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A Quantitative Respirometric Method for Monitoring Compost Stability

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Compost stability was quantified using dissolved oxygen (D. O.) respirometry during composting of municipal solid waste (MSW) in a pilot-scale system. Changes in stability of samples taken at various times during the composting process were verified with chemical and physical tests. Rates of change of oxygen level in air over a compost sample incubated in a flask at 37°C were converted to a rate of O₂ uptake/(g volatile solids · hour). Oxygen uptake, determined with D. O. respirometry and converted to rates of dry matter loss, was correlated with actual rates, calculated from energy balances observed in the pilot-scale system. The method can be used either as a simple quality control measure or in a more complex way to calculate rates so that efficiency within or among composting facilities can be compared.

Introduction

Compost stability, or the degree to which the biodegradable fraction in solid wastes has been diminished during composting, has interested operators of composting plants and compost users for decades. Knowledge of the rate of stabilization and the stability of the compost produced allows fine tuning of the process and comparison of process efficiencies among systems. Stability affects the potential for microbial activity in composts. Thus, the potential for odor generation by the product is determined by stability (Miller, 1993). Finally, the potential for regrowth of pathogens in composts and phytotoxicity, or plant disease suppression induced by composts are affected by stability (Chen *et. al.*, 1993; Farrell, 1993; Hoitink *et. al.*, 1993). Evaluations of composting systems that do not include stability as a variable (i.e. Johnston *et. al.*, 1989), fail to identify those that cannot meet process parameters and are prone to failure (Stentiford, 1993).

The term "compost stability" should not be confused with "compost maturity". The term maturity has many meanings. It is often assessed through sensory activity or

the potential for plant growth. For example, the "smell" of a mature compost to a significant degree is a function of the microorganisms (i.e. Actinomycetes) that have recolonized the compost after peak heating. Maturity is best assessed with plant growth and a combination of several other assays (Chen and Inbar, 1993; Garcia *et. al.*, 1992; Hirai *et. al.*, 1983; Inbar *et. al.*, 1993). Stability can be determined by rates of O₂ uptake, CO₂ produced or heat released as a result of microbial activity.

Several procedures have been developed to measure this property of composts. Jourdan (1988) followed heat output in a dewar flask as a result of microbial activity. This procedure is very easy to use and inexpensive. However, density and moisture content of the compost sample critically affect the results due to the high specific heat of water relative to that of solids in the compost. Willson and Dalmat (1986) used a strongly alkaline solution to absorb CO₂ and a pressure gauge to determine oxygen uptake in a sealed flask containing a compost sample. Usui *et. al.* (1983) utilized a coulometer which chemoelectrically replaced oxygen consumed during composting. The latter is an accurate but costly procedure. This group found that stability determined for a solid compost sample did not differ from values obtained on a slurry prepared from the compost. Finally, Haug and Ellsworth (1991) proposed yet another procedure. They utilized a constant pressure respirometer on a compost slurry.

In this paper we report a procedure for determination of compost stability that utilizes a dissolved oxygen (D. O.) meter. The procedure was developed in the field of water quality to determine biological or chemical oxygen demand. The Clark-type polarographic probe used in this work measured the decline in oxygen concentration over a compost sample in a flask. Therefore, stability could be determined on a solid compost sample rather than a slurry. This reduced the potential for errors caused by oxygen deficiency or shifts in microbial populations or activity of subcomponents of compost microbiota as a result of major changes in water matric potential during the preparation of a slurry from compost (Miller, 1989). Finally, the validity of the D. O. meter data was compared with actual rates of dry matter loss derived from energy balances observed in a pilot-scale composting system.

Methods And Materials

The equipment used to determine the rate of respiration, based on oxygen consumption, is illustrated in Figure 1. The drop in oxygen level (100% level = 20.94% O₂ at a barometric pressure of 760 mm Hg) over a compost sample incubated at 37°C in a sealed Erlenmeyer flask was monitored for one hour with a D.O. meter attached to a data logger. The rate of respiration of the compost sample (based on volatile solids content) was then calculated from the change in oxygen level with time.

An operating temperature of 37°C was chosen for this respirometry test to minimize lack of microbial activity associated with incubation of high temperature compost samples (i.e. 60°C or 140°F) at low temperatures (25°C or 77°F). The biological vacuum created by such a temperature shock, when the temperature drops to 25°C, results in low activity of thermophiles (McKinley and Vestal, 1984) that may last 24-48 hours until mesophilic microorganisms have colonized the compost (Chen *et. al.*, 1988). Thus, an incubation temperature of 25°C could easily yield false stability readings, particularly in the short-term assay used in this procedure. All other factors affecting the rate of respiration during composting were controlled and are given in detail below.

D. O. System

The partial pressure of oxygen in air over a compost sample in a sealed 500 mL Erlenmeyer flask was measured with a membrane-covered, Clark-type polarographic

probe (Yellow Springs Instruments, Yellow Springs, OH, model 5718). The D. O. probe was fitted with a no. 7 rubber stopper to seal the neck of a flask. The oxygen sensor in this probe is covered by a membrane that is permeable to oxygen and certain other gases, including H_2S , SO_2 , halogen gases, nitrous and nitric oxides. Diffused oxygen reacts rapidly at the cathode, causing a current to flow which is measured. Since this reaction is fast, the oxygen pressure inside the membrane is assumed to be zero. Thus, the amount of oxygen diffusing through is proportional to the oxygen pressure outside the membrane. The probe is equipped with a thermistor to correct for slight variations in temperature. Fluctuations in barometric pressure are corrected by adjusting the calibration value according to tables given in the manufacturers' recommendations.

The accuracy of the probe calibration supplied by the manufacturer was checked with three standard gas combinations (21% oxygen, standard air, 10% oxygen, and pure nitrogen). The results indicated that the probes had an accuracy of $\pm 0.5\%$. Probe response time to abrupt changes in concentration of gases was less than 20 seconds.

The drop in oxygen level was monitored with a Yellow Springs Instruments, (Yellow Springs, OH) model 58 D. O. meter. The voltage output of the D. O. meter was transferred to a data logger (Campbell Scientific Inc., Logan, UT, model CR10). Stored digital information was retrieved either manually or directly into a personal computer.

The compost samples (three replicates/treatment) were placed in flasks on a nylon mesh screen (Tetko Inc., Elmsford, NY, #3-1000/58) that served as a plenum. The screens covered the bottom of the flasks and were supported by several short lengths of Tygon® tubing (Figure 1). A length of 8 lb test fishing line tied to the middle of the nylon screens permitted easy retrieval for cleaning. Finally, the flasks were weighted with a lead ring to prevent floatation and tipping and placed in a 37°C water bath covered with an insulating lid.

Compost samples were aerated with air humidified by passing through a sparger made from a 1 L flask fitted with a two-hole stopper and two glass delivery tubes. One

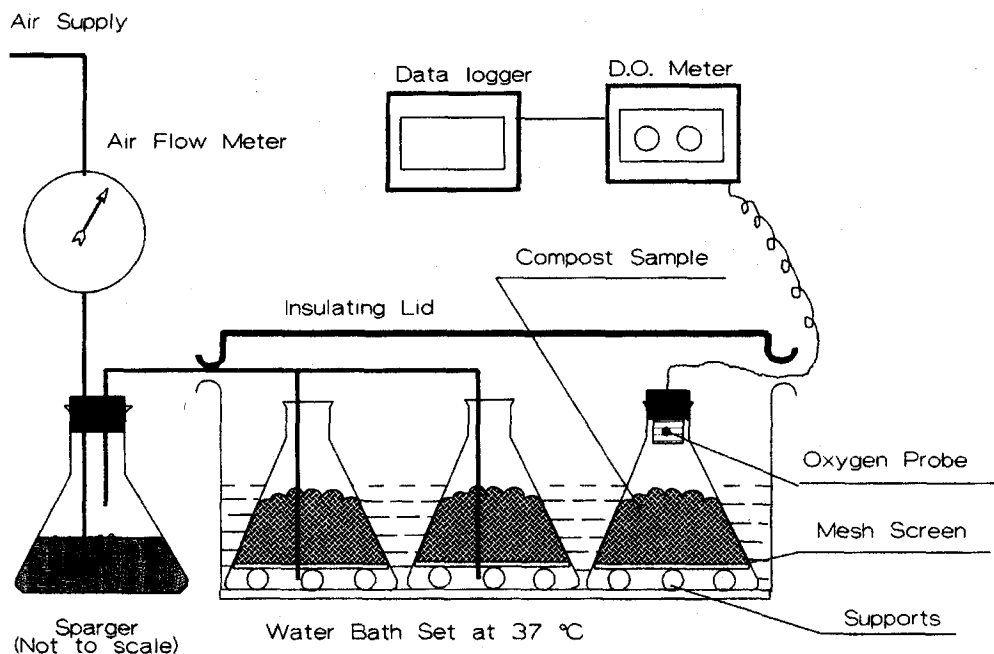


Figure 1. Schematic Diagram of Dissolved Oxygen Respirometry System.

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tube for incoming air was fitted with a piece of 6.4 mm (1/4") tubing connected to an aquarium air stone. The air stone was positioned in the water and served to produce small air bubbles. The second outgoing tube above the water line delivered the moist air to a home-built manifold. This manifold (for six samples) was constructed from seven plastic T-fittings, 6.4 mm (1/4") tubing and 146 mm (5 3/4") long disposable Pasteur pipettes to deliver air to the bottom of the flasks. The sparger was maintained at ambient temperature (25°C) so that air entering the compost sample was not saturated at 37°C. This prevented condensate from accumulating in the plenum space under the compost sample. During preliminary tests it was determined that even though the rate of aeration was 2.5 L/min for a six-flask manifold (400 mL/200 mL compost per flask), the compost temperature did not drop below 36°C as a result of evaporative cooling. The moisture content of the compost decreased approximately 2% (w/w) during the 16 hour incubation period. Finally, the air just above the compost sample in the flask contained near 20.94% or atmospheric O₂ content. Therefore, process temperature, water matric potential and oxygen concentration did not limit microbial activity in the compost (Miller, 1989).

Respirometry Procedure

Compost samples were passed through a 9.5 mm (3/8") screen to remove glass, plastics and other inerts or oversized materials. The moisture content of the compost was adjusted to within a range of 50-55% (w/w) to prevent water saturation and anaerobic conditions or inhibition of microbial activity as a result of low or high water matric potentials. A 60 g compost sample (dry weight basis) was then placed in each of three flasks. When loosely packed, this amount of compost filled approximately 200 mL of a flask.

The D. O. meter was calibrated per manufacturer's instructions using a 500 mL side-arm flask filled with approximately 300 mL water. This flask was positioned in the water bath with the flasks containing compost so that both were at 37°C. Immediately after calibration, the probe was sealed firmly into a sample flask. The oxygen level in air was then recorded every 10 minutes for one hour. The probe was recalibrated before insertion into the next flask.

After D. O. readings had been recorded, the total volume of free air space in each sample flask was determined to convert the rate of change of oxygen level, a relative rate, to oxygen uptake expressed as mg O₂ per g of compost volatile solids (VS) per hour (mg/g VS·hr). First, the weight of the 500 mL Erlenmeyer flask containing the compost and nylon supports was determined. Next, the neck of the flask was marked to indicate the bottom of the stopper/probe assembly. Water to which Tween® 80 (2 drops/L, J. T. Baker Chemical Co., Phillipsburg, NJ) had been added was then poured slowly down the side of the flask to the marked level. During this time, the flask was tapped gently with a rubber mallet to prevent air bubbles from being trapped in the compost sample. After one hour, the weight of the water-filled flask was obtained having ensured that the water meniscus was still at the stopper mark level. The air volume was assumed to be equal to the total volume of added water. Volatile solids in the screened compost samples was determined by ashing separate samples (4 hours at 550°C, VS = 100 - % ash content).

Data Analysis

The mean oxygen level of three subsamples was calculated and a linear regression was performed for percent oxygen level versus real time. The regression gave the slope

value S used in the oxygen uptake equation. R^2 values exceeded 0.98 in all cases. Significance of differences among slopes was determined with the student t -test.

Oxygen uptake, based on volatile solids content, was calculated as follows:

$$\text{Mean O}_2 \text{ uptake} = \frac{C * V * S * 60 * D}{K * Wt * VS}$$

where O_2 uptake is oxygen uptake expressed as mg O_2 per g of volatile solids per hour (mg/g VS·hr). The other variables were:

C – volume fraction of O_2 in air; usually 0.21,

V – volume of air in flask (mL),

S – slope of relative O_2 uptake rate (change in oxygen level per minute),

60 – factor change from minute to hours,

K – constant factor based on the calibration value corrected for elevation above sea level, (e.g. 100 at sea level, 98 at 170m [558 ft], 90 at 880 m [2887 ft] — obtained from D. O. meter manufacturer's recommended calibration procedure),

Wt – Compost dry matter weight in flask (g),

D – The density of the oxygen (g/L) at experimental conditions were converted from STP (Standard Temperature and Pressure, 1 atm pressure, 273.15 K, O_2 density = 1.429 g/L). The experimental conditions were 310.15 K (37°C) at 100% water vapor saturation in air, O_2 density = 1.1816 g/L, and

VS – the fraction of volatile solids (from 0 to 1.0).

Results of mean rate of oxygen uptake were plotted versus composting time to show the compost stability history.

Chemical and Physical Analyses

Chemical analyses of the municipal solid waste (MSW) compost were performed at various times during the process. After sampling and screening, dry solids content (%) was determined by microwave oven drying of samples to constant weight. The pH of each sample was determined on a saturated paste of the sample immediately after screening.

Solid samples ($n=3$ per treatment) were frozen and analyzed for ash content, total nitrogen (%) and total carbon (%) content at the Research Extension Analytical Laboratory (REAL), The Ohio State University, Wooster. Total nitrogen analysis utilized a Macro N analyzer (Foss/Heraeus/UIC, Joliet, IL) for oxidative digestion. The lower limit of detection is 200 ppm. Total carbon was determined using CO_2 coulometry (model 5020, Coulometrics Inc., UIC, Joliet, IL). The total sample carbon was converted to CO_2 by oxidation at 1100°C. The detection limit is less than 1 ppm. The total C:N ratio was then calculated.

Water extracts prepared from additional samples by the saturated paste method were acidified with concentrated sulfuric acid to avoid loss of ammonia if the pH of the compost was above 7.0. Water extracts were then frozen and analyzed at REAL for total carbon, total Kjeldahl nitrogen (TKN), inorganic carbon, nitrate-N, ammonium-N and conductivity.

Total Kjeldahl nitrogen in compost was determined by a micro Kjeldahl method. Nitrate-N and ammonium-N were determined by a nitrate electrode and a distillation/titration method, respectively (APHA *et. al.*, 1992). Organic nitrogen was determined by the difference between TKN and ammonium-N content. Total water soluble carbon and water soluble inorganic carbon was determined using CO_2 oxidation by

TABLE 1.
Chemical analyses of raw composting ingredients¹

	Inerts %	% Total Solids	% Ash	% Total Carbon	% Nitrogen	C/N	pH
Raw MSW	37.4	60.3	21.2	38.3	1.23	31.1	5.3
Poultry manure	0	39.8	62.0	30.8	2.60	11.8	8.6
MSW+ manure	19.0	56.5	27.2	35.3	1.83	19.3	6.9

¹Insert material removed

coulometry and a coulometry instrumentation modification (UIC, Inc., Joliet, IL model 5130 acidification module for inorganic carbon). Water soluble organic carbon was determined by the difference between total water soluble carbon content and the water soluble inorganic carbon content. Electrical conductivity (soluble salts) was determined with a Solu Bridge Conductivity Indicator (Beckman Instruments, Cedar Grove, NJ).

Pilot-Scale Composting

Homogenized raw municipal solid waste was obtained from the full-scale municipal solid waste (MSW) composting plant in St. Cloud, MN. The biodegradable components in this feedstock consisted mostly of paper and some food waste. It was treated 66 hours in a rotating drum homogenizer, screened (25 mm or 1") and then shipped overnight to the pilot-scale composting facility at The Ohio State University, Wooster. Pieces of glass, metals and remnants of plastic films were evident in the raw waste. This raw feed stock was then amended with poultry manure to adjust the C/N ratio to an optimum level for composting of MSW (Nakasaka *et al.*, 1992). This mixture was then loaded into two 200 L pilot-scale composting vessels. Analyses of the MSW raw feed stock, the poultry manure and poultry manure-amended MSW are presented in Table 1.

The pilot-scale composting vessels and composting procedures were operated as described previously (Hansen *et al.*, 1989; Marugg *et al.*, 1993). A two-speed fan system provided aeration under temperature feedback control. The low and high speed fans provided air-flow rates of 1 and 7 kg/hr, respectively. The high speed fan activated at a trigger temperature of 60°C to keep the compost in each vessel within the optimal temperature range (Finstein and Hogan, 1993; Kuter *et al.*, 1985; McKinley and Vestal, 1984). Temperature was monitored at three points within the compost in each vessel (bottom, middle, top) and at the exhaust port. Oxygen, CO₂ and NH₃ in the exhaust air were monitored intermittently.

Samples of a known weight were collected during turning of the compost to determine dry matter content, the rate of respiration using D. O. respirometry, and various chemical properties. Water was added during mixing to maintain a moisture content between 40 and 50% (w/w). While this moisture content may appear low enough to limit the rate of composting, the content of inerts in this MSW compost was so high (44.3 to 65.8% for the stabilized compost) that a moisture level >50% (w/w) would have filled the free air space in the compost with water. After turning the compost, the new total weight was determined to verify moisture content. The vessels were then reattached to the process monitoring and control system.

Air flow rates and top temperature histories for a typical MSW run are presented in Figure 2. Sharp drops in temperature on days 3, 6, 10, 13, 17 and 24 occurred when the compost was turned.

Rates of dry matter loss during composting in the pilot-scale vessels were evaluated using energy balances (Keener *et al.*, 1993; Marugg *et al.*, 1993). Heat released per unit time at various intervals during the test was divided by the heat of combustion. From the heat release values, the amounts of dry solids and rates of dry solid losses in the vessel were then calculated.

The following equation gives the energy balance for the composting system and details of the method:

$$Q_S = Q_G + Q_{ai} - Q_{ao} - Q_L$$

where Q_S = rate of change of energy stored in the compost,

Q_G = rate of heat generated during composting,

Q_{ai} = energy flow into system via incoming air,

Q_{ao} = energy flow out of system via exhaust air,

Q_L = rate of heat loss through the vessel walls.

Solving the energy balance for rate of heat generation gives:

$$Q_G = Q_S + Q_L + Q_{ao} - Q_{ai}$$

Since $Q_G = h_c \, dm/dt$,

where h_c = heat of combustion (high heating value)

and dm/dt = rate of dry matter loss during composting,

we can solve for dm/dt :

$$dm/dt = (Q_S + Q_L + Q_{ao} - Q_{ai})/h_c$$

Evaluation of the Q 's was based on measured airflow rates, temperatures in and out of the system, and estimated specific heats and heat transfer properties of materials in the appropriate energy equations (Keener *et al.*, 1993; Bird *et al.*, 1960). Heat of combustion was set at 20,000 kJ/kg. To confirm the validity of the estimated dm/dt values, integrated values of dry matter loss were compared with mass balance values derived from the total weight and moisture content of the compost determined during remixing. Dry matter loss was compared with O_2 uptake by using the conversion factor 1.37 kg O_2 evolved per kg of dry matter loss.

TABLE 2.
Chemical analyses of manure-amended MSW compost at various times during the composting process

	Day 0	Day 3	Day 6	Day 10	Day 13	Day 17	Day 24	Day 31
pH	6.9	7.3	6.9	7.8	7.4	7.6	7.6	7.8
Dry Matter (%)	—	61.5	66.5	73.8	73.7	75.5	70.3	61.5
before turning		±5.1 ¹	±0.5	±3.8	±1.8	±3.2	±0.8	±5.0
after turning	56.4	54.9	57.0	57.3	56.0	53.9	53.1	—
	±1.6	±5.4	±0.5	±0.5	±0.4	±0.7	±0.8	
Ash (%)	27.2	27.9	27.5	30.5	34.4	41.8	46.2	48.4
	±2.1	±0.15	±0.20	±0.78	±0.35	±0.50	±1.1	±1.3
Soluble Salts (mmhos)	28.8	25.6	14.6	13.9	5.0	10.1	14.3	16.8
	±0.78	±0.85	±0.01	±0.40	±3.5	±0.10	±0.25	±0.05
Total Carbon (%)	35.3	34.4	36.3	31.2	31.2	30.3	28.2	25.6
	±0.70	±0	±0.92	±0.60	±0.60	±0.20	±2.0	±0.05
Total Nitrogen (%)	1.83	1.61	1.32	1.43	1.55	1.64	1.86	2.01
	±0.18	±0.08	±0.04	±0.01	±0	±0.05	±0.06	±0.04
C/N Ratio	19.5	21.5	27.7	21.8	20.2	18.5	15.2	12.8

¹Represents standard error.

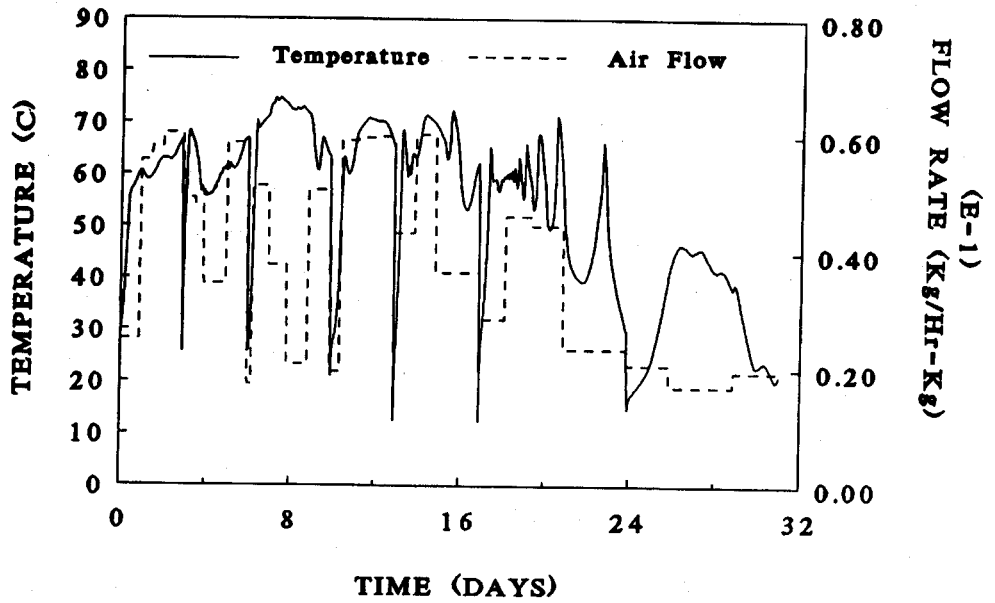


Figure 2. Temperature History (Top Line) and Air Flow (Bottom Line) During Composting of MSW Using a Setpoint of 60°C.

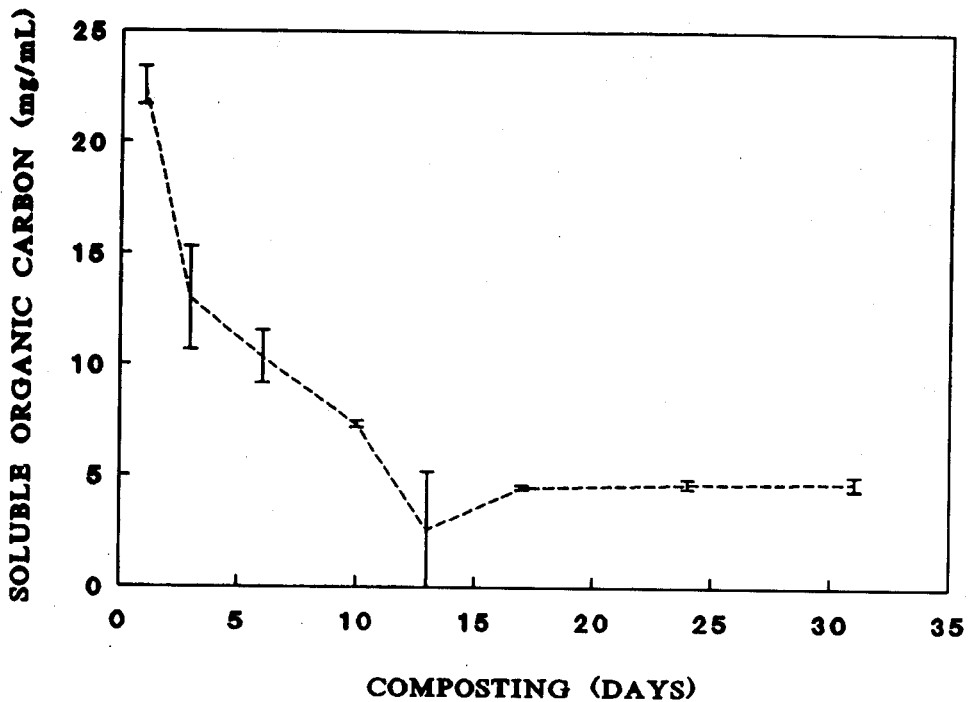


Figure 3. Changes in Water Soluble Organic Carbon Concentrations with Time in Water Extracts of Poultry Manure-amended MSW Compost. Bars Represent Standard Errors (n = 3).

Results

Chemical analyses performed on the compost samples are presented in Table 2. The pH remained near neutrality throughout the process. Both salinity and the total C/N ratio in the compost declined with time. Soluble organic carbon in water extracts (Figure 3) declined from high initial values ranging from 17 to 23, down to 4 mg organic C/mL on day 13. It remained at that low concentration thereafter. The water extract organic C to organic N ratio was 19 early during the process and declined to a value of 7.7 by day 10. Finally, mean volatile solids content (Figure 4) decreased from an initial value of 72.1% to 51.6% by day 31. The greatest rate of decrease occurred between days 6 and 17.

The change in oxygen level in air, determined with the D. O. meter for MSW compost samples harvested at various times during the composting process from the pilot-scale vessels, significantly ($p = 0.01$) decreased with composting time (Figure 5). Values for samples harvested on days 3 and 6 decreased from 100% saturation to under 10% in one hour. By day 10, the drop in percent saturation was 40 points over one hour. By day 31, this value dropped less than 10%, reflecting a significant increase in stability.

Conversion of the change in percent oxygen saturation in air to a rate of oxygen uptake (Figure 6) shows the decrease in microbial activity and increase in compost stability with time of composting. A high initial rate of oxygen uptake (2.0 mg/g VS·hr) was observed for the first six days. Rates remained at a high level until day 10, but then dropped to a high level of stability (0.50 mg O₂/g VS·hr) by day 31.

Total dry matter loss, based on mass and energy balances, observed during composting in the pilot-scale system are shown in Figure 7. A comparison of means for the entire process reveals that the two procedures yield data that did not differ. Slopes and

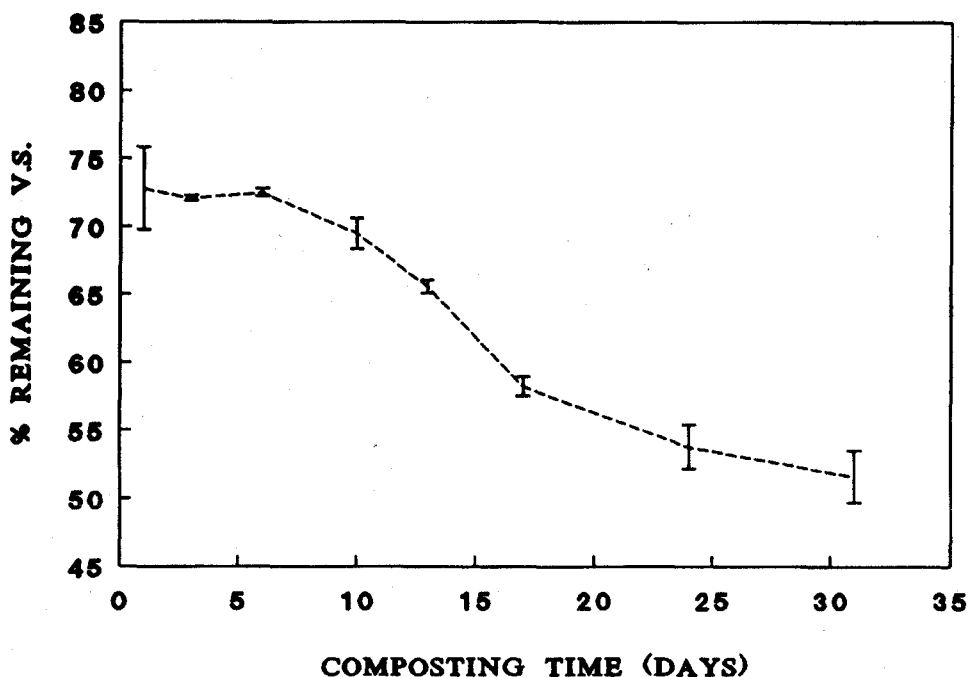


Figure 4. Mean Percent Volatile Solids in Screened (<9.5 cm) Poultry Manure-amended MSW Compost. Bars Represent Standard Errors ($n = 6$).

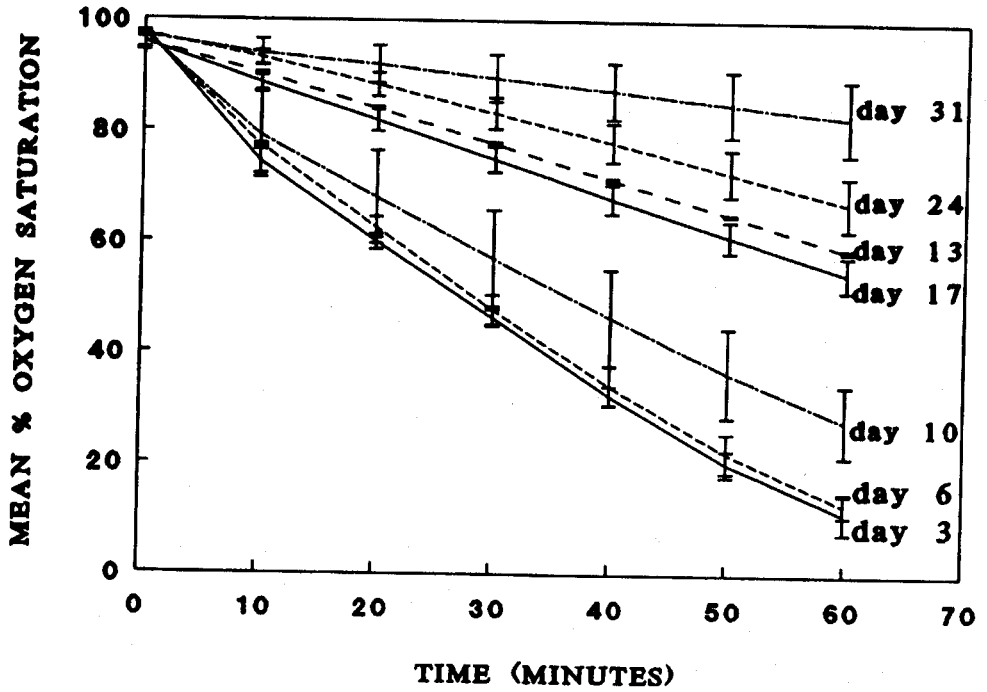


Figure 5. Mean % Oxygen Saturation in Air, Based on D.O. Respirometry, for Poultry Manure-amended MSW Compost as a Function of Composting Time. Bars Represent Standard Errors (n = 6).

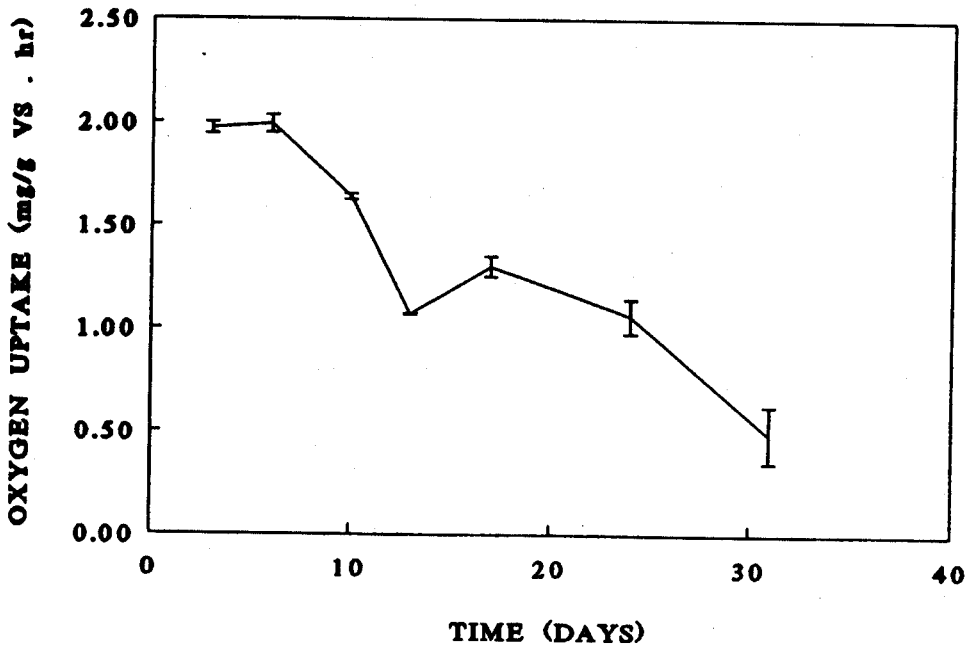


Figure 6. Mean Oxygen Uptake with Time During Composting of Poultry Manure-amended MSW. Bars Represent Standard Errors (n = 6).

intercepts of linear regression lines of dry matter loss against time did not differ significantly ($\alpha = 0.05$).

Calculated rates of dry matter loss, based on conversion of D. O. respirometry data, and measured rates using energy balances, are presented in Figure 8. Early and late during the process the D. O. meter results were very similar to those obtained in the pilot-scale composting vessels. D. O. meter observations made at mid point in the process did not match this well.

Discussion

Changes in chemical and physical properties observed in this work during composting of the poultry manure-amended MSW are in agreement with those reported previously (Hirai *et. al.*, 1983, Garcia *et. al.*, 1992 and Saviozzi *et. al.*, 1992). Although the water extract organic C to organic N ratio reached a value of 7.7 on day 31, the stability of the compost at that time apparently had not yet reached the range of 5-6 required to support a positive plant growth response upon utilization (Hirai *et. al.*, 1983). This was to be expected because this range is not reached until composts have been cured.

The D. O. meter provided a good indication of the degree to which the compost had been stabilized in the pilot-scale composting vessels. A comparison of data in Fig. 3, 4, 5 and 6 supports this observation. However, comparison of rates of dry matter loss, calculated from D. O. meter oxygen uptake rates and actual losses observed in the pilot-scale system (Fig. 8), revealed that the correlation was not significant ($\alpha = 0.05$). This is not surprising. The incubation temperature of the D. O. meter samples was 37°C, whereas, compost temperatures ranged from 50 - 64°C. Early during the process, when the microflora in the compost still has a wide temperature range for activity, the two approaches yielded identical values. Similarly, late in the process, when temperatures in the pilot-scale vessels declined and mesophiles recolonized the system, calculated D. O. meter rates also were in the same range as those observed in the pilot-scale system. The lack of correlation during the middle of the process was associated with that period during the composting process when the microflora is highly adapted to high process temperature (McKinley and Vestal, 1984) and least capable of absorbing sudden changes in temperature. The pre-incubation period of 16 hr in the D. O. meter test apparently was not adequate to fill the biological vacuum created by the temperature differential. The predominant microbes were less efficient at the lower temperature. Chen *et. al.*, 1988, demonstrated that microbial activity in compost samples under such conditions may be affected over a period of 2-3 days.

Data in Figures 3 and 4 reveal how the drop in the relative rates of O₂ uptake could be used to monitor the process in a given composting plant. The City of Akron, Ohio, municipal sewage sludge composting facility indeed has used this abbreviated D. O. meter procedure since 1987 to monitor gross impacts of changes in operational procedures for a given feedstock or various aspects of the process on the relative stability of the compost, and therefore product quality. The same procedure also was used to develop a relationship between stability and percent VS for a yardwaste composting system operating under temperature feedback control (Marugg *et. al.*, 1993). The correlation coefficient (R^2) between percent VS and stability based on the simplified D.O. respirometry procedure was 0.84 ($\alpha=0.01$) (Grebus, 1992). A more rigorous procedure is to determine specific values for stability, based on % VS and D. O. respirometry, as illustrated in Figure 6. This approach would allow comparison of efficiency within or among composting systems utilizing similar types of feedstock.

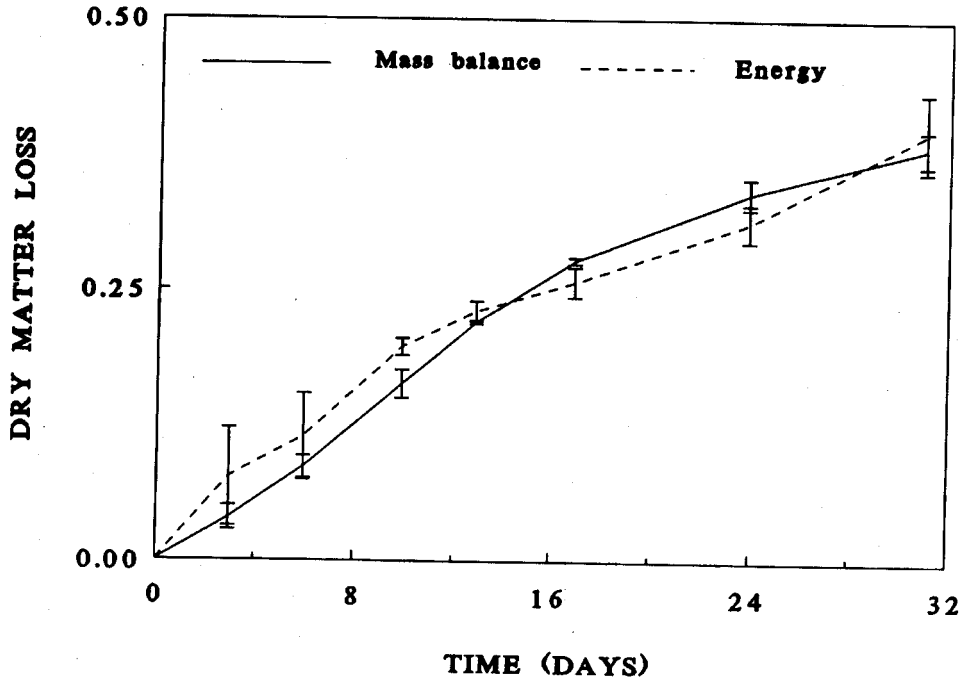


Figure 7. Dry Matter Loss, Based on Mass and Energy Balances for Poultry Manure-amended MSW Compost as a Function of Composting Time. Bars Represent Standard Errors ($n = 2$).

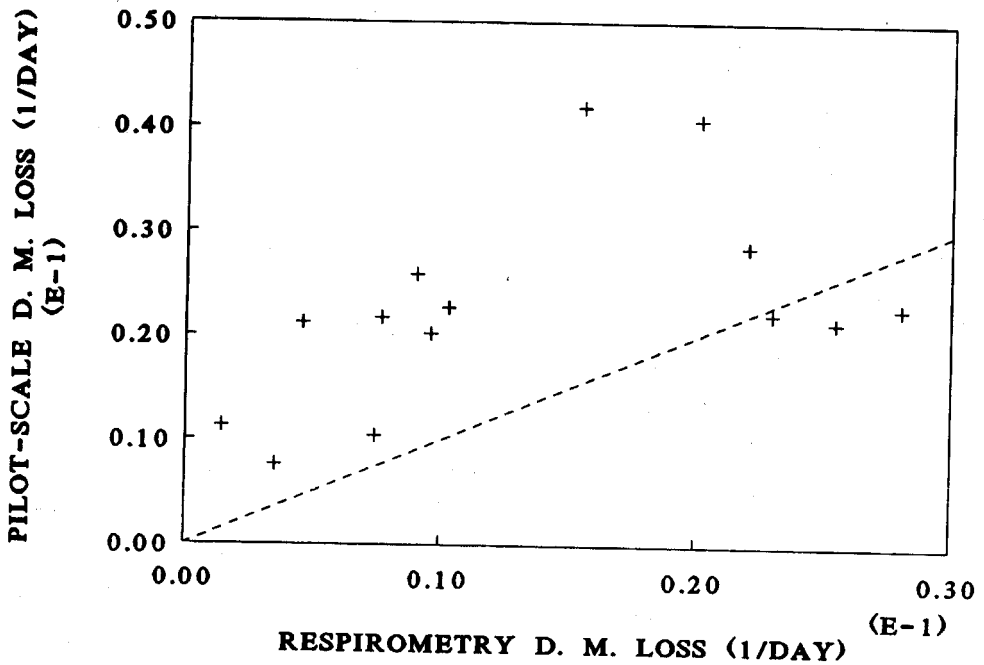


Figure 8. Relationship Between Rates of Dry Matter Loss, Based on Energy Balances in the Pilot-scale System, and Rates of Dry Matter Loss Calculated from O_2 Uptake Rates for the Poultry Manure-amended MSW Compost.

We chose 37°C as a constant incubation temperature in this D. O. meter test because of our interest in following changes in activity for a specific waste throughout the composting process. If this sensitive O₂ procedure were to be used to compare the stability of the final product for various composting systems, the degree to which compost samples have been recolonized by mesophiles or "cured," would be one of several factors to be considered.

In our work, oxygen uptake was calculated on a VS basis, derived from ashing of samples. For MSW, it is necessary that one be aware of pitfalls associated with ashing. Contaminants such as polyethylene and other film plastics contribute to VS, even though they are not biodegradable. The composting process concentrates these inerts with time. The actual stability of the biodegradable fraction in MSW composts, therefore, may be less than that presented in Figure 6. A solution to this problem is to express stability on the basis of the biodegradable or "compostable fraction," as proposed by Keener *et al.*, (1993). A detailed procedure describing the use of D. O. respirometry for quantifying compost stability may be requested in writing from the senior author.

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