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Variability of Temperature, pH, and Moisture in an Aerobic Composting Process

STEVEN H. ATCHLEY AND J. B. CLARK*

Department of Botany and Microbiology, University of Oklahoma, Norman, Oklahoma 73019

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This study measured the environmental variability which exists in a commercial aerobic composting process. The specific process studied is carried out in six decomposition cells which present six different phases of the process. Temperature, pH, and moisture content were determined in several randomly chosen sample sites in each cell, both at the beginning and at the end of the time the material was left in the cell. Temperature and pH varied greatly from one sample site to another in each cell, whereas moisture content was less varied. A significant rise in both temperature and pH was observed at two stages of degradation.

Although composting of organic wastes has been used since ancient times, modern composting techniques probably started with the work of Sir Albert Howard in the 1920s (4). Since that time, much literature has accumulated which has been reviewed by Golueke (2) and by Finstein and Morris (1). Much of the reported work has centered on the identification and enumeration of various microorganisms found during the stages of the composting process. Succession of microorganisms during the process has also been studied. In practically all such cases, the material being composted has been viewed as a homogeneous mass that undergoes a series of changes. Even the determinations of the effects on the process of physical parameters, such as temperature, have been, for the most part, based on the concept that the material being composted was homogeneous.

Material being composted is a very heterogeneous mass throughout the process. This mass consists of a large number of different environments, and the final product is the cumulation of all the processes carried out under these many environments. The determination of the average for any composting mass cannot truly describe the conditions which actually exist during the process. This project was undertaken to determine the extent of the variability at the sample sites in municipal compost during the total process of composting.

MATERIALS AND METHODS

Process description. All data were taken at the Naturizer Composting Plant in Norman, Okla. This plant passes municipal refuse through six decomposition cells, each of which measures 10 by 10 by 100 ft (ca. 3.05 by 3.05 by 30.48 m) in size and contains a conveyor, or moveable floor, by which the refuse is moved sequentially through the process. A flow diagram of the Naturizer system is shown in Fig. 1. Refuse is received by the plant and moved by a conveyor to a rotary drum pulverizer which reduces the particle size. At this point of the process, secondary sludge is added to bring the moisture content to about 70%. Cell 1 is filled to a depth of 3 to 5 ft (ca. 0.9 to 1.52 m) with the refuse-sludge mixture and allowed to stand for 24 h. At the end of this time, the contents of the cell are transferred to cell 2 by movement of the conveyor floor of the cell. The material falls off the end of the conveyor onto a moving conveyor in cell 2 and is thus distributed throughout the length of cell 2. This process of moving between cells aerates the material. After 24 h in cell 2, the material is moved in the same fashion to cell 3. Between cells 3 and 4, the material is again passed through a pulverizer to remix the material and then passed by conveyor belt to cell 4. Passage from cell 4 to 5 and then to cell 6 is also at 24-h intervals. At the end of the six-day process, the material is passed through a sieve and stored. The relatively high temperatures measured in cell 6 indicate that the compost either is still undergoing decomposition or is in a state of cooling at the end of the process. The material stabilizes while in storage, and the temperature drops. Any material unable to pass through the sieve is returned to cell 1. This is thought to act as an inoculation of the incoming refuse since the raw refuse is found not to decompose so quickly when this material is left out.

Sampling procedure. The environments around cellulosic samples were chosen for study since municipal refuse is composed of 35 to 55% cellulose (5). Cellulose is a nonsoluble substrate that is difficult to degrade and is easily recognizable in the composting mass. Random sites containing cellulose were chosen throughout the composting mass. The temperature at each site was measured with a thermistor probe, with caution to cause as little disturbance as possible. The sample was then removed from the mass and placed in a nylon mesh bag. By use of the nylon bag, it was

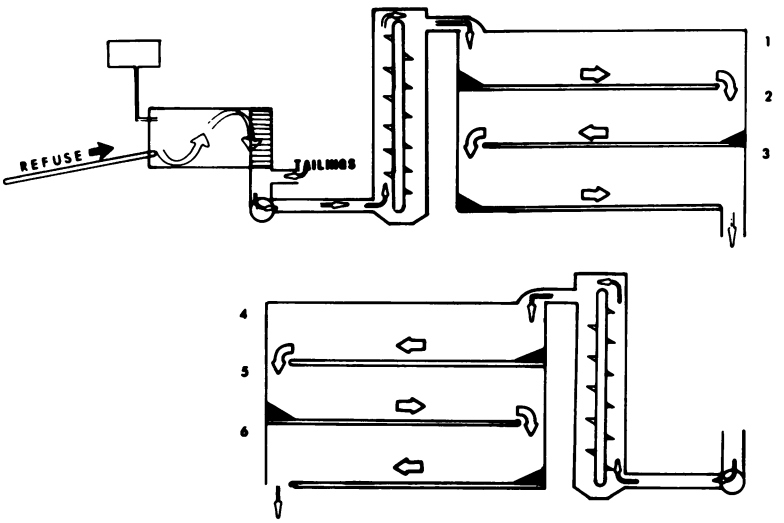

FIG. 1. *Flow diagram of the Naturizer aerobic composting process. Refuse is received on a conveyor and fed into a rotary drum pulverizer where secondary sludge is added to increase the moisture content. The material is then sequentially passed from cell 1 to cell 6 in approximately 6 days with a 24-h stop in each cell. The material is remixed by grinding between cells 3 and 4.*

possible to replace the sample in the mass in a contained form which allowed a free flow of moisture and gases to the sample (6). This allowed the contained sample to be exposed to the same environmental conditions as though it were not contained. Before the sample was placed in the nylon bag, a small portion was removed for pH and moisture determinations. The contained sample was then physically tagged with an underground cable marker. The tagging procedure allowed the sample to be found again, even when deep in the composting mass. After tagging, the sample was carefully replaced in the site from which it had been collected.

A minimum of seven samples was chosen from each cell at the time the material was placed in the cell. At the end of 24 h, before being passed into the next cell, the samples were located, and by carefully pushing aside a minimum amount of the composting material surrounding the flagged bag, the temperature probe was placed directly into or on the surface of the bagged substrate. The sample was never disturbed in any other manner before the temperature measurement was made. The procedure may have reduced the temperature at some sites, but in all cases, the temperature was steady when measured and did not show a change indicating that disturbance for measurement caused a change.

After completion of the temperature measurements, a sample was removed for pH and moisture measurements. The nature of the sampling process made it impossible to follow single samples through the total six cells. Instead, samples were chosen from each cell at the time the material was passed into the cell, and measurements were made again before the material was passed into the next cell 24 h later. pH measurements were made by weighing 1 g of the sample and mixing it with 50 ml of distilled water. Moisture content was determined by placing a weighed sample at 75°C for 48 h and then reweighing the sample.

RESULTS

The data collected from each composting cell are given in Tables 1 through 6. All sites monitored in cell 1 showed a rise in temperature. In cell 2, only two sites showed a rise in temperature from the initial reading upon passage into the cell to the final reading 24 h later. A contrast can be seen between the temperatures during composting in cell 1 and those in cell 2. The temperature values found initially in cell 3 continued the fall begun in cell 2 to a low of 27°C, but had risen to a high of 60° C by the end of the time period. Again, the variation of temperatures from one site in the mass to another is evident. The grinding between cells 3 and 4 increased aeration and cooled the mass initially. Cooler temperatures were found at the beginning in cell 4, but the final temperatures for that cell showed a significant rise for most sites. The highest temperatures found throughout the process were in cell 5. This was the only cell in which few sites of mesophilic temperatures were encountered. The beginning temperatures in cell 6 were characterized by the same high temperatures found in cell 5. However, in this cell, the temperature readings in all sites fell from the values found at the beginnning of the cell. The temperature variability was still very broad.

The pH values found throughout the process varied. The widest range of pH values was found

TABLE 1. *Temperature, pH, and moisture measurements for cell 1*[a]

Sample	Site (depth)	Temp (°C)		pH		Moisture (%)	
		Initial	Final	Initial	Final	Initial	Final
Cardboard	4 in. (ca. 10.16 cm)	31	58	7.94	7.90	63	64
Newspaper	6 in. (ca. 15.24 cm)	33	41	8.10	7.95	63	60
Paper	1 ft (ca. 30.48 cm)	22	61	7.01	6.32	58	62
Newspaper	Surface	33	48	6.40	7.06	55	54
Newspaper	1 ft (ca. 30.48 cm)	22	43	7.18	6.57	68	66
Paper towel	2 ft (ca. 60.96 cm)	33	53	7.38	8.27	49	46
Cardboard	2 ft (ca. 60.96 cm)	35	51	7.52	6.87	51	49

[a] Initial readings were taken at the time of cell loading. Final readings were 24 h later.

TABLE 2. *Temperature, pH, and moisture readings for cell 2*[a]

Sample	Site (depth)	Temp (°C)		pH		Moisture (%)	
		Initial	Final	Initial	Final	Initial	Final
Newspaper	1 ft (ca. 30.48 cm)	47	46	5.29	8.27	70	59
Cardboard	1 ft (ca. 30.48 cm)	48	52	7.31	6.60	66	67
Cardboard	1 ft (ca. 30.48 cm)	53	52	5.34	8.81	56	56
Paper bag	Surface	35	39	8.90	8.70	48	34
Newspaper	Surface	45	39	6.70	8.22	54	49
Paper towel	2 ft (ca. 60.96 cm)	59	51	7.10	8.51	49	40
Newspaper	2 ft (ca. 60.96 cm)	61	37	7.99	7.75	67	38

[a] Initial readings were taken at the time of cell loading. Final readings were 24 h later.

TABLE 3. *Temperature, pH, and moisture readings for cell 3*[a]

Sample	Site (depth)	Temp (°C)		pH		Moisture (%)	
		Initial	Final	Initial	Final	Initial	Final
Paper	1 ft (ca. 30.48 cm)	34	43	6.01	7.08	68	51
Paper	2 ft (ca. 60.96 cm)	43	60	6.38	6.70	50	45
Newspaper	Surface	27	36	6.25	7.36	37	35
Paper towel	Surface	42	44	7.21	6.88	46	45
Cardboard	3 ft (ca. 91.44 cm)	37	56	6.93	6.34	39	38
Cardboard	1 ft (ca. 30.48 cm)	39	54	7.41	7.23	41	35
Newspaper	1 ft (ca. 30.48 cm)	33	40	6.55	6.33	58	60

[a] Initial readings were taken at the time of cell loading. Final readings were 24 h later.

TABLE 4. *Temperature, pH, and moisture readings for cell 4*[a]

Sample	Site (depth)	Temp (°C)		pH		Moisture (%)	
		Initial	Final	Initial	Final	Initial	Final
Cardboard	1 ft (ca. 30.48 cm)	42	54	8.79	7.94	56	55
Paper	1 ft (ca. 30.48 cm)	55	40	8.54	7.77	53	51
Paper bag	Surface	34	43	7.67	7.33	29	41
Paper	Surface	44	41	7.24	7.80	49	49
Newspaper	3 ft (ca. 91.44 cm)	36	39	6.98	7.21	36	29
Cotton	2 ft (ca. 60.96 cm)	46	61	7.88	8.02	46	45
Cardboard	2 ft (ca. 60.96 cm)	25	56	6.89	8.10	52	40

[a] Initial readings were taken at the time of cell loading. Final readings were 24 h later.

in cell 2. The pH values found initially in cell 4 revealed a sharp rise in most values from those found at the end of cell 3. The high readings continued in cell 4 and throughout cell 5. None of the sites tested in cell 5 was acidic.

Moisture contents found in the six cells did not show the wide variation found with temperature and pH. However, a considerable difference was found between samples in each cell. It was observed that the cooler temperatures found in cell 3 were mostly in the drier environments. The moisture contents measured initially in each cell were usually higher than the final readings. This was probaby due to the redistribution of

TABLE 5. *Temperature, pH, and moisture readings for cell 5*[a]

Sample	Site (depth)	Temp (°C)		pH		Moisture (%)	
		Initial	Final	Initial	Final	Initial	Final
Newspaper	Surface	51	55	7.47	8.47	60	60
Milk carton	Surface	58	59	7.04	7.48	31	36
Unidentifiable	3 ft (ca. 91.44 cm)	54	61	8.02	8.50	42	42
Paper	2 ft (ca. 60.96 cm)	50	65	8.65	8.41	50	55
Unidentifiable	Surface	61	66	7.98	8.25	60	52
Cardboard	1 ft (ca. 30.48 cm)	53	67	8.58	8.48	65	61
Paper	1 ft (ca. 30.48 cm)	40	59	8.43	8.47	57	58

[a] Initial readings were taken at the time of cell loading. Final readings were 24 h later.

TABLE 6. *Temperature, pH, and moisture readings for cell 6*[a]

Sample	Site (depth)	Temp (°C)		pH		Moisture (%)	
		Initial	Final	Initial	Final	Initial	Final
Paper	Surface	55	46	7.33	7.76	57	43
Unidentifiable	1 ft (ca. 30.48 cm)	62	39	8.47	7.40	49	35
Unidentifiable	1 ft (ca. 36.48 cm)	51	47	8.52	7.62	44	43
Cardboard	1 ft (ca. 30.48 cm)	66	53	7.88	7.91	51	49
Unidentifiable	Surface	42	40	8.97	9.22	42	34
Newspaper	2 ft (ca. 60.96 cm)	58	51	6.99	7.23	46	43
Paper	2 ft (ca. 60.96 cm)	37	31	8.23	8.24	39	32

[a] Initial readings were taken at the time of cell loading. Final readings were 24 h later.

moisture during the agitation when one cell was dumped into the next cell, since the water in each cell tends to drain to the bottom when the contents are stationary.

Table 7 gives the mean temperature and pH for each cell during the process and only shows the trends during the total process. The mean temperature rose to an initial peak of 47°C in cell 2. It then fell to 42°C in cell 3 and rose until cell 5. In this cell, a second, and higher, peak was seen. Mean pH values followed the same trend.

TABLE 7. *Mean values for temperature and pH in cells 1 through 6*

Cell	Temp (°C)	pH
1	40.3	7.32
2	47.4	7.53
3	42.0	6.76
4	44.0	7.73
5	57.1	8.16
6	48.4	7.98

DISCUSSION

The concept that there are two distinct phases in composting, mesophilic and thermophilic, does not totally apply in the Naturizer process (2, 5, 7). The mesophilic stage is thought to be promoted by an abundance of available nutrients and ambient temperatures. The mesophilic organisms are highly active and cause an increase in the temperature of the composting mass. This rise in temperature causes cessation of the mesophilic stage and onset of the thermophilic stage. However, thermophilic temperatures were found in the initial cell of the Naturizer process, and in only one cell (cell 5) were thermophilic temperatures not found. It is the abundance of the thermophilic sites that produces a high average temperature for the mass. Every decomposition cell in this aerobic process contained mesophilic sites, or cool spots. With the limited data collected, it is impossible to determine an accurate percentage of mesophilic and thermophilic spots. The entire mass does not undergo a shift from one temperature range to another, but only a trend in those directions.

pH values also are not indicative of the entire mass. The initial pH of refuse is reported to be about 6 (5). A drop in the pH of refuse during the initial stages of composting has been reported (5) and is considered to be due to the production of organic acids. Farther along in the process, the pH is reported to rise to 7.5 to 8.5 and then return to neutral in the finished product. According to the data reported here, the pH of sites monitored showed both increases and decreases in value throughout the process. The mean pH of the sites studied showed a trend toward higher values in the early stages of the process.

Table 7 indicates that there are two peaks in the mean temperature and pH of the process. These two peaks seem to coincide for pH and temperature. The high temperatures would in-

dicate high metabolic activity of the microorganisms within the mass. This should cause production of large amounts of CO_2 and organic acids, thus causing a lowering of the pH. However, the pH rises instead. This shows that much more work must be done to understand the processes which occur.

Another peak of temperature and pH was observed in cell 5. It was during this stage of the process that ammonia was readily detectable by smell. A significant drop in temperature and pH was observed in cell 3. This might be attributed to the drop in moisture content at this stage.

The wide range of values in temperature, pH, and moisture content found throughout this process shows that composting is a complex series of microbiological processes that needs more study from a microenvironmental point of view. This variability also leads to some serious questions concerning the survivability of pathogenic microorganisms during the composting process. Several workers (3, 8) have stated that pathogenic microorganisms do not survive composting due to the high temperatures reached. However, in each stage of the process, mesophilic temperatures were found. This affords a probability that a pathogen might encounter only mesophilic temperatures throughout the entire process and thus survive.

Rather than consider composting as a single process with several different stages, the process should be considered as a collection of many distinct and varied sites in which many different microorganisms can be involved in the catabolic breakdown of the material. The determination of the succession of microorganisms in the mass may not reveal the total decomposition process which occurs. It is the succession of the microorganisms in each microenvironment and their cumulative action which cause the final decomposition.

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