Available online at www.sciencedirect.com
ScienceDirect
Bioresource Technology 99 (2008) 5120–5124
BIORESOURCE TECHNOLOGY

Short Communication

Evaluation of composting as a strategy for managing organic wastes from a municipal market in Nicaragua

Montserrat Aulinas Masó, August Bonmatí Blasi *

Laboratory of Chemical and Environmental Engineering, University of Girona, Campus Montilivi, s/n, 17071 Girona, Spain

Received 26 January 2007; received in revised form 6 September 2007; accepted 10 September 2007
Available online 19 November 2007

Abstract

A pilot-scale study was undertaken to evaluate alternatives to the solid waste management of a Central American municipal market located in Estelí, Nicaragua. The municipal solid waste from the local market is the second largest contributor to the municipal solid waste (MSW) stream. Waste from the market without any previous sorting or treatment is open dumped. The options evaluated in this study were windrow composting, windrow composting with yard waste, bokashi and vermicompost. Significant differences between the properties of composts produced were found; however, all of them reduce the initial waste volume and are potential useful agronomic products for a survival agrarian milieu.

Keywords: Material flow analysis; Market waste; Windrow composting; Bokashi; Vermicompost

1. Introduction

The population of Nicaragua has increased fivefold over the last fifty years undergoing a population explosion in its urban areas mainly due to rural migration. Estelí is the largest city in the north of Nicaragua with a population of 84,811 urban inhabitants. MSWs are disposed in a sanitary landfill 7 km north of the city; however, open dumping is still commonly practiced. These practices have created serious environmental and public health problems.

In order to improve MSW management the study of major municipal waste fluxes is necessary. Material flow analysis (MFA) is a framework used to identify material flows and to trace the origin of pollution problems of a specified system (Sokka et al., 2004). Waste fluxes from markets are relevant since they are one of the major waste fluxes in the municipalities and usually have a high organic fraction. Aerobic treatments aimed to stabilize the organic fraction of solid wastes can result very useful.

The aims of this study were 1. to identify and quantify the waste fluxes of the Alfredo Lazo municipal market in Estelí municipality; 2. to characterize the composition of the solid wastes produced in detail, and 3. to evaluate four techniques for composting the organic fraction namely windrow composting, windrow composting with yard waste, bokashi and vermicompost.

2. Methods

2.1. Market's material flow analysis

MFA was used in order to quantify its main input-output flows in the municipal market so as to diagnose the main solid waste problems. The fluxes were estimated through interviews with the market manager, surveys to the salesmen and a quantification and characterization of a one-week sample of the municipal market's solid waste (seven trucks of waste collection in seven consecutive days). The samples were classified and weighed to

* Corresponding author. Tel.: +34 972 41 82 81; fax: +34 972 41 81 50.
E-mail addresses: aulinas@lequia.udg.es (M. Aulinas Masó), august.bonmati@udg.es (A. Bonmatí Blasi).

0960-8524/$ - see front matter
doi:10.1016/j.biortech.2007.09.083

determine the proportions of the different fractions namely organic waste, plastics, metals, paper-cardboard, glass and textile.

Furthermore, as nitrogen is considered an important nutrient as well as a potential polluting element in aquatic ecosystems, equivalent nitrogen flows was also calculated from nitrogen levels of fresh products obtained from literature (Bartrolí, 2003).

2.2. Composting tests

Table 1 shows the main characteristics of the 4 different tests performed. Organic matter from the market was manually sorted from the total amount of solid waste, and piles were formed as follows:

- *Compost windrow* (*CO*): One layer of organic wastes from the market (the biggest layer), one layer of cattle manure and a thin layer of soil and ashes. It was all mixed and watered till around 50–60% of humidity according to hand-squeezing test (FCQAQ, 1994).
- *Compost windrow with yard waste* (*COYW*): Six successive layers of organic wastes from the market and municipal pruning (2:1 v/v), all of them well mixed and watered following the test mentioned before.
- *Bokashi* (*Bk*): A layer of organic wastes from the market, a layer of cattle manure (coming approximately to 170 kg of organic wastes), a thin layer of vegetal coal and a thin layer of rice husk (2.3 kg each), all of them watered with yeast and sugar from cane dissolved in water. This procedure was repeated three times and materials were turned over frequently.
- *Vermicompost* (*Vc*): Materials used in the assay were pre-treated before beds formation as follows. Cattle manure was soaked with water for 20 days in order to reduce pH, and organic waste was partially degraded in order to protect worms from the high temperatures that are reached in the first step of aerobic biodegradation. After these initial processes a mixture of cattle manure and organic solid wastes from the market was used to form vermicompost beds with a height of no more than 0.5 m (local population use to produce vermicompost only with manure). The moisture content of the material was maintained between 70% and 80%. The concentration of worms used was between 600 and 700 worms/m^3 (200 g/m^3) as recommended by Röben (2002).

2.2.1. Process control

Temperature was measured at least three times per week with a temperature probe 50 cm long. Moisture was controlled with the hand-squeezing test according to FCQAQ (1994). Aeration was done by periodically turning the piles depending on moisture and temperature state. Volume of the pile was measured periodically taking the principal measures (height, length, width and diameter, depending on the case). Piles of CO and COYW were assimilated to triangular base prisms whereas piles of Bk to cones.

Chemical characterization and germination tests were done on the final product of each process as described below.

2.2.2. Analytical methods

Total Kjeldhal nitrogen (TKN), total solids (TS) and volatile solids (VS) were analyzed by standard methods (APHA, 1998). pH of the water extract (1:5) was measured using a pH meter, and nitrate-N, ammonium-N, available phosphorous P_2O_5, total phosphorous and potassium (K_2O) were measured according to the Austrian norms (MASAH, 2001). Four potentially toxic elements (Pb, Mn, Zn and Hg) were measured at the end of the processes using atomic absorption spectrometric methods (APHA, 1998). C:N ratio was calculated using Eq. (1) (MASAH, 2001).

$$\frac{C}{N} = \frac{(VS \times 0.58)\%\ \text{dry matter}}{(\text{Kjeldhal-N})\%\ \text{dry matter}} \quad (1)$$

Several authors (Chikae et al., 2006; Helfrich et al., 1998) identified germination index as the most sensitive parameter for determining compost phytotoxicity. Germination tests were therefore performed with *Phaseolus vulgaris* and *Zea mays*. Relative germination index (GI) was calculated using Eq. (2) according to Chikae et al., 2006:

$$GI = \frac{\text{number of seeds germinated in the sample}}{\text{number of seeds germinated in the control}} \times 100 \quad (2)$$

Analytical values were tested statistically using SPSS 12.0.

Table 1
Characteristics of the assays performed

	Repetitions	Materials	Process control	Time (days)
Compost (CO)	3	Organic wastes from the market (OW), cattle manure, ashes	Turn over and watering. Measurement of temperature, moisture and size	79
Compost + yard waste (COYW)	4	OW, yard wastes (YW)	Turn over and watering. Measurement of temperature, moisture and size	68
Bokashi (Bk)	3	OW, cattle manure, vegetal coal, ashes, rice husk, leavening, sweet	Frequent turn over. Measurement of temperature, moisture and size	13
Vermicompost (Vc)	2	OW, cattle manure and worms (*E. foetida*)	Watering and incorporation of new material. Control of worms	30

3. Results and discussion

3.1. Quantification of market flows

Fig. 1 shows the market fluxes considered and their quantification. The solid waste produced was 1003.5 tones per year (7.7% of total MSW produced in Estelí; Flores et al., 2003). Organic waste was the most significant proportion and accounted for about 90.9% of the solid waste with an average density of 366 kg/m^3. The remaining waste was made up of plastic and compounds, paper and cardboard, glass, textile and metals (in percentage 5.38, 3.00, 0.42, 0.26 and 0.05, respectively).

As shown in Fig. 1, 3.9 tones of N exited the system through solid wastes. Their impact on soils, surface and ground water should be high since there is no good management at the landfill (wastes are not covered; there is not a proper waterproofing of the vessel with the consequent runoff of leachates, no control of gases and odours, etc.).

These figures show that more than 90% of wastes produced in the market are organic matter that could follow path **b** instead of the present path **a** (Fig. 1); they could be composted in order to reduce the organic load in the landfill as well as to produce an organic fertilizer or soil amendment. The valorization of organic waste (through compost) could be of high interest in the area, enabling the reduction in the use of chemical fertilizers and enhancing the protection of soils and groundwater.

3.2. Composting tests

3.2.1. Temperature profile

Average profile temperatures for CO, COYW and Bk are shown in Fig. 2 (Vc temperature remains constant). For all these composting processes there was good activation and they reached temperatures above 55 °C on the second day of the process. A thermophilic phase was observed between the 5th and 10th day. This range is clearly shown for COYW and Bk but it somehow fluctuated in the CO process.

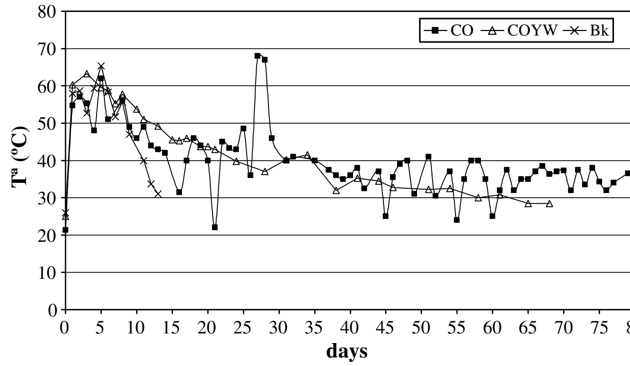

Fig. 2. Temperature evolution in composting experiments.

After this phase, the behaviour of different processes changed. The Bk test rapidly lowered the temperature, reaching ambient temperature in just thirteen days. This could be explained by the high activity of the process due to the inoculation with active microorganisms. COYW progressively lowered the temperature, holding a mesophilic range for over one month. CO temperature oscillated more and reached the maturation phase much later than COYW. The lack of structuring material such as yard waste could be the reason for a more heterogenic behavior in the CO process.

3.2.2. Volume reduction

The initial mass was considerably reduced in all cases. CO has the highest mass reduction (67.3%), followed by COYW. The minor reduction of volume in COYW piles, although they showed the best temperature profile, can be attributed to he high content of lignin (weakly biodegradable) in yard wastes. It is noteworthy that the mass reduction in the Bk test was 54.4% in just 15 days.

The product was sifted with a 5 × 5 mm trap. So at the end 50% of the transformed material appears to be fine

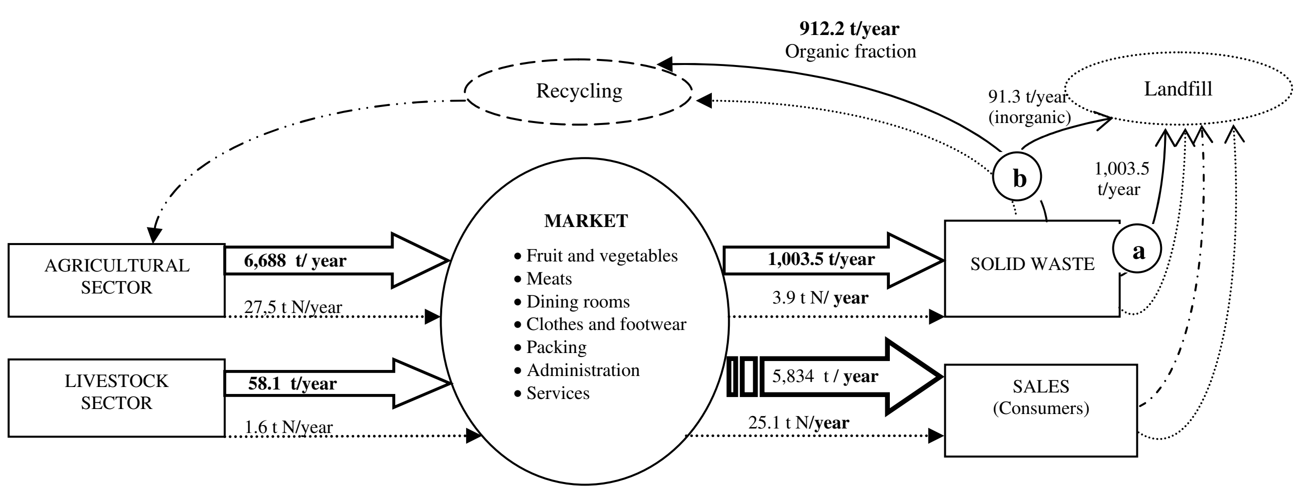

Fig. 1. Flow diagram of the system studied.

compost (<5 mm), 30% rough compost (>5 mm) and 20% of the volume was inorganic material (plastics, pieces of glass) that could not be sorted at the beginning.

3.2.3. Compost characteristics

In this section the characteristics of the composts produced are discussed.

3.2.3.1. Moisture and pH. Moisture between 30% and 40% in mature compost is the usual value established in reviewed regulations (Spanish, European and Austrian). In the present study, almost all samples fit in the mentioned interval; only vermicompost, with the highest moisture content (62.9%), is out of limits, indicating that it is necessary to dry it before sale. All samples were in the range of satisfactory values of pH (7–8.5).

3.2.3.2. Nutrients: N, P, K. Vermicompost (Vc) was the sample with the highest values of macronutrients. Worms are able to transform the non assimilable minerals of organic wastes and livestock wastes into phosphates and nitrates which are directly assimilated by plants (Garg et al., 2006; Tognetti et al., 2007).

C to N ratio from different samples was calculated at the end of the processes as an indicator of the composting operation (Padmavathiamma et al., 2007). Samples of COYW had the lowest ratio (13.7, while other samples were between 26 and 32) indicating the best performance of the composting process. Temperature profiles verify that there was a good thermophilic and mesophilic range and, therefore, a good biodegradation (Fig. 2). These results show as well the importance of structuring material such as yard waste to equilibrate the composition of the market's waste and improve oxygen distribution.

3.2.3.3. Potentially toxic elements. Pb and Hg were below detection levels. With reference to Zn levels, all types of compost produced could be applied in agriculture as their values are below the maximum permitted level of 500 ppm (European Comission, 2001; MASAH, 2001; Ministry of the Presidency, 2005). The high levels of Mn (900 ppm in CO, 700 in Bk, 583 in COYW and 500 in Vc) could be explained by the transference of metals from the source materials to the final manure, as suggested by Manungufala et al. (2007); several Mn batteries were found when sorting solid wastes from the market. These results show the importance of a good waste sorting at source to prevent the transference of metals or other pollutants. A better solid waste management should be introduced in the market in order to obtain fine quality compost.

3.2.4. Germination test

Data from Table 2 show the number of *Phaseolus vulgaris* and *Zea mays* seeds germinated in each substrate as well as the results of relative germination index (GI). There was good seed germination for all samples excluding those of *Phaseolus vulgaris* sown in Bk and in CO. According to levels of toxicity established by Uribe (2003), the results obtained showed that Bk substrate and CO substrate were "very toxic" and "toxic" for *Phaseolus vulgaris* seeds, respectively. These results probably indicate an insufficient stabilized product or the presence of any other toxic substances for these seeds (Said-Pullicino et al., 2006). Although, it is necessary to perform other tests such as those done by Eghball and Lesoing (2000) and Helfrich et al. (1998) in order to understand the cause or origin of this phytotoxicity.

Table 2
Average number of germinated seeds and GI (%) results for different substrates used in the test

Substrate	Number of germinated seeds		GI (%)	
	Phaseolus vulgaris	*Zea mays*	*Phaseolus vulgaris*	*Zea mays*[a]
CO	13.00 $s = 2.64$	20.00 $s = 1.00$	60.00	136.36
COYW	21.33 $s = 4.72$	14.00 $s = 3.60$	98.46	95.45
Bk	1.00 $s = 1.73$	14.33 $s = 4.04$	4.62	131.82
Vc	17.50 $s = 0.70$	21.50 $s = 0.70$	83.08	146.59
Control	21.67 $s = 0.57$	14.67 $s = 1.52$	100.00	100.00

[a] % higher than 100 due to the lower germination in *Zea mays* control compared with the other substrates.

3.3. Evaluation of composting techniques performance

Results showed that composting processes in a tropical climate with a dry season are possible, obtaining organic fertilizer of good quality in less than three months. However each technique has advantages and drawbacks. Bokashi is a very quick process, but requires more investment in initial products and the product obtained presents some toxicity as described in Section 3.2.4. Vermicompost is specially appreciated in the area, but requires specific knowledge on worm's breeding and care. COYW looks like the most suitable technique: process performance and the compost quality is better than CO, and doesnot require extra product. Furthermore, treating pruning together with MSW can be considered as an improvement in municipal waste management.

4. Conclusions

The municipal market Alfredo Lazo produces a considerable quantity of wastes amounting to 1003.5 tones per year. Most of the waste produced is organic (90.9% of wastes) with a nitrogen content of 2.8%. The techniques assayed to produce compost are time consuming but low cost, and for these reasons they could be easily extended to other Central America municipalities; however, it is important to apply appropriate technologies at each location. Although all of them can produce an organic fertilizer of good quality, to our opinion based on the results obtained, we would recommend producing compost with yard waste (not commonly used in the country).

Considering the lack of scientific data and the multiple difficulties on their generation, we believe that our work will provide useful new data to strength the local political decisions going to more sustainable waste management practices in the municipality.

Acknowledgements

The research was supported by an Alfa European Program (II-0334-FA).The authors express their appreciation for the valuable effort made by all members of CentralRisk network as well as the unconditional help of the inhabitants of Estelí.

References

APHA (American Public Health Association), AWWA (American Water Works Association), WEF (Water Environmental Federation), 1998. Standard Methods for the examination of water and wastewater. 20th ed., APHA, Washington DC: American Public Health Association.

Bartrolí, J., 2003. Avaluació ambiental del cicle del nitrogen a Catalunya: aplicació de l'anàlisi del flux de substàncies. PhD Thesis, University of Girona.

Chikae, M., Ikeda, R., Kerman, K., Morita, Y., Tamiya, E., 2006. Estimation of maturity of compost from food wastes and agro-residues by multiple regression analysis. Bioresour. Technol. 97, 1979–1985.

Eghball, B., Lesoing, G.W., 2000. Viability of weed seeds following manure windrow composting. Compost Sci. Util. 8 (1), 46–53.

European Comission, 2001. Commission Decision 2001/688/EC of 28 August 2001 establishing ecological criteria for the award of the Community eco-label to soil improvers and growing media.

Flores, J., Ortega, Y., García, Y., 2003. Diagnóstico del Manejo de los desechos sólidos en la ciudad de Estelí. CURN-Estelí, Nicaragua.

FCQAQ (Federal Compost Quality Assurance Organization), 1994. Methods book for the analysis of compost.

Garg, P., Gupta, A., Satya, S., 2006. Vermicomposting of different types of waste using *Eisenia foetida*: A comparative study. Bioresour. Technol. 97 (2006), 391–395.

Helfrich, P., Chefetz, B., Hadar, Y., Chen, Y., Schnabl, H., 1998. A novel method for determining phytotoxicity in composts. Compost Sci. Util. 6 (3), 6–13.

Manungufala, T.E., Chimuka, L., Maswanganyi, B.X., 2007. Evaluating the quality of communities made compost manure in South Africa: A case study of content and sources of metals in compost manure from Thulamela Municipality, Limpopo province. Bioresour. Technol.. doi:10.1016/j.biortech. 2007.02.2006.

MASAH, 2001. ÖNORM 292: Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über Qualitätsanforderungen an Komposte aus Abfällen (Kompostverordnung).

Ministry of the Presidency, 2005. Real Decreto 824/2005, de 8 de julio, sobre productos fertilizantes. BOE núm. 171, Spain.

Padmavathiamma, P.K., Li, L.Y., Kumasi, U.R., 2007. An experimental study of vermi-biowaste composting for agricultural soil improvement. Bioresour.Tehcnol.. doi:10.1016/j.biortech. 2007.04.028.

Röben, E., 2002. Manual de compostaje para municipios. Loja, Ecuador.

Said-Pullicino, D., Erriquens, F.G., Gigliotti, G., 2006. Changes in the chemical characteristics of the water extractable organic matter during composting and their influence on compost stability and maturity. Bioresour. Technol.. doi:10.1016/j.biortech.2006.06.018.

Sokka, L., Antikainen, R., Kauppi, P., 2004. Flows of nitrogen and phosphorous in municipal waste: a substance flow analysis in Finland. Progress in Industrial Ecology 1 (1/2/3).

Tognetti, C., Mazzarino, M.J., Laos, F., 2007. Improving the quality of municipal organic waste compost. Bioresour. Technol. 98 (2007), 1067–1076.

Uribe, L., 2003. Inocuidad de abonos orgánicos. En "Taller Abonos orgánicos CATIE/GTZ/UCR/CANIAN" editado por Gloria Meléndez y Gabriela Soto.