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COMPOST: OXYGEN UPTAKE AND STABILITY

by

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Summary:
Standardized methods for determining compost stability are essential for the production of marketable compost. This research used respirometry to determine the specific oxygen uptake rate (SOUR) and its relation to stability. Sour tests were conducted periodically on a dairy manure solids/wood shavings mixture composted over a 46 day period. SOUR curves were plotted and compared to C/N and CEC curves. The mean SOUR was 1.72 mg O_2/(g VS·hr) initially and 0.737 mg O_2/(g VS·hr) after 46 days. A first derivative of the SOUR curve expressed the rate of microbial activity changes taking place during the composting process. It was determined that the substrate became essentially stable at about day 29.

Keywords:
Compost; stability; maturity; solid waste; livestock manure.

ABSTRACT

Standardized methods for determining compost stability are essential for establishing healthy markets for compost. Characterized by low microbial activity, the conditions present in stable compost restrict pathogens, offensive odors, and the degenerative displacement of plant nutrients. Stability is a prerequisite for proper storage and usage as a soil amendment.

This research studied specific oxygen-uptake rates (SOUR) for determining stability. SOUR has been used by the wastewater industry to measure sludge stability for years. An N-Con Comput-OX electronic respirometer was used to measure oxygen uptake rates. Oxygen uptake rates were periodically measured for dairy manure solids/wood shavings mixtures composted over 46-days. SOUR curves were created on a volatile solids basis and compared to carbon-to-nitrogen ratios (C/N) and cation-exchange capacity (CEC) curves, two indicators used in the past for determining compost stability.

The mean SOUR was 1.72 mg O_2/(g VS·hr) initially, and 0.737 mg O_2/(g VS·hr) at 46 days. SOUR, C/N and CEC curves showed strong correlations, supporting the hypothesis that lower SOURs reflected decomposition of more stable organic material.

Besides SOUR, rate of changes in SOUR was also studied. Rate of changes in SOUR, termed degradability, approached zero as microbial activity approached steady-state conditions, suggesting that degradability was also correlated with stability.

From this study, compost operators can learn how microbial activity can be measured using electronic respirometry. Using SOUR can help determine compost stability and possibly alert the operator to parameters limiting the compost process.

INTRODUCTION

Composting has become a financially attractive alternative to landfilling certain solid waste. Facility growth and large compost inventories have created the need for an expanded market. However, before markets can be sustained, standardized measures of quality and consistency are needed. Standardization of testing can help with process control and provide the necessary indicators of quality.

Characterized by moderate and almost unchanging microbial growth, stability is considered the *sine qua non* of compost quality. Stability gives benign organisms a competitive advantage over pathogens such as *Salmonella* and *Pythium*, which are more competitive in volatile, high growth rate conditions (Inbar et al., 1990). Also, nutrients do not become tied up in high microbial growth, but are left available for plant needs. Furthermore, stability minimizes O_2 uptake and anaerobic conditions, which can create offensive odors and heavy metal dissolution.

Though some authors use them synonymously, stability and maturity are defined differently in this paper. For stability, Haug (1980) provided a subjective, yet practical definition: "the point at which the rate of oxygen consumption is reduced so that anaerobic or odorous conditions are not produced to the extent that they cause problems with storage and end use of the product." A more theoretical definition might be the point where readily degradable substrate is diminished so that its decomposition rate does not control the overall rate of decomposition. Instead, the rate of decomposition is determined by the rate of enzymatic, macromolecular decomposition. True stability occurs when microbial activity continues at a constant, moderate rate. Methods for determining stability must include the assurance that microbial activity has decreased as a result of low concentrations of readily degradable substrate, not suppressed from parameter limitations, e.g., low pH or moisture content.

Maturity, on the other hand, is defined as the condition where compost poses no adverse effects on plants and is determined empirically using bioassays (Chen and Inbar 1993). In view of the larger number of variables, industry standardization of maturity is more difficult to obtain than stability. The decomposition needed to reach maturity varies with the type of vegetation grown and the agricultural or horticultural practice employed. The crop's nutrient needs, crop resistance to disease, and the time between compost spreading and crop planting all affect the decomposition needed for compost to reach maturity.

BACKGROUND

Historically, age has been the most common determinant of stability. Age is a subjective measurement and requires ample experience and a consistent substrate. Age becomes less precise when substrates, operating conditions, and technology changes.

Niese (1963) was first to observe a correlation between stability and temperature. Later, Woods End Research (1993) developed a numerical ranking system based on the maximum temperature rise occurring after mixing compost in a Dewar flask. The system resembled the Rottegrad index used in Germany, which related oxygen uptake to the potential for heat generation (Jimenez and Garcia, 1989).

Yet, a problem with temperature stems from the influence of other factors. For example, the addition of water to compost can initiate displacement of fungi by bacteria. As bacteria consume fungi, heat is generated, causing temperatures to increase (Harada et al. 1981). Other factors include pile size and weather conditions. Using the Woods Hole method, many of these factors are eliminated. The major advantages to temperature measurement are its simplicity and low cost.

Harada et al. (1981) tested chemical analyses methods, including carbon to nitrogen ratio (C/N) changes. Total carbon content decreased as CO_2 evolved, while total nitrogen content remained constant; thus the fall of C/N reflected decomposition. Iannotti et al. (1993) found the trend in water extract C/N to be similar. C/N had its drawbacks: ammonia volatilization could cause changes in nitrogen, and considerable time and laboratory expertise were needed to measure C/N.

Harada et al. (1981) also studied changes in cation-exchange capacity (CEC). CEC not only reflected the decomposition rate, but also directly measured the capacity of compost to hold nutrients, an important point when compost is used as a soil amendment. Although C/N was more common in the literature, CEC seemed to present a more suitable method for measuring degree of decomposition. The short-cut method developed by Harada et al. required less laboratory equipment and expertise without losing accuracy.

Respirometric methods determined microbial activity in compost by measuring oxygen uptake and carbon dioxide evolution (which are on 1:1 molar basis under aerobic conditions). Michael et al. (1993) measured carbon dioxide evolution in yard-waste compost. The yard waste was kept in several containers under optimal composting conditions. Exhaust gases from the aerated compost containers passed through a NaOH solution. The NaOH was titrated to determine the CO_2 evolved. CO_2 evolution indicated microbial activity.

Pressel and Bidlingnier (1981) studied oxygen-uptake in compost. They found, as expected, oxygen uptake rates were high in raw material, presumably as microbes grew rapidly from digesting the readily degradable substrate. Over several weeks, as readily degradable substrate diminished, the microbial activity and oxygen uptake rate also diminished.

Researchers have contrived several methods for measuring the oxygen-uptake rates in compost. The standard bottle method, for example, uses dissolved compost in an oxygen-charged solution. The dissolved O_2 is measured and recorded using a dissolved oxygen (DO) meter. This method did not, however, account for undissolved O_2. Also, the aqueous testing environment differed from the actual composting environment. Organisms predominated in solution that were normally not found in less-aqueous environments. There was also the potential for oxygen deficiency, microbial shifts, and changes in water matrix during slurry preparation (Iannotti, et al., 1993).

The "Warburg" method measured the change in pressure in a flask containing compost and alkaline solution. Under the constant temperature, constant volume conditions, a decrease in pressure showed a decrease in O_2 concentration. Yet, with this apparatus, only small samples were able to be tested. Low O_2 concentrations in the air surrounding the compost could have slowed O_2 diffusion (Pressel and Bidlingnier, 1981).

Iannotti et al. (1993) used an apparatus consisting of membrane-covered, Clark-type polarographic probe and DO meter. Samples were placed in sealed 500 ml Erlenmeyer flasks and kept at 37°C under constant-volume, constant-temperature conditions. The DO meter measured the O_2 concentration in the surrounding air. Oxygen concentrations were recorded for an hour on a volatile solids basis. Testing poultry manure amended municipal solid waste (MSW), Iannotti et al. measured SOURs and obtained 2.0 mg O_2/(g VS·hr) for raw and 0.5 mg O_2/(g VS·hr) for stable compost.

In this research, an electronic respirometer was used to detect pressure changes in the air surrounding the compost under constant temperature and volume conditions. The compost was kept in a container with an alkaline solution to be a sink for CO_2 given off during decomposition. When pressure dropped in the reactor, measured amounts of O_2 were metered into the reactor. Oxygen concentration, therefore, remained nearly constant. Electronic respirometry originated as a system for determining biochemical oxygen demand (BOD) of wastewater, so for this research, some adaptations in the reactor were made.

MATERIALS AND METHODS

The raw material composted in this study consisted of dairy manure solids mixed with residual bedding material (wood shavings). Because the dairy manure was high in moisture, the mixture was first pumped over a screen. After screening, the moisture remained higher than recommended in the literature for composting. The problems of high moisture (compaction) were mitigated as the addition of bedding material improved the structure of the mixture by increasing free air space (FAS).

The dairy solids mixture was composted in rectangular bins, 0.3 x 0.3 x 1.2 m, constructed from plywood and covered by 1.9-cm polystyrene insulation. The insulation helped conserve heat, simulating the larger mass of compost in windrows. The material itself was held on a wire-mesh screen, 15-cm above the base of the bin. By suspending the compost, a plenum was formed to allow aeration by a fan.

A personal computer (PC) controlled the fan operation and monitored temperatures in the compost using two thermocouples spaced equally (approximately 0.3 m vertically). The PC turned the fans on for thirty seconds each hour to provide routine aeration and moisture removal. When the average of the two thermocouples exceeded 55°C, the PC turned the fan on until the heat dissipated and the temperature again fell below 55°C. The compost was mixed periodically, once every three to five days for the first two weeks, then once a week for the remainder of the 46 days.

Because the N-Con Comput-Ox respirometer was designed for testing liquids, new reactors had to be developed for compost. The new reactors (Figure 1) were glass beakers, 7.5 cm in diameter and 1 liter in volume. Inside the reactor, a 5-cm segment of PVC pipe supported a round mesh screen holding the compost. By suspending the compost above the bottom of the reactor, a plenum was formed in which a magnetic stirring bar rotated to circulate air. The reactor was sealed by an expandable plumber's plug, and attached to the underside of the plug was a KOH container. On top of the plug was a nipple that connected the reactor to the respirometer through an oxygen delivery tube.

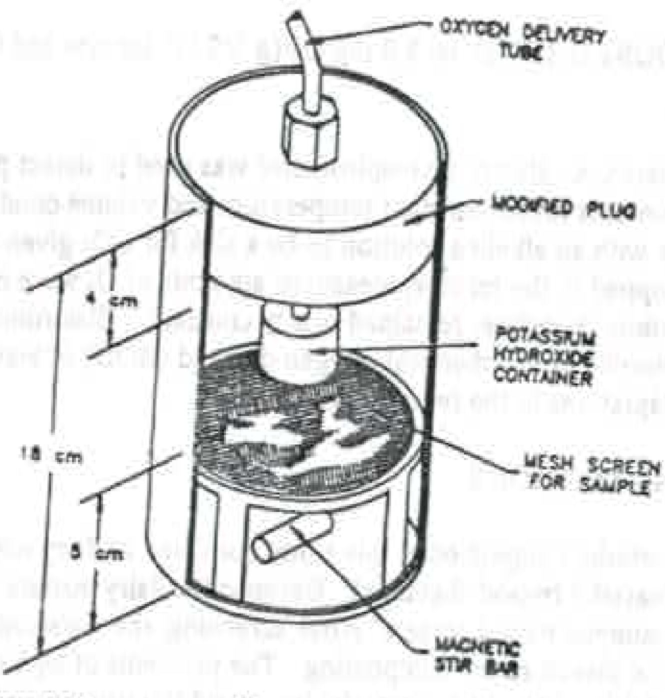

Figure 1. Reactor used for measuring O_2 uptake of compost

After each periodic mixing of the bins, a one liter sample of compost was removed. From the sample, four 40-g aliquots were separated and put into the reactors. The remainder of the sample was used to test for total solids, volatile solids, C/N, and CEC.

The reactors were kept at 40°C by a circulating water bath. The reactors were left open for one hour in the water bath before starting tests. This allowed the compost sample temperature to equilibrate with the bath, preventing errors from increased pressure as temperature increased.

The reactors were capped with the plugs and connected to the respirometer. Pressure sensors in the respirometer detected pressure drops inside the reactors. Once a pressure drop was detected, O_2 was metered into the respective reactor until the pressure returned to normal (atmospheric). A PC continually monitored O_2 flow rates and every fifteen minutes recorded the rates. Tests were run for four hours.

Other physical and chemical analyses were run. Total solids (TS) were determined after drying samples of the compost for 24 hours at 105°C. Volatile solids (VS) were determined by placing the dried samples in a muffle furnace at 550°C for one hour and then weighed. (Standard Methods, 1989). Carbon was determined using a wet oxidation method for determining total carbon (Methods of Soil Analysis 2nd edition, 1982). Total Kjeldahl nitrogen (TKN) was used as the nitrogen component determining C/N (Standard Methods, 1989). CEC was determined using the shortcut method developed by Harada et al. (1980).

RESULTS

SOUR was determined from respirometry using the O_2 uptake rate on a VS basis (Table I). Figure 2 graphically illustrates O_2 uptake from day 0 to day 46. Plotting the mean SOUR at each sampling day, the curve in Figure 3 was developed and shows an exponential decrease of SOUR over time. Readily degradable substrates were plentiful at the start and spurred a microbial growth rate increase. As those substrates were consumed, the growth rate fell off quickly. The slope of the curve decreased, but leveled to a nearly steady-state condition. Over the test period, the SOUR decreased from 1.72 to 0.737 mg O_2/(g VS•hr). This was comparable with the 2.0 to 0.5 O_2/(g VS•hr) found for poultry manure/MSW by Iannotti (1993).

Days	Bin 1	Bin 2	Bin 3	Bin 4	Avg	Std Dev.
0	1.918	1.744	1.601	1.619	1.721	0.146
4	1.809	1.298	1.332	1.216	1.414	0.268
7	1.509	1.388	1.330	1.225	1.363	0.118
12	1.374	1.379	1.002	1.025	1.195	0.210
17	1.097	0.956	0.877	1.042	0.993	0.097
25	0.941	0.929	0.891	0.867	0.907	0.034
33	0.866	0.760	0.663	0.774	0.766	0.083
46	0.742	0.758	0.725	0.723	0.737	0.016

Table I. Specific Oxygen Uptake Rates in mg O_2/(g VS·hr) for bins 1, 2, 3, and 4

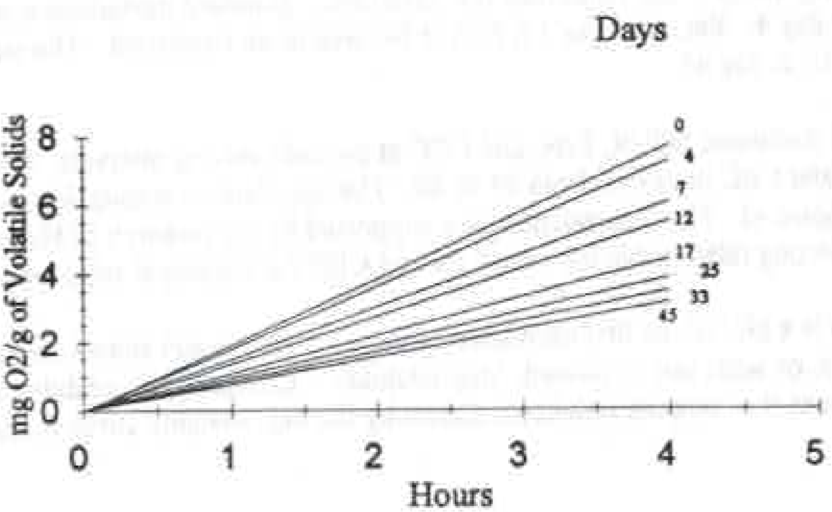

Figure 2. Oxygen-uptake plotted over the four hour test period for samples from Bin 1

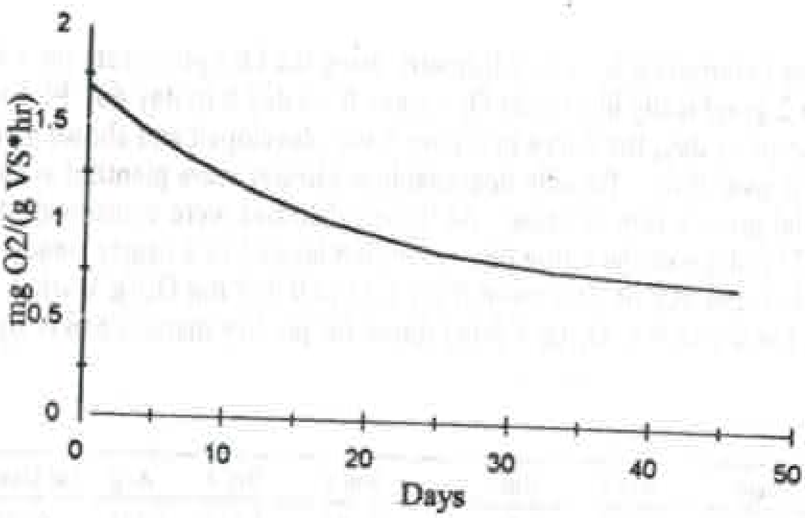

Figure 3. Mean Specific Oxygen Uptake Rate (SOUR)

Differences in SOUR were apparent among bins in the early period of composting. At day 0, the compost Bin 1 had a SOUR of 1.918 O_2/(g VS•hr), which contrasted with Bin 3, which had a SOUR of 1.601 O_2/(g VS•hr). VS among the bins was essentially the same. Compost temperatures in the bins ranged from 26 to 58°C during the 46 day period. The standard deviations among the four bins confirmed the difference. Standard deviations were 0.146 on day 0 and 0.268 on day 4. Yet, after day 17, SOUR became more consistent. The standard deviation dropped to 0.016 at day 46.

Table II compares SOUR, C/N, and CEC at periodic mixing intervals. C/N decreased from 59 to 37, and CEC increased from 24 to 39. The correlations among SOUR, C/N, and CEC were strong (Figure 4). These correlations are supported by the research of Harada et al. (1980) who showed a strong relationship between C/N and CEC for municipal solid waste compost.

Figure 5 is a plot of the first derivative of Figure 3 curves and shows the rate of change of SOUR over time, or what can be termed, 'degradability'. Compost degradability decreased and approached zero as the compost stabilized, shown by the degradability curve in Figure 5.

Days	SOUR (mg/(g VS *hr))	C/N ratio	CEC (meq/100g ash-free)
0	1.721	59.470	23.534
4	1.414	50.680	28.736
7	1.363	49.158	28.351
12	1.195	43.838	32.386
17	0.993	40.829	36.749
25	0.907	38.389	38.313
33	0.766	39.536	36.203
46	0.737	37.554	38.754

Table II. Mean SOUR, C/N and CEC

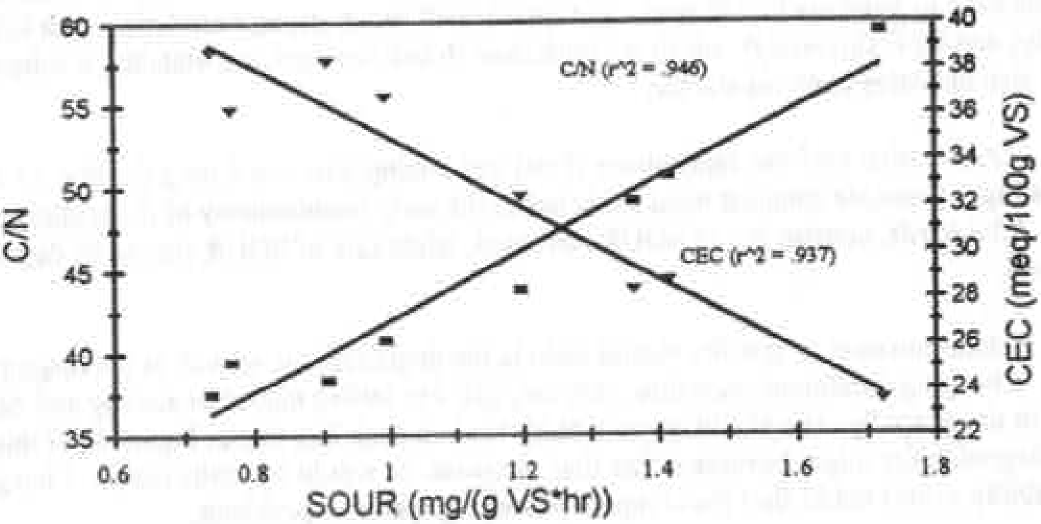

Figure 4. Regression line plots of SOUR vs. C/N and CEC

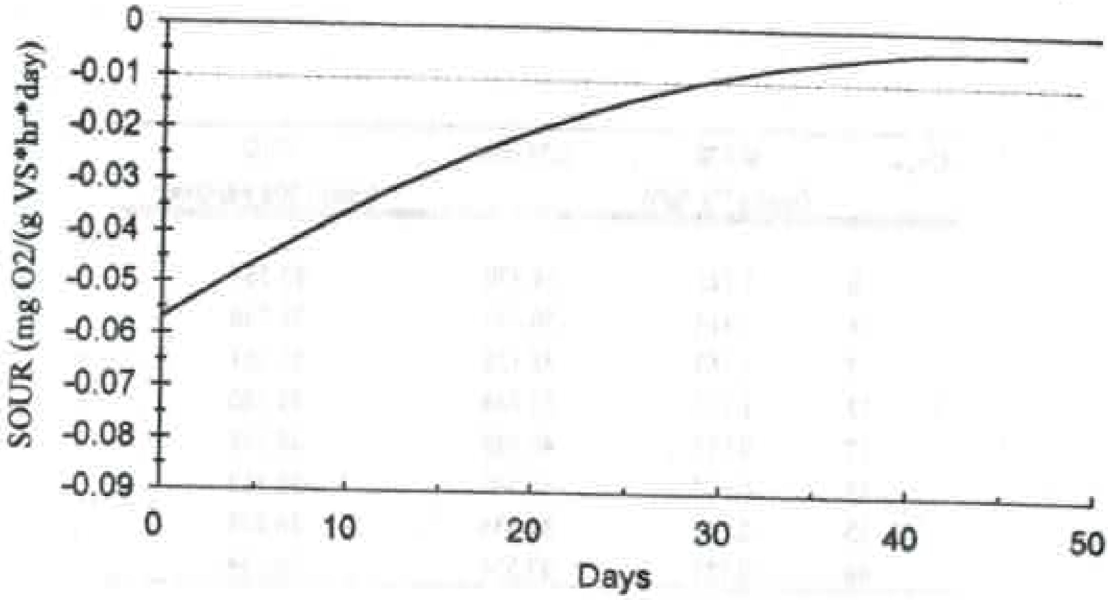

Figure 5. First derivative of the SOUR curve (Figure 3) indicating rate of change with time

CONCLUSIONS

The data gathered in this research supported the accuracy of electronic respirometry as a measure of microbial activity in the compost process. According to the manufacturer, the respirometer equipment could precisely measure O_2 within the range of the rates tested. Respirometer tests were run for four hours, and O_2 uptake was recorded every 15 minutes. This data was used to generate SOUR lines. Because SOUR had a strong correlation with C/N (directly) and CEC (inversely), which are both used to indicate compost stability, it follows that SOUR also indicates compost stability.

SOUR varied between replications (bins) and mixing intervals during the first 17 days of composting. Unstable compost most likely led to the early inconsistency of the replications (bins). Afterwards, consistency of SOUR increased, while rate of SOUR change or degradability decreased.

A determination of stability should include the degradability, as well as the magnitude of SOUR. Changing conditions, moisture, aeration, pH, can inhibit microbial activity and cause SOUR to drop rapidly. The SOUR curve would then not look like that in Figure 3. If this were to occur, degradability might increase rather than decrease, as would normally occur. Changing degradability values could alert the compost process operator to problems.

Electronic respirometry and SOUR measurement have several advantages: accuracy, measurement speed, ease of use, and potential for integration into a process control system.

SOUR from respirometry is a measure of *ongoing* microbial activity under almost constant kinetic conditions, whereas chemical analyses like C/N and CEC measure the effect of *past* microbial activity under changing kinetic conditions. Electronic respirometry measures activity in a controlled, optimal environment. Lastly, SOUR has a background of use as a standard for determining stability of sludge in the wastewater industry.

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