

COMPOSTING OF < 100 mm FRACTION OF MUNICIPAL SOLID WASTE

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(Received 29 October 1991, accepted in revised form 18 May 1993)

A low cost solution for management of municipal solid waste in small municipalities was investigated; composting experiments were done using domestic waste. Particles > 100 mm were removed, the screened substrate (< 100 mm) was used for composting experiments on static piles. The results have shown that the size of waste does not affect composting. Though the inert material left greatly adds to the porosity, rainfall does not markedly affect the process; in fact excessive dryness gave the least stable end product, and total nitrogen, ammoniacal nitrogen and phosphorus content were the best pointers to the instability.

Key Words—Composting, municipal solid waste, maturity, Spain.

1. Introduction

Composting of organic waste is an established technology. The application of the process to municipal solid waste has not always been fully successful, however, for which the principal causes are: inappropriate application of the technology producing low quality or even harmful products; difficulties in selling the compost and in recovering plant instalment and operating costs.

In north-west Spain, where much of the population lives in communities of less than 3000 people, the dispersion of waste generating centres is an additional problem, when installing a composting plant.

Current practice in Spanish municipal solid waste (MSW) composting plants, is the removal of inert, non-fermentable elements (plastic, glass, metal, etc.) from the raw waste prior to fermentation. In general terms, the size of raw waste is reduced and the inert fraction is eliminated using a combination of sieves, air sorters, magnetic separators and other devices. Although the market offers many possibilities in this respect, suited to different loads (Martegani & Zoglia 1985), pretreatment is the costliest part of the entire process (Glaub *et al.* 1984) and means a minimum volume of waste must be processed for cost effectiveness.

The present work suggests a simplified treatment suitable for areas generating little waste, in which refuse passes through a short pre-treatment for removing inert solids of size > 100 mm or more, before composting in static piles with forced ventilation. The necessity of covering the piles for protection from heavy rains was also studied.

2. Material and methods

Two 3 × 3 × 1.25 m piles of refuse were made. After breaking the bags to expose their contents, raw waste was screened through a 100 mm trommel, the oversize particles were

rejected and the undersize fraction was employed for composting. This fraction retains the organic matter present in raw waste mixed with inert elements such as cans, plastic bottles and paper of size < 100 mm. One pile was kept covered under a $9 \times 4 \times 2$ m plastic tunnel for protecting it from rain during composting. The tunnel had both ends opened. The other pile was left uncovered. Both piles were ventilated using centrifugal blowers of 2 h.p. (horse-power) and 1 h.p. for the unenclosed and enclosed piles respectively; different fan powers were used because more air was expected to be needed for the pile exposed to rain. Fans were connected to the piles by a 10 cm diameter rigid PVC tube, 150 cm of which protruded into the pile, and was opened only at the end; preliminary trials showed that for the employed size, and pile porosity, such a configuration did not produce uneven air distribution. Temperature feed-back control was used to operate the blowers, 65°C being chosen as set point.

Pile temperature was measured at various points with a thermoresistance mounted at the end of a PVC tube. Oxygen content was measured with an Eijelkamp oxymeter on an 80 cm metal plate.

2.1 Sampling procedure

At the start of the experiment three 10 kg samples of raw screened substrate were taken, air dried, inert materials were hand picked and the remaining waste, mainly organic, was crushed and screened using a 2 mm mesh. This sample is reported as initial.

During composting, 1 kg samples from two random points in the pile were taken on days 29, 55 and 80 after the beginning of the experiment, samples were air dried, inert elements removed and the remaining waste was screened to 2 mm.

After 110 days of composting, compost was manufactured by sifting the piles in a horizontal sieve with a 2 mm mesh. Several 1 kg final samples were taken from the undersize fraction and carefully homogenized.

2.2 Chemical analysis

The pH was measured potentiometrically in a 1:2 solution of 10 g of sample in distilled water, N using Kjeldahl procedure, ammoniacal N using MgO according to I.P.L.A. (1984) and organic matter by calcination of a sample at 550°C for an hour. Heavy metals were measured after mineralization of duplicate samples in concentrated $\text{HNO}_3\text{-HClO}_4$ acid (4-1) on a hot plate at about 150°C ; blanks were carried out under identical conditions, digested samples were diluted and analysed by AAS, and analytical grade reagents were employed. Phosphorus was measured according to M.A.P.A. (1982).

For moisture determinations, 300 g samples were dried in an oven at 105°C for 24 hours. Air temperature and rainfall were measured at a meteorological station sited 300 m from the site of the experiment.

3. Results

Figures 1 and 2 show the mean time the blower was on and how the temperature and oxygen content of the piles varied at three different points within the pile. Ten days from the start of the process, thermophilic conditions were reached in both piles and blowers started operating, except in the unenclosed pile in which failure of a sensor caused a 10 day delay. While ventilation was forced the temperature in the enclosed pile oscillated between $60\text{--}65^{\circ}\text{C}$, close to the control temperature value, and the temperature profile

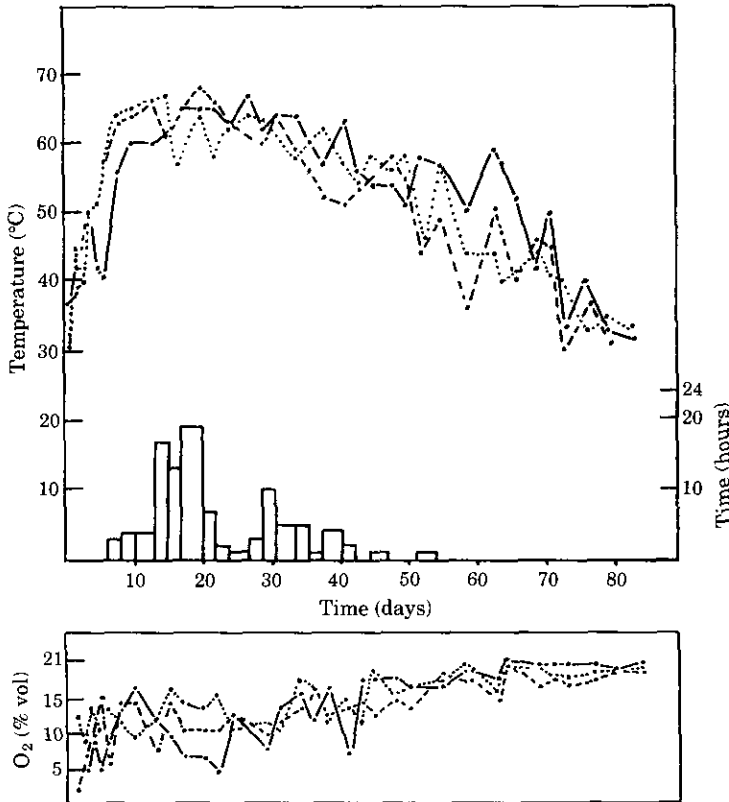


Fig. 1. Temperature ($^{\circ}\text{C}$) and % oxygen (v/v) of the enclosed pile. (●.....●) top; (●---●) middle; (●—●) base. The vertical bars show the mean blower demand times.

fitted the general model proposed by Stentiford *et al.* (1985) for static piles quite well. The range of variation in the unenclosed pile was greater, 35–65 $^{\circ}\text{C}$, due probably to an excess of ventilation. Choosing an adequate blower schedule, despite the extensive bibliography on the subject, is difficult since there is no valid rule for adjusting this parameter.

When the period of feed-back temperature control had finished, the temperature fell gradually in both piles, and more quickly in the outermost layer than deep within the pile.

O_2 levels in both piles generally stayed above 10% guaranteeing aerobic conditions throughout the experiment. In the unenclosed pile O_2 levels fell below 10% during the failure of the control system, until ventilation was restored. Low oxygen values were recorded on day 30–45 during moments when the blower was off. The action of the blower leads to temperatures and oxygen levels which encourage microbial activity and oxygen consumption (Finstein *et al.*, 1983). After the period of blower demand the oxygen levels in both piles were very high, indicative of non intense fermentation.

The pattern of humidity (Fig. 3) in the enclosed pile indicates excessive dryness produced by joint action of heat produced during fermentation and great porosity given by size of waste. In this pile after 20 days, moisture conditions were borderline for the survival of microorganisms. In the unenclosed pile the rainfall helped to keep moisture values within optimum levels (Fig. 4).

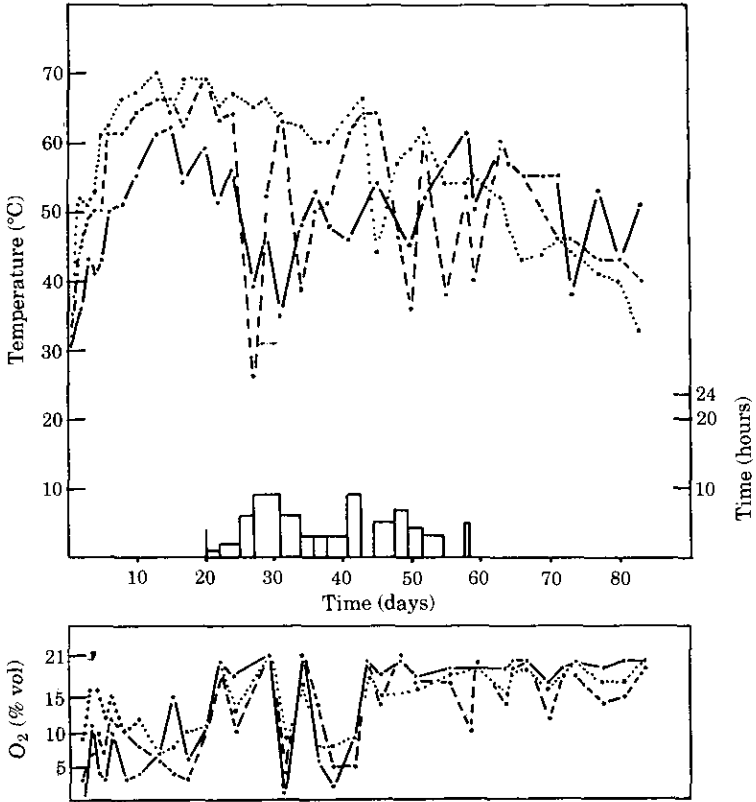


Fig. 2. Temperature (°C) and % oxygen (v/v) of the unenclosed pile. (●.....●) top; (●---●) middle; (●—●) base. The vertical bars show the mean blower demand times.

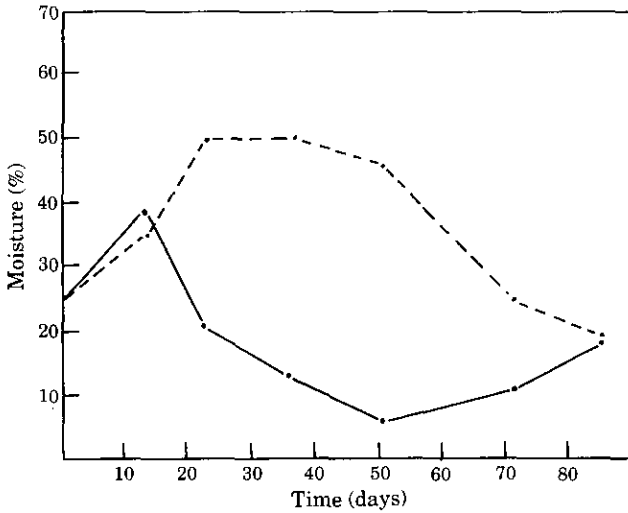


Fig. 3. Moisture content of enclosed pile (●—●) and unenclosed pile (●---●).

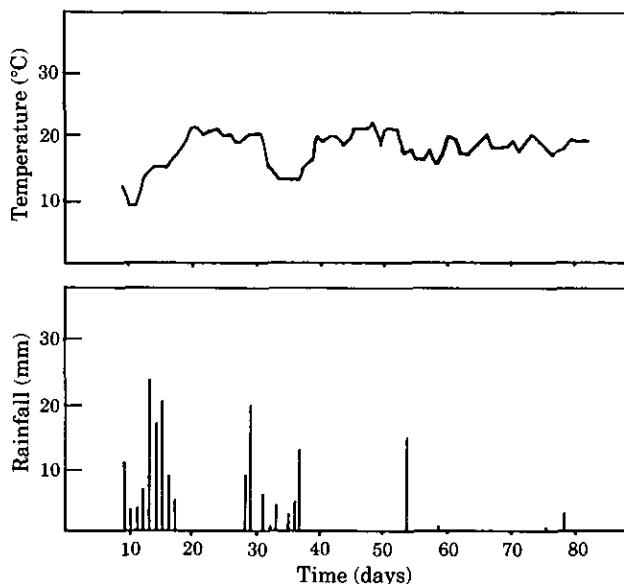


Fig. 4. Mean temperature and rainfall (vertical bars) during the experiment.

TABLE 1

Variations on nutrient contents of enclosed pile (EP) and unenclosed pile (UP). Organic matter (OM), total nitrogen (N), carbon-nitrogen ratio (C/N) and total phosphorous (P). All values in % dry matter (except pH)

Day	pH		OM		N		C/N		P	
	EP	UP	EP	UP	EP	UP	EP	UP	EP	UP
Initial	6.5	6.5	36	36	1.84	1.84	9.7	9.7	0.40	0.40
29	7.5	7.7	34	29	2.19	1.96	7.7	7.3	0.45	0.45
55	6.9	7.5	31	31	1.59	2.42	9.7	6.4	0.35	0.48
80	7.1	7.6	30	29	2.12	2.48	7.0	5.8	0.43	0.63
Final	7.8	8.0	25	26	1.41	1.74	8.8	7.4	0.32	0.66

TABLE 2

Initial and final values of cadmium (Cd), lead (Pb), mercury (Hg), zinc (Zn) and nickel (Ni) of enclosed (EP) and unenclosed (UP) piles. All values in ppm dry matter

Day	Cd		Pb		Hg		Zn		Ni	
	EP	UP	EP	UP	EP	UP	EP	UP	EP	UP
Initial	0.3	0.3	114	114	0.17	0.17	270	270	14.5	14.5
Final	0.4	1.6	210	234	1.49	0.67	240	910	25	35

Table 1 shows the variation in different chemical parameters during the experiment. The fraction analysed is characterized by low values of organic matter and C/N ratio, and these parameters show similar patterns in both piles. The values of total nitrogen, phosphorus and ammoniacal N (Fig. 5) show more marked differences. Table 2 shows the initial and final concentration for heavy metals, initial values corresponding to the

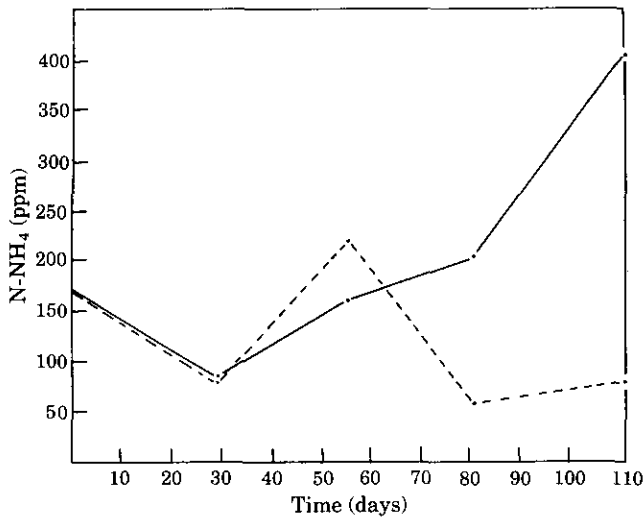


Fig. 5. Ammoniacal nitrogen content of enclosed pile (●—●) and unenclosed pile (●— —●).

organic part of screened substrate employed for composting trials. During composting a significant increase in heavy metal content was produced and the unenclosed pile showed a greater increase.

4. Discussion

4.1 Temperature and oxygen evolution

It is widely believed that reducing the granulometry benefits composting by increasing the contact between the material and microorganisms (Jeris & Regan 1973, Diaz *et al.* 1982). Nevertheless, the rapid increase in the temperature at the start of the experiment and the period of blower demand seem to indicate otherwise, in accordance with results obtained by Begnaud & de Blignieres (1987) in experiments with 80, 150 and 250 mm fractions. The coarse size of the material employed seems to provide sufficient oxygen to give thermophilic conditions at the beginning of the composting process, without any need for extra ventilation, though in larger piles this oxygen reserve could be exhausted more rapidly.

Given the porosity of the material, excessive precipitation could lead to anaerobic conditions; however in the experiment described here and despite the relatively small size of the piles, rain does not seem to adversely affect the evolution of temperature and oxygen levels, coinciding with the findings of Haug (1980), Le Bozec & Resse (1986) and Finstein *et al.* (1986a). Excessively low humidity levels, however, are widely recognized as limiting the microbial activity with an associated fall in heat production (Schulze 1961, Haug 1980, de Bertoldi *et al.* 1983, Finstein *et al.* 1986a,b). In the enclosed pile in spite of low moisture levels, no sharp cooling is noted because heat is lost slowly by conduction (Finstein *et al.* 1986a, Le Bozec & Resse 1986). Nevertheless the fall in ventilation demand during days 30–40 may show, as Finstein *et al.* (1986a) has suggested, biological limitations linked to dryness, introducing the need for dampening the material.

Finally noting the lack of a clear-cut relation between temperature and heat production which might lead to composting being continued unnecessarily, the high

TABLE 3
Chemical characterization of compost from different sources. All values in % dry matter

	Summer ^a	Winter ^b	c	d	e
OM	51.3	38.69	50–60	35–45	32–46
P	0.24	0.33	0.21–0.64	0.27–0.38	0.23–0.19
N	1.17	1.21	1–2	1.25–1.50	0.96–1.18
C/N	22.2	16.3			16–20

^aLa Bozec (1985), ^bMezzanotte *et al.* (1986); ^cLustenhower *et al.* (1987);
^eEl-Helwagi *et al.* (1988).

percentage of oxygen on day 40, together with no demand for ventilation suggested the end of fermentation; nevertheless piles only reached the temperature of the surroundings in about 30 days.

4.2 Chemical evolution

Chemical parameters (pH, organic matter, C/N) are widely held to be indicators of the end point of composting, but in reality such use is not always easy. The C/N is of little worth when initial values are already low (Willson & Dalmat 1986), and changes too gradually for it to be a reliable marker of the degree of stability (Finstein *et al.* 1986a). Changes in pH occur at the start of the process, so pH is not a meaningful indicator of its termination. Final values of organic matter can be altered by leaching, incorporating of soil during treatment (Godden & Penninckx 1986); some of these interferences can explain the similar values in the two piles in spite of the different moisture evolution.

During composting the final balance of nitrogen slightly decreases in absolute terms, due to initial ammonia volatilization, but in terms of dry weight there is a slight increase due to losses of C as CO₂ (Haug 1980, Ferrari 1983, Bishop & Godfrey 1983, de Bertoldi *et al.* 1988). According to Haug (1980) and Zucconi & de Bertoldi (1986) the presence of significant amounts of ammoniacal nitrogen at the end of the process demonstrates instability. The enclosed pile contained the most ammoniacal nitrogen and the least total nitrogen at the end of the process; the instability is probably related to the extreme dryness. The large increase at the end of sieving, when particle size decreases leading to greater contact between the material and the microorganisms, marks the restart of ammonification in the incomplete degraded residue.

The piles showed marked differences in phosphorus content; data for this element is scarce and often contradictory (Bishop & Godfrey 1983, Van der Hoek & Oosthoek 1983, Le Bozec & Resse 1986, El-Halwagi *et al.* 1988). In general, as in the case of nitrogen, an overall increase in the percentage of phosphorus on a dry weight basis would be expected at the end of composting due to the losses of carbon during fermentation, if it proceeds correctly. This increase should surpass that of nitrogen since no phosphorus is lost by volatilization or lixiviation. The large difference in phosphorus values at the end of the experiment, may be a confirmation of the greater stability of the unenclosed pile. Le Bozec (1985) also found higher values for N and P in winter piles than in summer piles (Table 3), however this was due to changes in waste composition. Final values of Table 1 for organic matter (OM) and C/N ratio are lower than compost from Table 3 because of the fine grade of compost; otherwise nitrogen and phosphorous contents are close to those in Table 3.

4.3 Heavy metals

Initial values of heavy metal content in Table 2 are near to median values calculated by Rousseaux (1988) for organic fraction of MSW, (Table 4). Median values were calculated from references of 5 European countries. Close values were also reported by Vallini *et al.* (1984) for the biodegradable fraction of urban refuse (Table 4).

Final values given in Table 2 are low when compared with other sources about compost from mixed refuse (Table 4). Values for Zn and Pb are 2–4 times lower, for Ni 2–3 times lower and for Cd and Hg 10–20 times lower than compost in Table 4. Only dates of column g and h, are close to values in Table 2. They were obtained with a similar experimental protocol, [raw MSW was screened to 50 mm, composted in static piles and the size of compost was less than 20 mm (Bardos 1989)].

Values in Table 4 show a wide range. Several factors influence heavy metal content and so comparisons between different sources are difficult.

The amount of inert material in compost has a direct influence on heavy metal concentration, increase in the grade means increase of the level of contamination; according to de Bertoldi (1986) an increase of compost grade from 8 to 24 mm gives a four times increase in plastic and glass content. The proportion of inert material in < 2 mm compost must be low and so with low concentration of heavy metals. The type of pre-processing also affects the amount of inert material in compost; if hammer mills or shredders are employed, the size of inert material changes. De Bignieres (1986) found that 90% of glass and plastic measured less 8 mm when a hammer mill or shredder was employed for grinding MSW. Le Bozec (1988) also pointed that the production of good-quality fresh compost (with a low inert content) seems to depend on an absence of grinding at the beginning of the process.

The screening procedure employed in the present work removed a large amount of inert elements at the beginning of the process; the remaining inerts did not alter in size and were easily removed at the end of composting.

Finally it is clear from Table 2 that composting itself increases the level of heavy metals. The increase for compost from selective collection is due to reduction in organic matter, but for compost from mixed refuse, levels of heavy metals increase because of liberation of contaminants from paints, plastic, metals etc. present in the composting pile. The magnitude of increase depends on the processing system, the worst quality occurs when all inert material remains in the composting pile, and the highest quality when organic components are collected separately. Contamination is expected to increase where moisture conditions increase the liberation and leaching of metals; however the large increase for Zn and Cd also suggests sample contamination.

Heavy metal content is the main limiting factor for the broad use of compost in agriculture. It is clear from Table 4 that compost from selective collection of urban refuse has the lowest heavy metal contamination. Because of fluctuation in waste composition, the low heavy metal content in compost obtained in the present work are merely illustrative; more widespread research on the distribution of heavy metals in granulometric fractions is necessary.

Acknowledgements

We gratefully acknowledge Dr. E. I. Stentiford for his comments on the results and Semana Verde (Silleda) for his technical assistance. This work was supported by C.O.T.O.P. (Xunta de Galicia).

TABLE 4
Heavy metal content of organic fraction of MSW, compost from selective collection and compost from mixed refuse. All values in ppm dry matter

	Organic fraction of MSW			Compost from selective collection			Compost from mixed refuse						
	a	b	c	d	e	f	g	h	i	j	k	l	m
Mean	1.7	3.0	0.5-0.8	0.3-2.5	1	2.5	1.1	1.2	5.5	3.9	5	5-10	1.6
Hg	1.0	0.9		0.06-0.9					2.4	3.9			
Pb	480	247	41-67	38-190	160	700	480	250	513	447	813	400-600	139
Zn	390	164.8	140-210	110-450	230	800	460	570	1570	1054	571	100-1000	797
Ni	29	18.6	9-14	16-26	10	35			45	71	50		44

(a) Rousseaux (1988); (b) Vallini *et al.* (1984); (c) Lustenhower *et al.* (1987); (d) Kranert & Bidlingmaier (1988); (e,f) Oosthoek & Vam (1986); (g,h) Bardos (1989); (i,j) Krauss *et al.* (1986); (k) Soliva *et al.* (1990); (l) Mezzanotte *et al.* (1986); (m) Nebreda *et al.* (1982).

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