United States
Environmental Protection
Agency

Water Engineering Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-85/059 July 1985

POTW-42

Project Summary

The Rutgers Strategy for Composting: Process Design and Control

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A strategy for sludge composting was developed to counter the tendency of other composting systems to operate at high temperatures that inhibit and slow decomposition. This method, known as the Rutgers strategy, can be implemented in a static pile configuration to retain structural and operational simplicity, or in a more elaborate enclosed or reactor structure system. The method maintains a temperature ceiling that provides a high decomposition rate through on-demand removal of heat by ventilation (thermostatic control of a blower).

Compared with the approach currently in widespread use, the Rutgers strategy yields high-rate composting that decomposes four times more waste in half the time.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The main determinant of composting process performance is decomposition rate. This rate is negatively affected by temperatures exceeding 60°C owing to the inactivation of the responsible microbial community. Nonetheless, composting masses typically self-heat to 80°C, at which point the rate of decomposition is low. A method known as the Rutgers strategy has been developed to counter this tendency by removing heat through on-demand ventilation (thermostatic control of a blower). Compared with the Beltsville method (the approach that is in current widespread use), the Rutgers strategy yields high-rate composting that decomposes approximately four times the waste in half the time.

Though the method can be used in enclosed (in-vessel) configurations, the unenclosed static pile is very suitable for its implementation. The static pile has the advantage of being structurally and operationally simple and capital nonintensive.

Sludge Management Goals

Composting advances sewage sludge management goals by decomposing putrescible (odor-causing) material, decreasing sludge volume, weight, and water content, inactivating pathogenic organisms, and producing a stabilized process residue. The residue is more easily stored and transported than the sludge, is more amenable to ultimate disposal, and might be put to use. Traditionally, the residue is used as a compost for application to soil. Related uses include application to disturbed land for reclamation purposes and use as a partial landfill cover material. A novel possibility resulting from the ability of composting to remove water is the use of the process residue as a waste-derived, low-grade, solid fuel.

Importance of Decomposition Rate

Composting advances sludge management goals to varying degrees, depending primarily on whether it achieves a high rate of organic matter decomposition. A high rate is desirable because it leads to odor control and cost effectiveness. Odor control is promoted through the accelerated decomposition of putrescible material. Similarly, a high rate of decomposition promotes cost-effective construction and operation by decreasing the facility time and space needed to achieve a given degree of stabilization, and by decreasing the amount of material to be handled during and after processing. However, the composting system tends to produce inhibitively high temperatures, which lead to a low rate of decomposition and a potential for malodors. The high temperatures result from excessive accumulation of biologically generated heat. Thus the central issue in composting process design is temperature control.

Significance of the Rutgers-Beltsville Comparison

The Beltsville static pile composting process, which was developed specifically for sewage sludge treatment and is widely used, has the advantage of structural and operational simplicity. However, this process (like others) tends to produce high temperatures that inhibit and slow decomposition. A means of countering this tendency is known as the Rutgers composting process control strategy. The Rutgers strategy can be implemented in static pile configuration, thereby retaining structural and operational simplicity while benefiting from rapid decomposition. The Rutgers and the Beltsville Processes are compared in Table 1.

The different results produced by the two strategies originate in the management of ventilation. The Rutgers strategy focuses on heat removal for temperature control, whereas the Beltsville Process maintains an oxygenated condition. These respective operational objectives are met through the different approaches taken to blower control, sizing, and operation mode. However, the physical, chemical, and biological dynamics governing the composting system dictate certain consequences that may not be immediately apparent: These are that a biologically favorable temperature, so obtained, is automatically accompanied by an oxygenated condition, whereas focusing on oxygen almost inevitably leads to inhibitively high temperature.

These principles pertain to composting in general, regardless of the nature of the waste or process configuration (i.e., static pile or enclosed composting).

Materials and Methods

Process control stratgegy was the experimental variable. Both strategies were implemented in a common configuration, the static pile, to permit a rigorous analysis of how the strategy affected system behavior and process performance.

Table 1. *Fundamental Differences in the Rutgers and Beltsville Composting Strategies*[*]

	Process Control Strategy	
Item	*Rutgers*	*Beltsville*
Process control operational objective	*Maintain 60°C temperature ceiling*	*Maintain O_2 at 5% to 15%*
Blower control	*Fixed schedule initially, followed by temperature feedback*	*Fixed schedule throughout*
Blower sizing	*Must meet peak demand for heat removal*	*Prescribed as 1/3 hp per 50-ton pile*
Blower operation mode	*Forced-pressure*	*Vacuum-induced*
Consequences of strategy	*System oxygenated; a high rate of heat generation[†] and vaporization; dryness may come to inhibit activity unless prevented; good pathogen kill.*	*System oxygenated; temperature peaks by default at an inhibitively high level (~80°C); a low rate of heat generation [†] and vaporization; good pathogen kill.*

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[*] *Both strategies were implemented in an unenclosed static pile configuration.*

[†] *Heat generation is equivalent to decomposition.*

The waste was a primary (raw) dewatered (belt-filter press) sludge cake derived from a municipal sewage. The sludge cake had a nominal moisture content of 76%, and a volatile solids content of 74%. Sludge and bulking agent (woodchips or recycled compost) were mixed in a pug mill and formed into piles weighing 4 to 36 metric tons.

Results

Effect of Control Strategy on System Behavior

Blower Operation

A direct side-by-side comparison of the Rutgers and Beltsville strategies (Table 1) was conducted with piles 9A and 9B (Fig. 1). In the Rutgers pile, a 10-hr period of baseline blower operation scheduled by timer (7% on time) was followed by a 460-hr period of time variable, on-demand operation mediated by temperature feedback control (Fig. 2). Demand for ventilation peaked at 100% from hr 96 to hr 135. After the onset of demand, the timer was disconnected, hence baseline operation did not resume when demand subsided. The blower serving the Beltsville pile was operated only as scheduled by timer, as prescribed. The schedule was decreased at hr 70 because the O_2 level was higher than prescribed.

O_2 and CO_2

Similar interstitial O_2 and CO_2 levels were observed in both piles (Fig. 2), but they resulted from dissimilar circumstances. In the Rutgers strategy, vigorous O_2 uptake was matched by commensurate ventilative resupply, resulting in a high O_2 level. In the Beltsville process, uptake and resupply were both sluggish and also resulted in a high O_2 level. The former reflects a high rate of decomposition, whereas the latter reflects a low rate. Thus maintenance of a high O_2 level is a necessary but not sufficient condition for rapid decomposition.

Temperature

In the Rutgers pile, the temperatures during the period of feedback control (taken as hr 10 to hr 380) ranged from 24° to 68°C, with a median of 53°C; they were greater than 60°C in 13% of 1755 observations. For the Beltsville pile, the period of summary is taken as hr 100 to termination to exclude the initial temperature ascent. Temperatures in this pile ranged from 45°C to 82°C with a median of 70°C; they were greater than 60°C in 91% of 1519 observations.

In both piles, a positive temperature gradient was established in the direction of airflow (Fig. 3). The gradient (upward in the Rutgers pile, downward in the Beltsville pile) was steeper and more regular in the Rutgers pile. This gradient represents the transfer of heat from the solid phase (composting matrix) to the gaseous phase (flowing airstream). As such, a steep, well-defined, gradient is indicative of vigorous biological decomposition.

Moisture Content

The moisture content of the Rutgers pile decreased from 67% to 29%, whereas that of the Beltsville pile decreased from 65% to 61% (Fig. 4). These values refer to whole samples (i.e., woodchip bulking agent not removed).

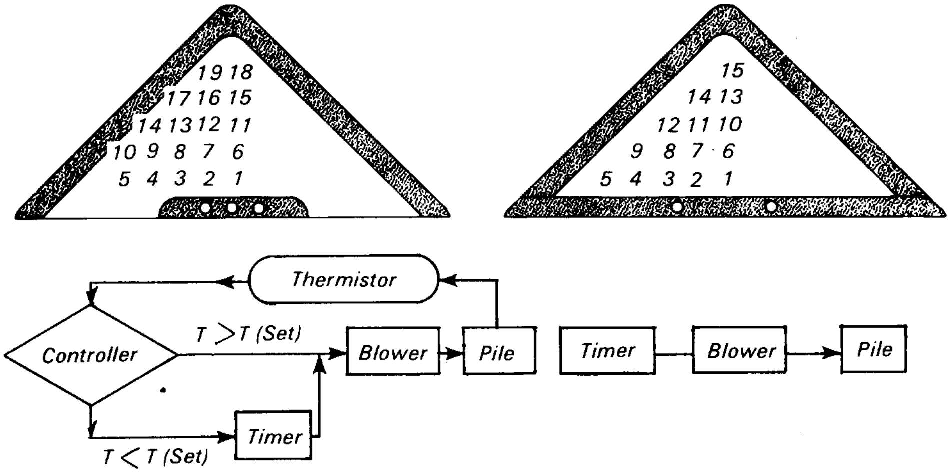

Figure 1. *Representative cross-sections and blower control logics of Rutgers (left) and Beltsville piles.*

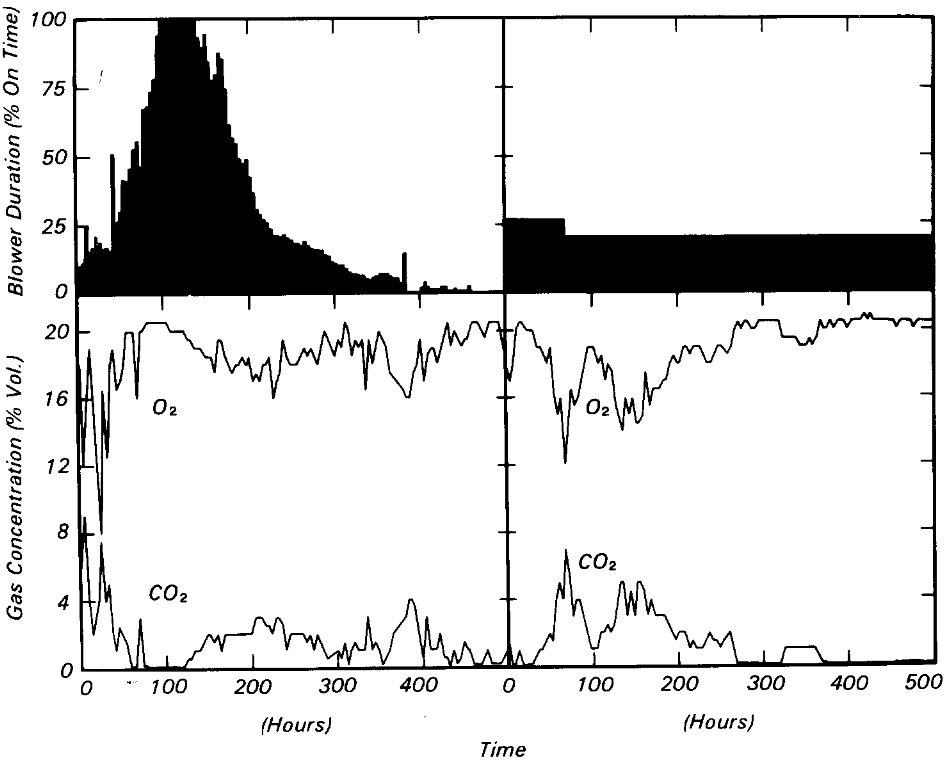

Figure 2. *Blower operation of Rutgers (left, Position 16) and Beltsville (Position 14) piles.*

The significance of drying during composting is two-fold. First, drying is linked to decompositon in that the vaporization is driven by heat generated at the expense of the organic waste. Hence the course of moisture content decrease indicates the course of decomposition. Second, drying is a sludge treatment goal per se.

Moisture Content as a Limiting Factor

Control of temperature leads to vigorous drying owing to the vigorous metabolic heat generation accompanying decomposition. Eventually, heat generation subsides and with it the demand for ventilation. This result may reflect a depletion of substrate and/or water. These possibilities were tested by adding water to a part of pile 4A (Rutgers strategy) at selected times (Fig. 5). The timer was not disconnected after the onset of ventilation demand (temperature feedback control), hence fixed-schedule ventilation was resumed.

For the initial period of feedback control (hr 12 to hr 352), the temperatures ranged from 25° to 63°C, with a median of 48°C; they were greater than 60°C in 1.8% of 1020 observations. During this period, the initial moisture content of 76% decreased to 22% (woodchips removed from these samples).

The addition of water revived demand for ventilation, but at a relatively low level. This result suggests that water depletion was the primary cause of the subsidence of demand and that substrate depletion was the secondary cause. Energy-poor sludges might exhibit the opposite sequence.

Mathematical Expression of Composting Process Control Dynamics

The control dynamics of the composting system can be expressed in mathematical form based on the behavior induced by the two strategies:

$$Q_v \cong 0.9m\,(h_{out} - h_{in})$$

where Q_v = heat removed through vaporization (energy/time)

0.9 = approximate proportion of the total heat removed through vaporization

m = dry air mass flow (mass dry air/time)

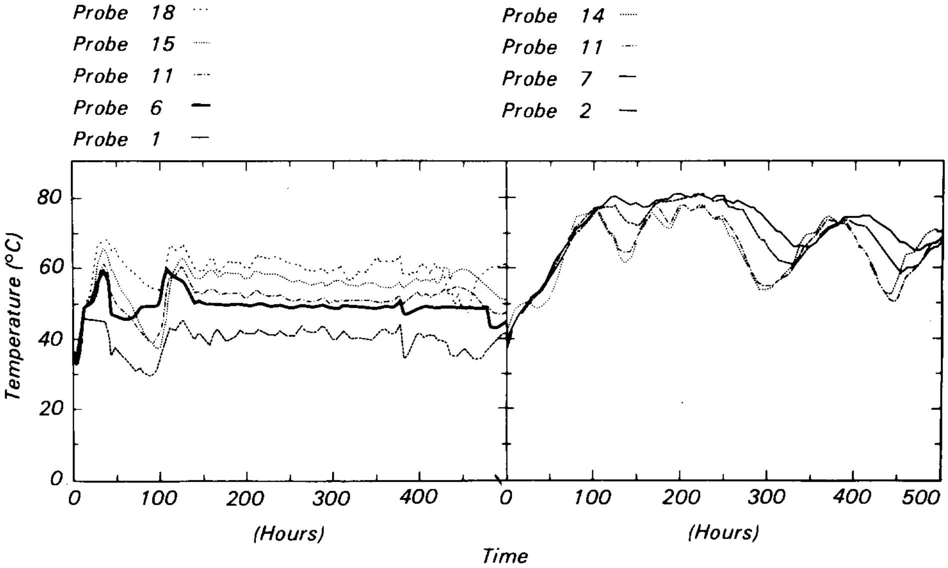

Figure 3. *Temperature of selected vertical series of probes. Left, Rutgers piles; right, Beltsville pile.*

h_{out} = enthalpy of the outlet air (energy/mass dry air)

h_{in} = enthalpy of the inlet air (energy/mass dry air)

The numerical constant (0.9) is based on the estimate that 90% of the ventilative heat removal is through vaporization (the remainder is through sensible heating).

The validity of the expression is constrained by ambient air conditions, (h_{in}), and by the interaction between heat generation and temperature. In this summary of the project, only the latter (overriding) factor is considered.

The goal in waste treatment is to maximize Q_v because it represents the rate of decomposition. Mathematically, a large Q_v is obtainable by making m and/or h_{out} large. This procedure is unrealistic, however, because the highest value of h_{out} attainable through biological action is associated with inhibitively high temperature (~ 80°C), which imposes a low rate of heat generation. Consequently, such a value of h_{out} is sustainable only in combination with a low m, yielding a low value of Q_v. This set of circumstances corresponds to the Beltsville process.

The heat generation/temperature interaction dictates that a high value of Q_v is sustainable by manipulating m so that h_{out} corresponds to ≤ 60°C. Since the rate of heat generation is time-variable, no specific value of m (specific ventilation rate) can be prescribed. Rather, ventilation must be constantly adjusted to match the instantaneous rate of heat generation. This formalizes the rationale for on-demand ventilative heat removal by means of temperature feedback control of a blower (i.e., the Rutgers strategy).

Bulking Agent: Replacement of Woodchips with Recycled Compost

Composting relies on gas exchange to remove heat and water vapor and to supply O_2. Although such exchange can theoretically be provided through mechanical agitation, such a procedure is operationally impractical and energy intensive. Thus agitation is not a practical means of temperature control, and its main role is to mix and abrade the materials.

The only practical means of removing heat in reference to temperature (thereby providing a high rate of decomposition) is through ventilation, which requires porosity to permit the passage of air. Since sludge cake by itself lacks porosity, it is mixed with a bulking agent.

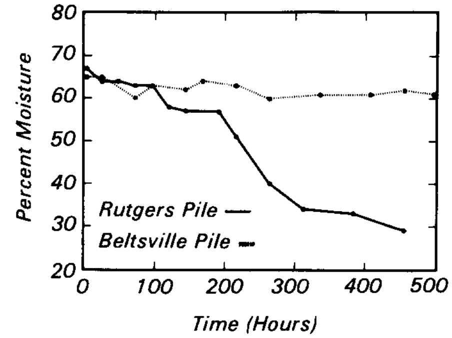

Figure 4. *Moisture content in central interior region of the piles.*

The usual bulking agent, woodchips, has serious drawbacks. In routine Beltsville-type operations, the purchase of woodchips and associated operations (storage, translocation, mixing, screening) represent about one-third of the overall costs. Furthermore, woodchip stockpiles are subject to colonization by *Aspergillus fumigatus*, a fungus that produces spores that can cause an allergic reaction and/or infect the human lung. A desirable approach would be to replace the woodchips with internally generated, recycled compost, provided that the advantages of the static pile configuration (no mechanical agitation) could be retained.

To do so, the recycled material must consist of physically stable aggregates and metabolically stable, dry material. Furthermore, the composting process itself should promote dryness to improve porosity as the composting progresses. These requirements are satisfied by the Rutgers strategy.

Static pile composting of sewage sludge using a compost bulking agent was demonstrated in three piles (11A, 11B, and 11C) with recycle ratios (dry weight recycle/dry weight recycle + dry weight sludge) of 0.3, 0.6, and 0.8. The behavior of these piles was similar to that of the sludge-woodchip mixtures controlled according to the Rutgers strategy with respect to blower operation, O_2 and CO_2 levels, temperature, and moisture content decrease. Without the rigidity imparted by woodchips, the piles using recycled compost decreased markedly in volume (Fig. 6).

Effect of Control Strategy on Materials Balance

Based on thermodynamic considerations, a ratio was derived between the decrements of organic matter and water on a mass basis. This ratio permitted calculation of materials balance (Table 2). With respect to piles 9A and 9B (direct comparison), the strategy designed to maximize the rate of biological activity resulted in the decomposition of 4.7 times more volatile solids in three fourths of the time. The overall result involving two other comparable piles was 4 times more decomposition in half the time. This result would presumably translate into savings in facility construction and routine operation, a more highly stabilized process residue, and greater reliability.

Cost of Water Removal

Drying per se is an important sludge treatment goal, and one of the benefits of

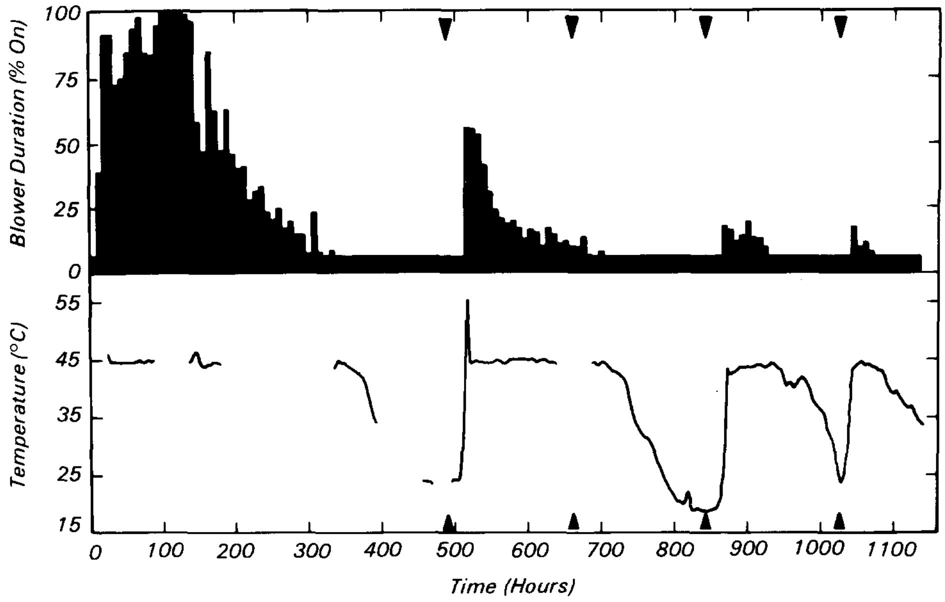

Figure 5. *Effect of water addition (arrows) on the behavior of a Rutgers pile. Upper graph, blower operation; lower graph, temperature at the control thermistor site.*

composting with the Rutgers strategy is extensive water removal. In contrast, nonbiological air drying is a process used solely for water removal. Field observation of air drying provided an estimate to compare the cost of composting with that of providing air for evaporative water removal. Assuming electricity @ 0.06/kWh, this estimate was as follows: Composting (mean of six piles), $0.32/metric ton of water removed ($0.31/ton); air drying, $6.43/metric ton of water removed ($6.33/ton). The 20-fold more efficient use of air by composting results from the biological generation of heat at the expense of putrescible material in the sludge.

Table 2. *Effects of Process Control Strategy on Materials Balance*

Control strategy (pile no.)	*Bulking agent*	*Composting time (days)*	*Total air delivered (ft³/initial wet metric ton x 10³)**	*Sludge volatile solids decomposed (%)*	*Water removed (%)*
Rutgers (9A)	*Woodchips*	*15.8⁺*	*307*	*72.3†*	*80.9*
Beltsville (9B)	*Woodchips*	*21*	*74.5*	*15.4†*	*19.4*
Rutgers (11B)	*Recycled compost*	*7.8⁺*	*323*	*23.8*	*76.1*

**In metric units (m³/initial wet metric ton) the values are: pile 9A, 9,580; pile 9B, 2,330; pile 11B, 10,100.*
⁺Time-zero to cessation of blower demand.
†Calculation based on no woodchip decomposition.

Conclusions

- The composting system tends to accumulate metabolically generated heat excessively, which leads to inhibitively high temperatures. The threshold to significant inhibition is approximately 60°C, and its severity increases sharply at higher temperatures. At 80°C (common uncontrolled peak temperature), the rate of decomposition is extremely low.
- This tendency can be controlled through ventilative heat removal in reference to temperature. The main mechanism of heat removal is evaporative cooling, which establishes a drying tendency. Implementation is by means of temperature feedback control of one or more blowers using standard (non-proprietary) equipment. The forced-pressure mode of ventilation is more efficient in removing heat and vapor than the vacuum-induced mode. In this manner, an operational ceiling of 60°C is maintained.
- Blower capacity (head and volume) must meet the peak demand for ventilation expressed through feedback control. A strong waste (e.g., raw sewage sludge) demands more ventilation than a weak one (e.g., digested sludge).
- A temperature gradient is established along the axis of airflow, whereas drying is relatively uniform along this axis. The temperature gradient imposes a height limitation above which a high rate of decomposition is not realizable.
- Managed in this way, decomposition and drying are related in that the decomposition generates heat, the heat vaporizes water, and the vaporization causes drying. Hence the stronger the observed drying tendency, the faster the sludge decomposition.
- A consequence of temperature feedback control is that the composting mass is well-oxygenated because more air is needed to remove heat than to supply O_2.
- Compared with a conventional approach, the Rutgers strategy resulted in 4 times more sludge decomposition in half the time.
- The cost of ventilation for water removal through composting and nonbiological air drying was as follows: Composting, $0.32/metric ton of water removed ($0.31/ton); air drying, $6.43/metric ton of water removed ($6.33/ ton). This 20-fold more efficient use of air in composting reflects the biological generation of heat at the expense of putrescible organic material in the sludge.

Recommendations

- Achieving a maximum decomposition rate should be the explicit goal of composting process design and control.
- Achieving a maximum decomposition rate should be approached through temperature feedback control of one or more blowers.

- The rate of decomposition should be assessed in terms of (1) the demand for ventilation and (2) the course of drying.
- This strategy (which employs on-demand ventilation through temperature feedback control) should be implemented at the lowest possible capital costs consistent with operational considerations.
- The unenclosed static pile configuration is structurally simple and very suitable for implementation; it should be the preferred configuration.

The full report was submitted in fulfillment of R806829010 by Rutgers University under the sponsorship of the U.S. Environmental Protection Agency.

Figure 6. *Before and after overview of piles using recycled compost as bulking agent. (Photos by Dr. F. C. Miller.)*

☆U. S. GOVERNMENT PRINTING OFFICE: 1985/559-111/20611

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Atal E. Eralp *is the EPA Project Officer (see below).*

The complete report, entitled "The Rutgers Strategy for Composting: Process Design and Control," (Order No. PB 85-207 538/AS; Cost: $23.50, subject to change) will be available only from:

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