can produce high-quality compost for application to a wide range of soil types to improve their productivity.

Acknowledgement

This research was partial sponsored by the State University of Zanzibar (SUZA), under the exhibition project funds. Mr. Mansour S. Nassor Amour H. Saleh and Mr. Khatib Juma are highly acknowledged for their support during the composting process. Thank to Mr. Masoud S. Salim of Kizimbani Agricultural Institute for chemical analysis of compost. The revision made by of Prof. S. Madumula and Ms Ismail, M. J is also appreciated

References

Brady, N. & Weil, R. (1996) *The Nature and Properties of Soils*, 12th ed. Prentice, New Jersey, USA, pp. 385, 495.

Canadian Council of Ministers of the Environment (CCME) (2005) PIN1340: Guidelines for Compost Quality, Support Document for Compost Quality Criteria.

Environmental Report (2004). State of Environment report for Zanzibar. Department of Environment, Ministry of Water, Land and Environment, Revolutionary Government of Zanzibar.

Hargreaves, J. C. & Adl, M. S. (2008) A review of the use of composted municipal solid waste in agriculture. *Agri. Ecosystem and Environ*., **123**, 1–14.

Hernandez-Berriel, Ma.C., Marquez-Benavides, L., Gonzalez-Perez, D.J. & Buenrostro-Delgado, O. (2008) The effect of moisture regimes on the anaerobic degradation of municipal solid waste Metepec (Mexico). *Waste Management* **28**, 14–20.

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 Manage*. **24**, 805–813.

Iglesias-Jimenez, E., Garcia, V., Espino, M. & Hernandez, J. (1993) City refuse compost as a phosphorus source to overcome the P-fixation capacity of sesquioxide-rich soils. *Plant Soil* **148**, 115–127.

Lasaridi, K., Protopapa, I., Kotsou, M., Pilidis, G., Manios, T. & Kyriacou, A. (2006) Quality assessment of composts in the Greek market: The need for standards and quality assurance. *J. Environ. Manag*., **80**, 58–65.

Rynk, R., van de Kamp, M., Willson, G.B., Singly, M. E., Richard, T. L., Kolega, J. J.,. Gouin, F. R., Laliberty Jr., L., Kay, D., Murphy, D. W., Hoitink, H. A. J. & Brinton, W. F. (1992) On farm compostion. Northeast Regional Agriculture and Engineering Service, Ithaca, New York.

Tanzania Census (2003) 2002 Population and Housing Census General Report Central Census Bureau of Statistics President's office Planning and Privatization, Dar-es-salaam, Tanzania (24^{th} August – 4^{th} September 2002).

Water Policy (2004) National water policy, Ministry of Water, Construction, Energy and Land, Revolutionary Government of Zanzibar.

Xing, Y. (2002) *Principle of Soilless Planting*, first ed. China Agricultural Press (in Chines).

Zhang, R., El-Mashad, H. M., Hartman, K. Wang, F., Liu, G., Choate, C. & Gamble, P. (2007) Characterization of food waste as feedstock for anaerobic digestion. *Biores. Techn*., **98**, 929–935.

Zhang, Y. & He, Y. (2006) Co-composting solid swine manure with pine sawdust as organic substrate. *Biores. Techn*. **97**, 2024–2031.

Zurbrugg, C., Drescher, S., Patel, A. & Sharatchandra, H.C. (2004) Decentralized composting of urban waste – an overview of community and private initiatives in Indian cities. *Waste Manag*. **24**, 655–662.