COMPOSTING OF SWINE MANURE SLURRY TO CONTROL ODOUR, REMOVE WATER, AND REDUCE POLLUTION POTENTIAL

by

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1. PREFACE

The research reported here was conducted under a collaborative research agreement of February 20, 1996, between Agriculture and Agri-Food Canada's (AAFC) Centre for Food and Animal Research (CFAR) and the Ontario Pork Producers Marketing Board (OPPMB). Contributions of $7000.00 from OPPMB and $35,000.00 from AAFC helped support this study. Compost pile system design, testing and operation was conducted between February and December 1996. Analysis of samples and data was completed during January to May in 1997. This report describes the research conducted and the results obtained. The potential for application of the results of this research to industry is also discussed.

2. EXECUTIVE SUMMARY

Swine manure slurry typically contains 94% to 97 % water. The large proportion of water in slurry increases handling costs for disposal and crop utilization in land application systems. Slurry handling costs could potentially be reduced by on-site reduction in the amount of slurry to be handled by using the composting process. A study was conducted at Agriculture and Agri-Food Canada's Centre for Food and Animal Research in Ottawa to determine the feasibility of using the low cost, low technology static pile, passive aeration composting process to control odour, remove water, and reduce pollution potential from dilute swine manure slurry. In this process, the piles are not turned over or moved ("static" pile) for aeration. Piles are aerated by natural convection (passive) movement of air through open-ended perforated pipes at the base of the piles as opposed to forced aeration using a blower and electric motor. Fresh air is drawn into the piles at the open ends of perforated pipes as warm air rises out of the piles.

Swine manure slurry was mixed with chopped barley straw to make four trapezoid-shaped compost piles with a volume of 5 m^3 (175 cu. ft.) each. Two of the four piles (the treatment piles) were equipped with a temperature-controlled automatic irrigation system to add dilute slurry to the piles, at a one hour interval, when the average temperature within the pile exceeded 50 ºC. Pile irrigation was started two days after assembly when peak temperatures (65-70 ºC) were reached in the piles , and was discontinued 8 days after pile assembly to prevent rapid cooling of the piles. The remaining two piles (the control piles) did not have an irrigation system. The piles were assembled on October 16, 1996 and were monitored for 60 days as follows.

1. The temperature in each of the four piles was monitored continuously at 25 locations at three different levels above the base of the pile every hour for 60 days;
2. the moisture content was measured in the slurry and chopped straw (raw materials) and in the compost mixture at the beginning and end of the monitoring period;
3. chemical composition (carbon, nitrogen, and mineral content) of the raw materials and initial and final compost mixtures was determined; and
4. odour emission from the piles was subjectively monitored; the oxygen content of air in each pile was continuously monitored for the initial six days after which it had to be discontinued due to a frequent need for removal of condensed water from the sampling tube.

The water content of the control piles was reduced by 75 % in 60 days. The treatment piles, to which additional dilute slurry and water was added, were able to remove at least three times more water than the control piles in the same period with little effect on the composting process. There was little difference between treatment and control piles with respect to temperature profiles during the 60 days of composting. Irrigation of the treatment piles temporarily lowered pile temperatures, which rapidly recovered to control values. Effect of irrigation treatment was not evident in the carbon, nitrogen, and mineral contents of the composted material, and in the pile oxygen content during the initial monitoring period. There was no offensive odour once the piles were assembled and composting process became active.

It was concluded from this study that using the simple, low cost, low technology, static pile passive aeration composting system can be a practical process to remove water from dilute manure slurries when the additional slurry is added gradually to compost piles after they have reached peak temperature. Farm-scale optimization of the process and a determination of the economic feasibility is required for the process to be of practical use at swine farms. This method of handling swine manure could be useful at farms which have dilute slurry, a limited land base for slurry application, severe odour problems, and a readily available carbon-rich substrate such as straw which could be used as a bulking agent for the composting process.

3. INTRODUCTION

Swine manure slurry typically contains 94 to 97% water. By reducing the large amount of water in the slurry, there is a large potential to reduce transportation and handling costs for disposal and the land area required for manure application. In this study, the feasibility of using the static pile, passive aeration composting process to remove water from dilute swine manure slurry was investigated. The advantage of using this type of system is that it is a simple, low cost process where the piles are not turned over or moved. Natural convection is used for pile aeration by placing open-ended perforated pipes at the base of the pile. Air is drawn into the pile when hot air within the pile rises out of the pile.

Composting acts as a drying process where water is released by evaporation and the respiration of microbes. Swine manure is readily composted, so this process could be used to reduce the amount of water and the quantity of manure requiring handling and disposal. As water is lost during the composting process, additional swine manure slurry could be added to maintain ideal moisture conditions for microbes, increasing water loss and decreasing volume as well as weight of the manure. Composting can also reduce the risk of pollution from odour, runoff, and nitrate contamination of ground water. Furthermore, a value-added product is produced.

The objectives of this study were to:

1. Determine the feasibility of using the static pile, passive aeration composting process, to remove water from dilute swine manure slurry (DSMS) and to develop a temperature feedback system for periodic irrigation of compost piles with DSMS (treatment piles).
2. Compare the temperature distribution and change in the treatment and control composting systems.
3. Determine composition (water content, carbon, nitrogen, and minerals) changes in the compost mixtures.
4. Make a qualitative assessment of odour release from the treatment and control piles; monitor oxygen content of the air in the compost piles.

Important parameters in determining this feasibility are;

1. The compost piles attain a temperature of 55ºC to 65ºC to indicate that the composting process is active and a temperature of greater than 55ºC is maintained for at least three continuous days to eliminate pathogens;
2. the amount of water that can be removed with periodic irrigation is substantially greater than that with non-irrigated composting;

3. manure nutrients are retained in the piles to prevent release of nitrogen as ammonia gas and loss by leaching which could result in water pollution; and
4. odour release be minimal or none and aerobic conditions are maintained.

A prototype test pile consisting of a mixture of sphagnum peat and swine manure was assembled on August 1, 1996, to test systems for temperature measurement, irrigation by temperature feedback, and air sampling for oxygen content. The prototype pile operation was discontinued after three weeks because the pile did not heat up beyond an average temperature of 37ºC, which indicated that the composting process did not get established in the pile. Two potential reasons were identified for the piles not heating up. Although the target value of the initial moisture content in the compost mixture was 70-75%, the actual moisture content was determined to be 80%. High initial moisture may have inhibited the process. The second possible reason for the pile not heating up could be the possible presence of a trace amount of antibiotic "bacitracin" in the manure used for composting, which may have inhibited the aerobic bacteria to initiate the composting process. Bacitracin was experimentally used on a small number of animals whose manure went into the storage pit. It is not absorbed in the animal gut, so all the antibiotic ingested and that which leaked from the drinkers probably went into the manure pit. Both factors, the presence of minute quantities of antibiotic and the high initial moisture content in the compost mixture might have prevented the prototype test pile from heating up. The temperature monitoring and irrigation systems used in the operation of the prototype piles where improved subsequently.

Four compost piles, using swine manure and chopped barley straw were assembled in mid-October to study the feasibility of using the composting process to remove water from swine manure slurry. The original intent was to test the system using chopped straw as well as peat as bulking agents. However it was decided to test the proposed system using straw only. Previous experience with poultry manure had shown that water removal was greater in straw piles than peat piles because peat tends to hold much more moisture than an equivalent weight of straw. Furthermore, straw is generally more widely available and less expensive than peat.

The following sections describe in detail the study procedure used, results obtained and conclusions drawn from the operation of compost piles with and without additions of extra swine manure slurry.

4. STUDY PROCEDURE

Four passively aerated, static compost piles, two with irrigation treatment and two for control, were monitored from mid-October to mid-December in 1996. Monitoring was discontinued when the average pile temperature dropped to about 10ºC.

Compost Pile Preparation

Swine manure slurry was mixed thoroughly with chopped barley straw to make four trapezoid-shaped piles of 5 m^3(175 cu. ft.) each. The piles were 3.4 x 2.9 m (11 x 9.5 ft) at the base, and were 1.2 m (4 ft) high. The piles were located in an open-front barn (photo 1) at the Agriculture and Agri-Food Canada Greenbelt Research Farm in Ottawa, Ontario. The barn had a roof, a compacted earth floor, and was enclosed on three sides. The layout of the piles and irrigation systems is shown in figure 1.

Slurry and straw were mixed in batches using a feed mixing truck equipped with three augers and a load scale. For each batch, 300-400 kg (660-880 lb) of straw was placed in the mixing truck with a skid-steer loader (photo 2) and 900-1200 kg (2000-2650 lb) of slurry was pumped in. The slurry to straw ratio was 3:1 by weight, for a targeted moisture content of 70-75%. The materials were mixed thoroughly for 20 minutes and were unloaded into the skid-steer through a side discharge conveyor.

A 5 cm (2 inch) thick base of previously composted swine manure was placed on the floor and five perforated ABS plastic pipes, 3 m (10 ft) long, 100 mm (4 inch) diameter, with open ends, were placed 0.5 m apart on the base (photo 3). The compost mixture was unloaded from the skid-steer on top of the pipes (photo 4). A wooden frame was used to construct each pile with the same volume and shape. At predetermined heights (figure 2) the compost mixture was levelled, and thermocouple grids (photo 5), irrigation manifold (in treatment piles only, photo 6), and oxygen sampling chamber (photo 7) were placed and then buried inside the pile. In the treatment piles, the ABS plastic pipe manifold (photo 6) was placed 0.75 m (30 inch) above the base. The gas sampling chamber (photo 7) was placed inside each pile 0.90 m (36 inch) above the base. The finished pile was then covered with a 10 cm (4 inch) thick layer of loose chopped straw for insulation.

Temperature Monitoring

Previous research had shown that temperature is symmetrically distributed in symmetrically shaped piles made from uniform compost mixtures. Thus, pile temperature can be determined from measurements in parts of the pile only. The temperature in one quadrant of each pile was continuously monitored on a one hour interval at 25 locations at 3 levels, 0.25, 0.55, and 0.85 m (10, 22, and 33 inches) above the base of the pile (Figure 2). Thermocouples were assembled in a grid pattern (photo 5) at each level with 12 on the lowest level, 9 on the middle level, and 4 on the top level (figure 2). Temperature was measured and recorded (photo 8) using type T thermocouple wire and a Campbell

Scientific 21X data logger with two AM416 relay multiplexers (Campbell Scientific, Chatham, Ontario).

Irrigation System

The irrigation system was designed to add about 30 L (6.6 gallons) of dilute slurry to the treatment piles during each pumping event, when the average temperature within the pile exceeded 50 ºC. The control piles did not have an irrigation system. A Campbell Scientific 21X data logger and controller was used to trip a relay to activate the irrigation pumps (G.E. 1/6 HP laundry tub pumps) in the treatment piles. Slurry was stored in 1100 L (240 gallon) plastic tanks (photo 9) and pumped through 32 mm (1 1/4 inch) flexible hose and a 32 mm (1 1/4 inch) perforated ABS pipe manifold located inside the pile 0.45 m (18 inch) below the top. Very dilute liquid swine manure (2% dry matter) was used initially for pile irrigation. The first 1000 L (220 gallons) of dilute slurry for each treatment pile was used up much faster than anticipated. The tanks were filled once more onsite with tap water from the barn, instead of dilute swine manure slurry from the remote storage tank, to avoid delays in irrigation of piles while they were hot. Tap water was considered to be an adequate substitute for dilute manure slurry for the purpose of this study.

Oxygen Monitoring

The oxygen content of the air inside the pile was measured with a Beckman medical gas analyser (photo 8) for the first six days but had to be discontinued due to large amounts of condensate that formed in the air sampling tubes. Samples were drawn from each pile through 6 mm (1/4 inch) vinyl tubing by vacuum pump leading to a gas sample chamber buried inside the compost pile, 0.3 m (12 inches) below the top, above the irrigation manifold. The gas sample chamber was constructed from 200 mm (8 inch) long perforated 50 mm (2 inch) ABS plastic pipe with both ends capped. One end-cap had a bulk head connector with 8 mm barbed fitting (photo 7).

Sample Collection and Analysis

The percentage of moisture, carbon, and nitrogen, in the slurry and straw was determined before they were mixed, and the mixture was sampled at the beginning and end of the 60-day composting period. Ash, calcium, magnesium, and potassium in the dry matter were also determined. Moisture was determined by oven drying at 110ºC for 24 hours. Carbon and nitrogen were determined by a LECO carbon-nitrogen analyser. Ash was determined in a furnace at 555ºC. Calcium, magnesium, and potassium were determined by atomic absorption.

5. RESULTS AND DISCUSSION

The results are discussed in terms of moisture content and water removed, the temperature distribution and oxygen content as indicators of the composting process, and the composition of the raw materials and the initial and final compost mixtures.

Composition of the Raw Materials and the Compost Mixture

Table 1 shows the average composition values for the slurry, straw, and their mixture initially and at the end of the 60-day composting period. The moisture content of the slurry and straw was 91 % and 10%, respectively. The initial compost mixture had a water content of 73%, which was within the target range of 70-75%, and a carbon to nitrogen (C:N) ratio of 29 in the dry matter (DM). This value would be a little less in the wet initial mixture because of a loss of volatile ammonia nitrogen from the mixture during drying. The recommended C:N ratio for compost mixtures is 20 to 30. The final compost mixture in the irrigated or treatment piles was a little wetter (59% DM) than in the control piles (49% DM). There was a small decrease in the carbon concentration during composting. The increase in nitrogen, ash, and mineral concentration at the end of the composting period resulted from the loss of volatile, biodegradable organic matter. Thus, the composting process resulted in an enriched material in terms of nitrogen and minerals in the dry matter.

Water Removal

The initial water content of the compost mixture for all piles was 73%. Each of the two treatment piles was irrigated with an additional 1000 L (220 gallons) of dilute slurry (98% water) initially, followed by 1000 L of water. No slurry or water entered the perforated aeration pipes at the base of the piles, and there was no difference in the moisture content of the soil underneath the four piles. Thus there was no evidence that water in the piles was removed by any mechanism other than evaporation.

In each of the two control piles, 75% of the water initially present was lost during 60 days of composting, which cumulatively in the two piles amounted to 1664 kg (3670 lb) of water (Table 2). In comparison, in the irrigated piles, in one pile 75%, and in the second pile, 79% of the water initially present plus the water added to the piles was lost during the same composting period of 60 days. The two treatment piles together had 2019 kg (4451 lb) of water initially, and 4000 kg (8818 lb) of water was added during irrigation. At the end of the composting period, these two piles together had 837 kg (1845 lb) of water left in them. Thus the total water removed in the two treatment piles was 5182 kg (6019 kg - 837 kg or 11,424 lb). Table 2 shows that the four piles initially did not have the same total weight of material even though they were shaped to the same volume. The initial weight of the compost mixture was 2770 kg (6107 lb) in the two treatment piles together and 3050 kg (6724 lb) in the two control piles. The water removal under the two treatment systems needs to be compared on the basis of equal initial weight of the compost mixture. If both systems had started with a total of

3000 kg (6614 lb) of initial mixture, the corresponding water removed would be 5612 kg (5182 x 3000 / 2770 kg or 12,373 lb) under the treatment (irrigation) system, and 1637 kg (3608 lb) under the control system. This indicates that, on the basis of an equal weight of compost mixture initially, the irrigated composting system removed 343% as much water as the non-irrigated composting system.

Temperature Profile in the Compost Piles

Temperature profiles inside the compost piles indicated effective microbial activity. The average temperature profile for 25 locations in the control and treatment piles is shown in Fig. 3. There was excellent agreement among the replicate piles of each treatment with respect to temperature distribution in the pile and change in temperature over the 60-day period. Peak temperatures of 65-70 ºC were reached in all piles within two days after assembly. These peak temperatures and the time to reach them were consistent with previous studies in which poultry manure and straw were composted. Pile irrigation was started after the peak temperatures were reached and was discontinued eight days after composting started to prevent rapid cooling of the piles. The average temperature of the treatment piles dropped rapidly when the irrigation system was started and returned to temperatures similar to those in the control piles when irrigation was stopped (figure 4). Thus, irrigation lowered the average pile temperature for a short time only. The temperature profile inside each control and treatment pile seemed to be characterized by three separate temperature zones. The temperatures were highest near the core of the pile (Fig. 5), lower between the core and the outside edge (Fig. 6), and the lowest at the outside edge (Fig. 7). Figures 5, 6 and 7 indicate that the average temperature distribution and change in each zone was similar in the control and treatment piles most of the time except during the irrigation periods. Temperature was maintained above 55 ºC for three or more days in all piles which would promote pathogen inactivation.

Odour Removal and Oxygen Content of Air in the Piles

Indicators of a well-functioning compost process are absence of odour and availability of sufficient amount (5 %) of oxygen inside the pile for microbial respiration. Except for a wet grass smell which persisted for the initial three weeks, odour was essentially absent around the compost piles. Smell of ammonia was also absent probably because of the favourable C:N ratio in the compost mixture. The oxygen content of air sampled for the first six days is shown in Figure 8. Oxygen was rapidly depleted from a normal concentration of 21% to between 2-8% within the first day of composting. This indicates that microbial activity began rapidly and was vigorous. After two days, oxygen content was close to 12% in all four piles before irrigation started in the treatment piles. During the irrigation period the oxygen content of air in the treatment piles dropped to between 2 and 7 %while in the control piles it remained at 12%. When irrigation was stopped, the oxygen content of air in the treatment piles increased to 12% within 8 hours. This indicates that the decrease in oxygen content after irrigation was probably due to increased water content and oxygen demand rather than from increased microbial activity. After four days, oxygen content of the air in each of the four piles was close to 12%. Oxygen monitoring was discontinued after six days due to frequent accumulation of large amounts of condensate in the sampling tubing. When pumping saturated air at 50-70ºC through sampling tubes at 4-15 ºC, it is necessary to have sufficient water traps and water vapour removed when using this type of gas analyser.

Mineral Balance

Mineral composition in terms of ash, calcium, magnesium, and potassium, was determined in the raw materials and in the compost mixture at the start and end of composting (Table 1). Solids and mineral content in the treatment piles at the start of composting were determined from the initial weight of material in the piles and the composition values in Table 1. It was not feasible to directly determine the weight of material in the piles at the end of composting. Therefore the solids and mineral content at the end were calculated assuming conservation of ash. Table 2 shows pile contents at the start and end of composting. Total solids, volatile solids and carbon were reduced in the piles. Similar values for calcium, magnesium, and potassium at the beginning and end of the composting resulted from conservation of ash. A mass balance for nitrogen in the piles was not possible because of the presence of volatile ammonia in the total nitrogen. Data in table 2 indicate that reductions in total and volatile solids, and in carbon contents were in the range of about 60 - 70 %.

6. CONCLUSIONS

Static pile, passive aeration composting can be a feasible method to remove water from dilute swine manure slurry. The results of this study suggest that at least three times more water can be removed by gradual addition of slurry to a composting mixture of straw and slurry compared to once only addition of slurry. This addition of slurry would have to be done gradually after the piles reach the peak temperatures of about 65ºC, and could continue until such time that the pile temperatures drop below 50-55ºC.

The temperature profile, odour release, oxygen content, and final mineral composition of the compost material were not affected by the irrigation treatment to any great extent. The rate of the composting process is limited by temperatures above 70 ºC and oxygen content below 5%. Temperatures in all piles were under this limit and oxygen content was below 5% only for a short time at the beginning of composting and temporarily in the treatment piles during the irrigation. This indicates that this method of composting is practical and that the irrigation treatment had no long-lasting effect on the composting process. Farm-scale feasibility testing is required.

7. APPLICATION TO INDUSTRY

Results from this study have demonstrated the technical feasibility of using the composting process to remove substantial amounts of water from dilute swine manure slurry. Normally, land application of manure slurry for crop production is the most desirable method of handling manure slurry. The proposed process would be attractive in situations where the slurry is very dilute (less than 2% dry matter) so that the cost of slurry transport would be relatively high, when odour is severe, particularly at the time of application, and when land base is inadequate.

Some conditions would be of help in increasing the practical usefulness of the process at swine farms. These include availability of a cheap bulking agent such as straw, a roofed shed which would prevent rainwater entry into the composting mixture, and close proximity of this roofed shed to the dilute manure slurry supply site so that slurry could be pumped directly to the composting piles (rather than hauled). Also, when applicable, a possible effect of some drug residues in the manure on the composting process would need to be considered. It is possible that such composting could be done using windrows which could be periodically turned over for aeration, that is, in a system other than passively aerated static piles, but this would require verification by actual testing. It is recommended that the concept of using the composting process to remove excess water from the dilute slurry be investigated on a farm scale. The process has worked well with both swine and poultry manure slurries on relatively small test piles. Feasibility testing on a large scale is required.

8. ACKNOWLEDGEMENTS

The study would not have been possible without the active support and encouragement of the Ontario Pork Research Committee and Agriculture and Agri-Food Canada management.

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9. TABLES

Table 1. Average composition values of raw materials and the compost mixture initially (day 0) and at the end of the composting period (day 60).

Material	Time (d)	Water (%)	C	N	Ash	Ca	Mg	K	C:N
			% dry matter						
Slurry	0	91	31.2	2.92	39.7	6.96	2.33	0.82	11
Straw	0	9.7	44	0.7	8.48	0.58	0.25	0.16	63
Compost mixture, control and treatment	0	72.8	39.9	1.37	18.1	2.21	0.78	1.55	29
Control	60	49.4	34.7	2.31	25.8	3.25	1.16	2.11	16
Treatment	60	59.4	36.3	2.4	24.8	3.22	1.12	2.16	15

Table 2. Pile content (kg) as measured at the start (day 0) of composting and calculated at the end of composting (day 60) assuming conservation of ash during composting.

	control 1		control 2		treatment 1		treatment 2	
Composition	start	end	start	end	start	end	start	end
Total weight	1710	621	1340	493	1260	747	1510	653
Water [1]	1236	310	978	240	2923 [1]	482	3096 [1]	355
Total solids	474	311	362	252	337	265	414	298
Volatile solids	389	226	300	190	271	199	371	225
Ash [2]	85	85	62	62	66	66	73	73
Carbon	191	112	146	93	134	96	163	109
Calcium	9.7	10	8.3	8	7.8	8.9	9.1	9.1
Magnesium	3.4	3.6	2.9	2.9	2.6	3	3.5	3.3
Potassium	7.2	7.6	6	5.8	4.8	5.2	6.7	6.9

[1] Mass of water for the treatment piles includes 2000 kg of irrigation water.

[2] Conservation of ash was assumed: The mass of ash at the start of composting = the mass of ash at the end of composting.

10. FIGURES

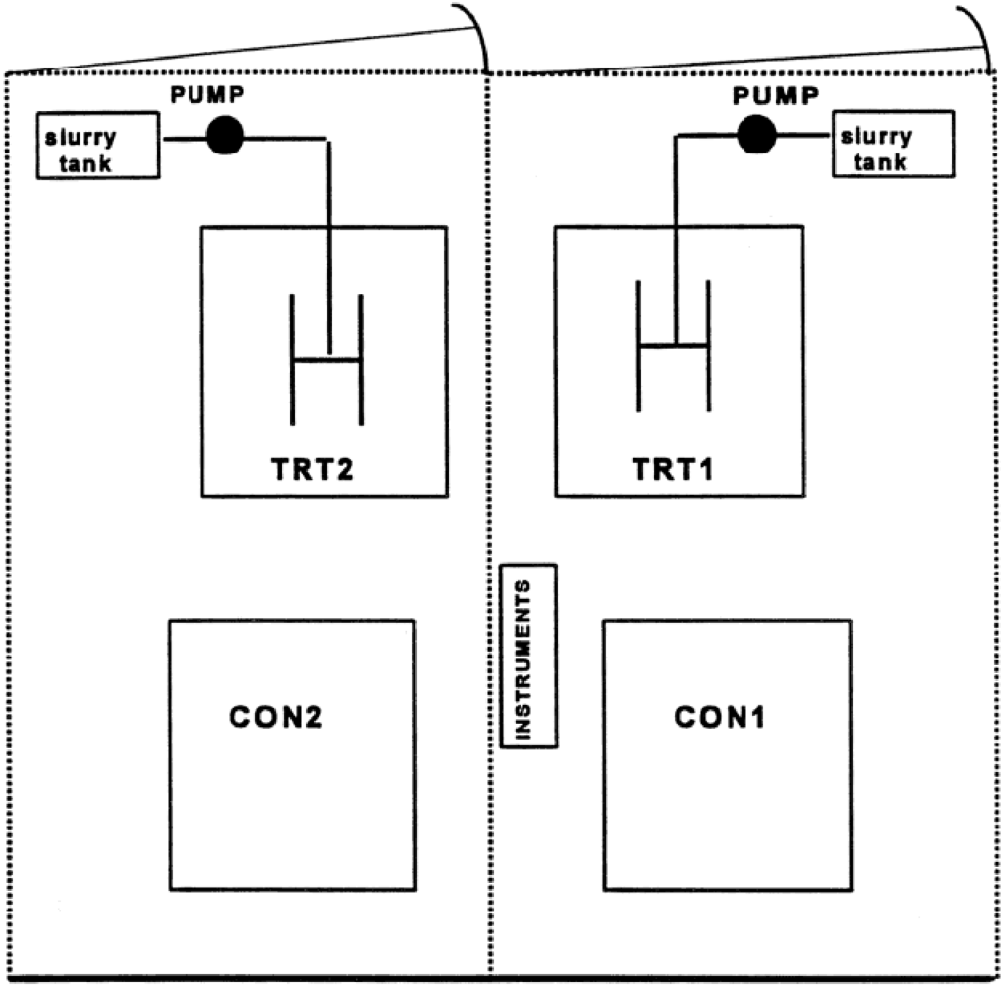

Figure 1. Layout of the control piles (CON1, CON2), treatment piles (TRT1, TRT2) piles, irrigation systems, and the instrument area with the data logger and controller, sampling valve and oxygen analyser.

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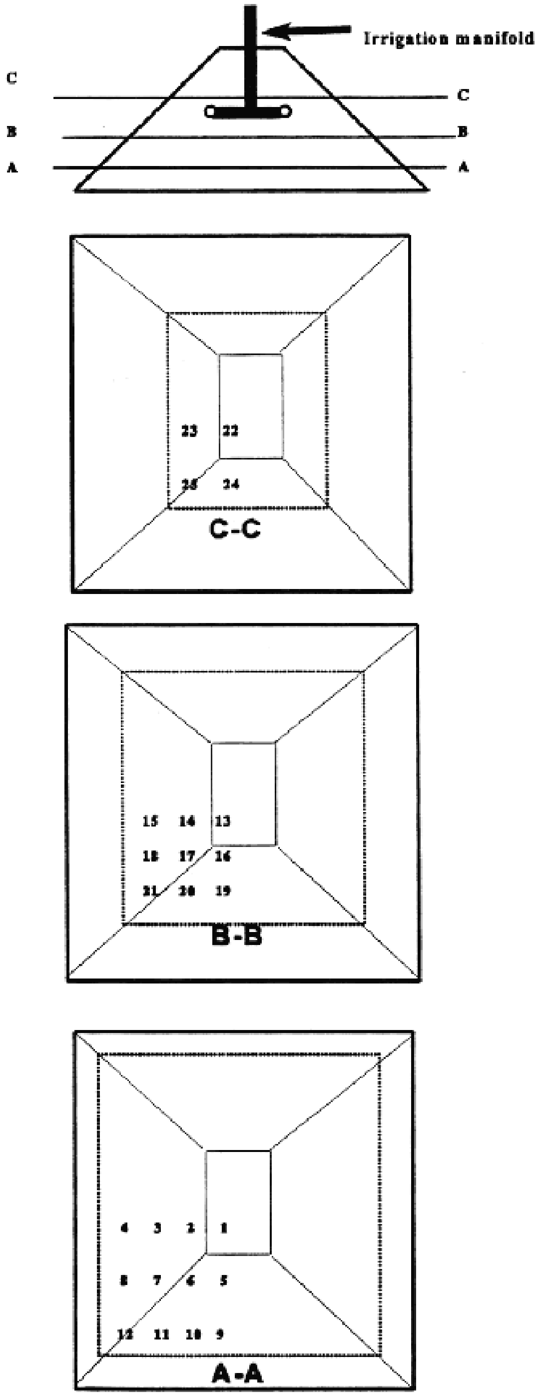

Figure 2. End view of a treatment pile with three plan views showing numbered thermocouple locations. Sections A-A, B-B, and C-C were 0.25, 0.55 and 0.85 m (10, 22, and 33 inches), respectively, above the base of the pile. Irrigation manifold was not used in the control piles.

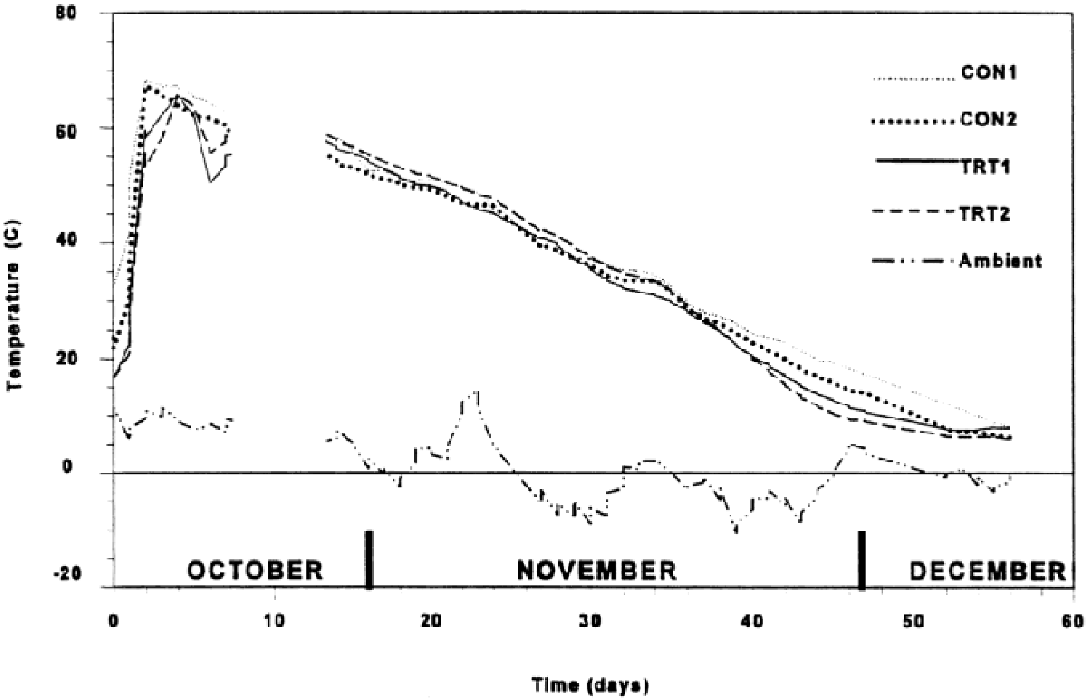

Figure 3. Average temperature measured at 25 locations in each control pile (CON 1, CON2) and each treatment pile (TRTI, TRT2), and ambient temperature. The data logger malfunctioned between day 8 and 14. Manual check of temperature during this period showed similar temperatures in the four piles .

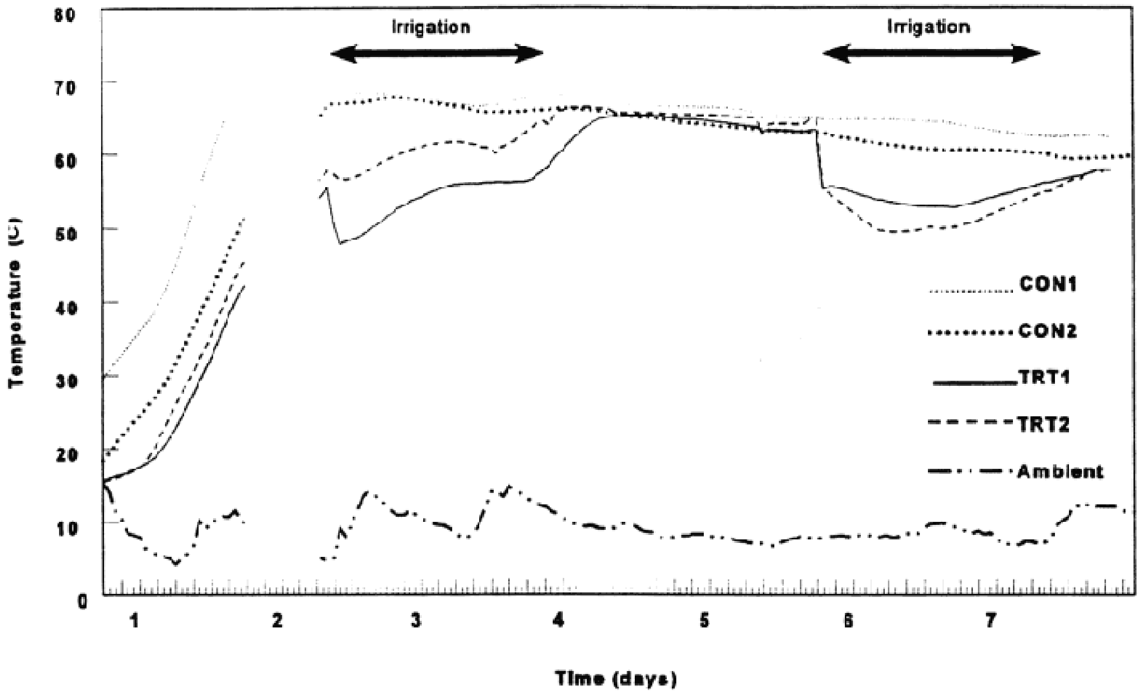

Figure 4. Average temperature of 25 locations in the first 7 days of each control pile (CON1, CON2) and each treatment pile (TRT1, TRT2) when pile irrigation was occuring.

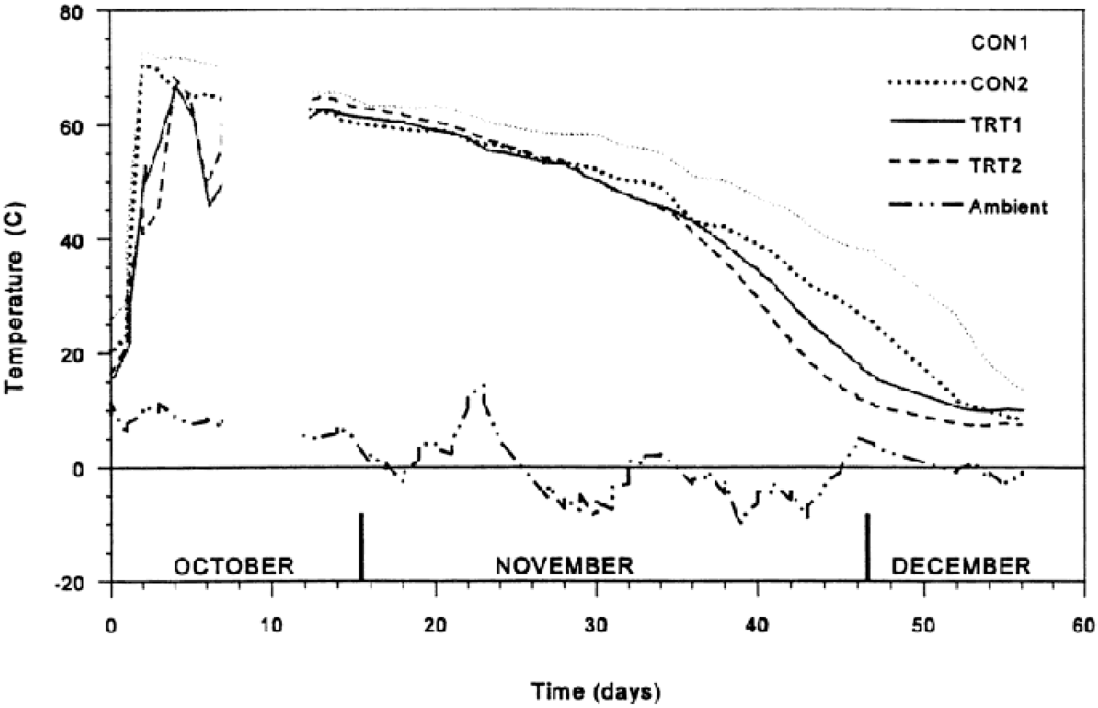

Figure 5. Average temperature at seven locations closest to the core for each pile (locations 1,2,13,14,16, 17 and 22 in Fig. 2). After day 35, core temperatures dropped faster in the treatment piles than in the control piles due to greater proximity of the treatment piles to below-freezing ambient temperatures because of location adjacent to the open end of the barn (Fig. 1)

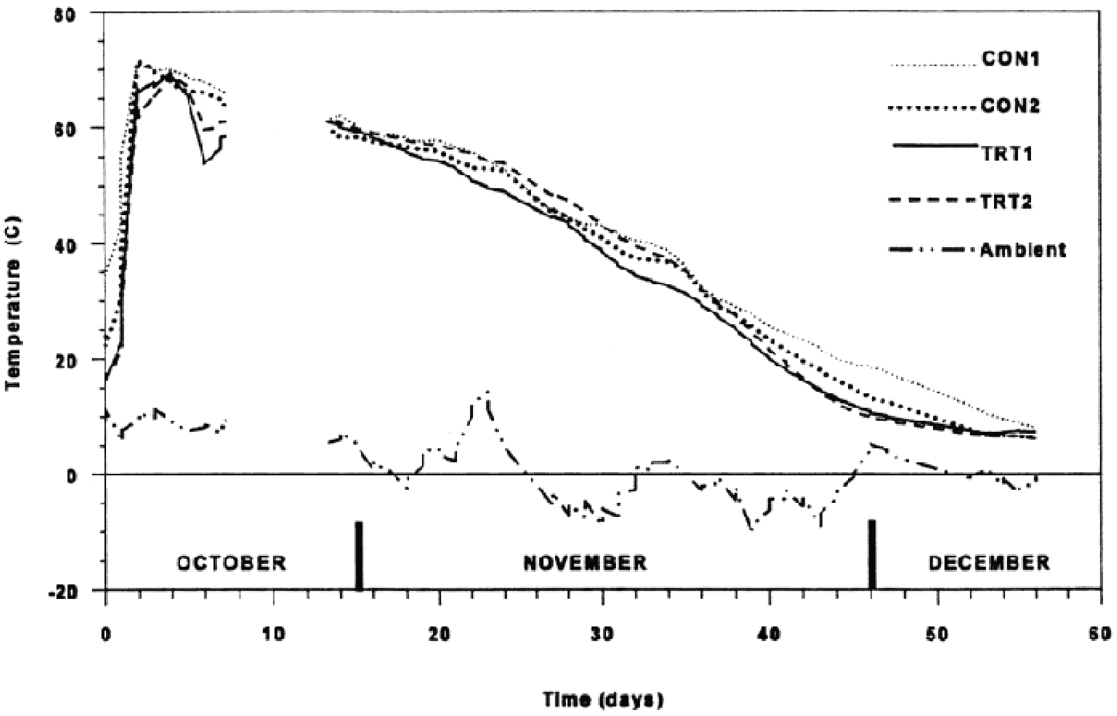

Figure 6. Average temperature at 11 locations between the core locations and the outside edge locations for each pile (locations 3, 5, 6, 7, 15, 18, 19, 20, 23, 24, 25 in Fig. 2) and ambient temperature.

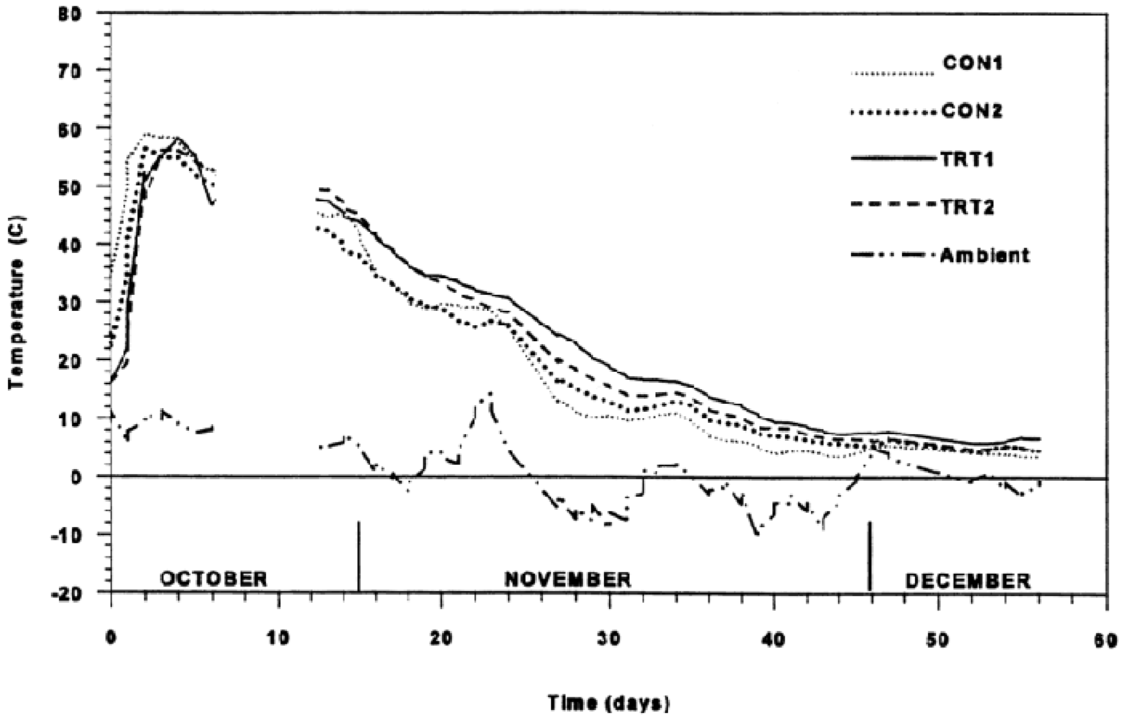

Figure 7. Average temperature at seven locations closest to the outside edge of each pile (locations 4, 8, 9, 10, 11, 12, 21 in Fig 2.)

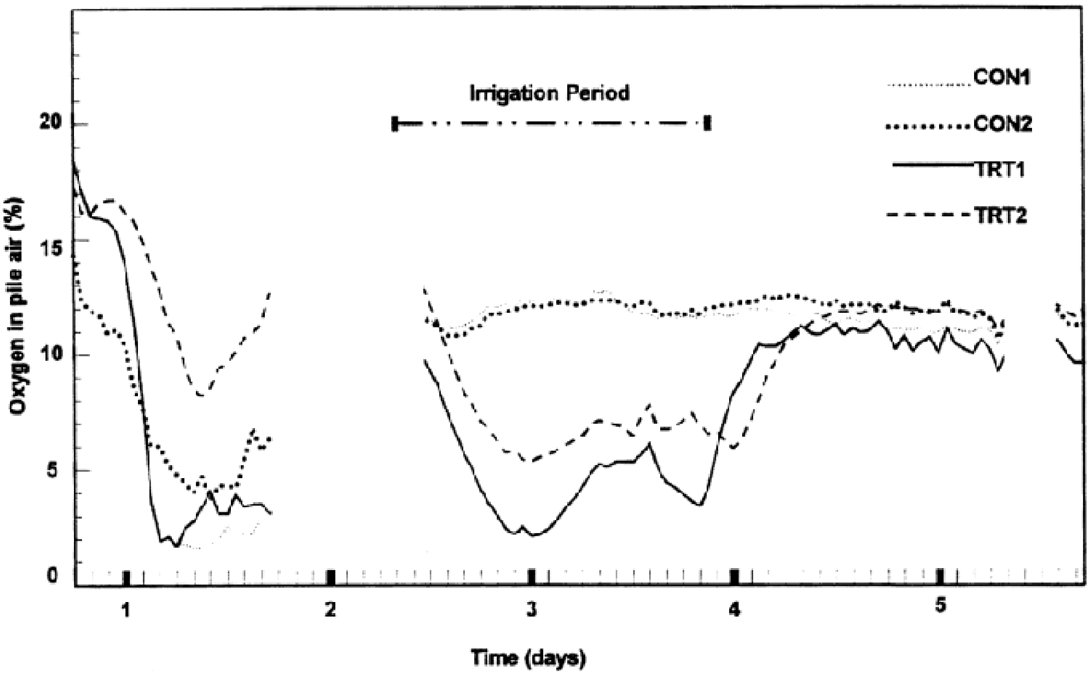

Figure 8. Oxygen content of air in the four piles. Missing data are due to accumulation of condensed moisture in the sampling tubes. Monitoring was discontinued after 6 days.

11. PHOTOS

Photo 1. View of the open-front, roofed barn used for compost pile preparation. Two pens were used for two piles in each pen (Photo 11). The treatment (irrigated) piles were located at the open end of the barn.

Photo 2. Weigh-scale and auger-equipped feed mixing truck and skid steer (bobcat) loader used for pile preparation. Compost mixture is being emptied into the loader through the side chute of the mixing truck.

Photo 3. View of the open-ended perforated aeration pipes, the wooden frame used to shape the piles, and 200-gallon slurry tank prior to pile preparation. The pipes were covered with a screen (taped in place) to prevent plugging of aeration holes.

Photo 4. Preparation of an initial prototype compost pile of peat and swine manure, used for testing the monitoring system. Thermocouple wires coming out of the pile are visible at the bottom.

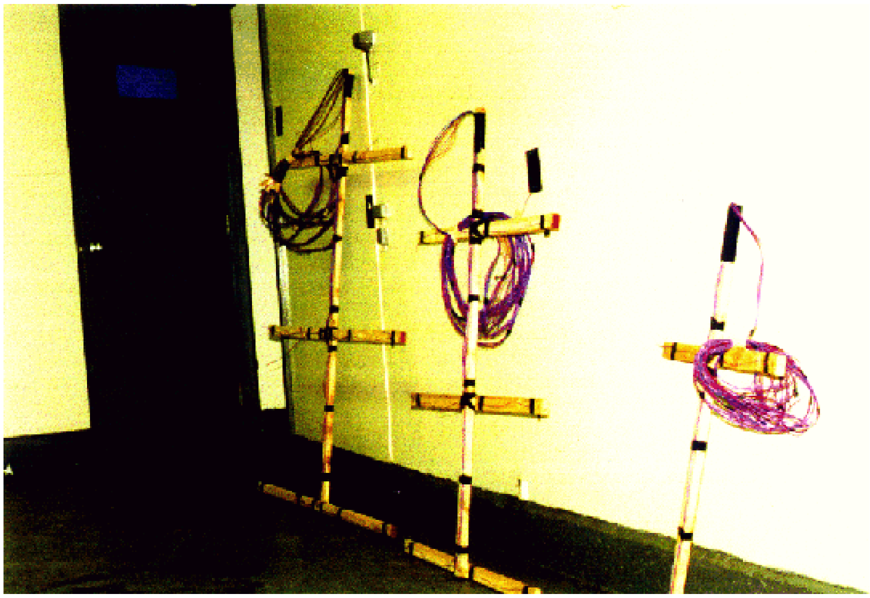

Photo 5. Temperature-monitoring thermocouple grids used in the piles.

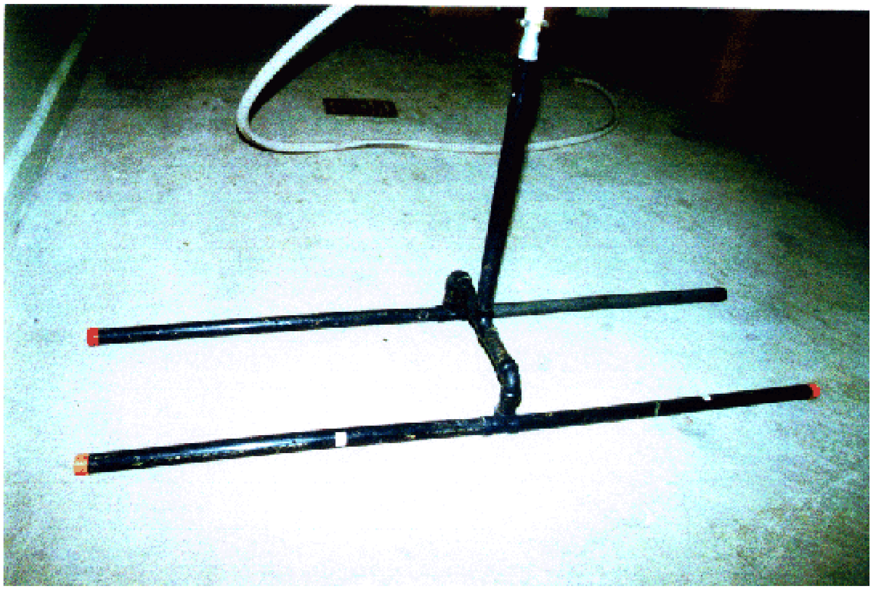

Photo 6. Manifold used to irrigate the piles with dilute swine manure slurry stored in 200 gallon tanks shown in photo 3.

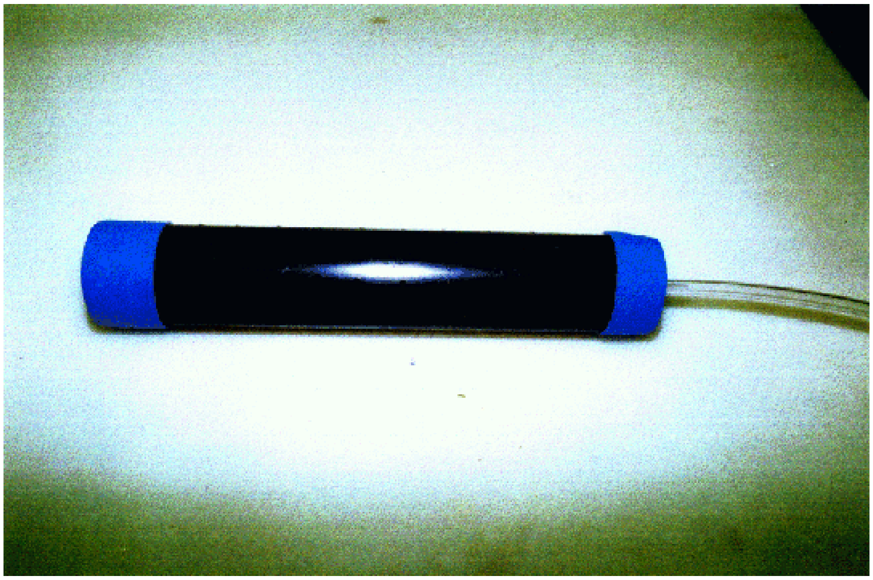

Photo 7. View of a gas sampling chamber which was placed inside each pile to monitor oxygen content of the air inside the piles.

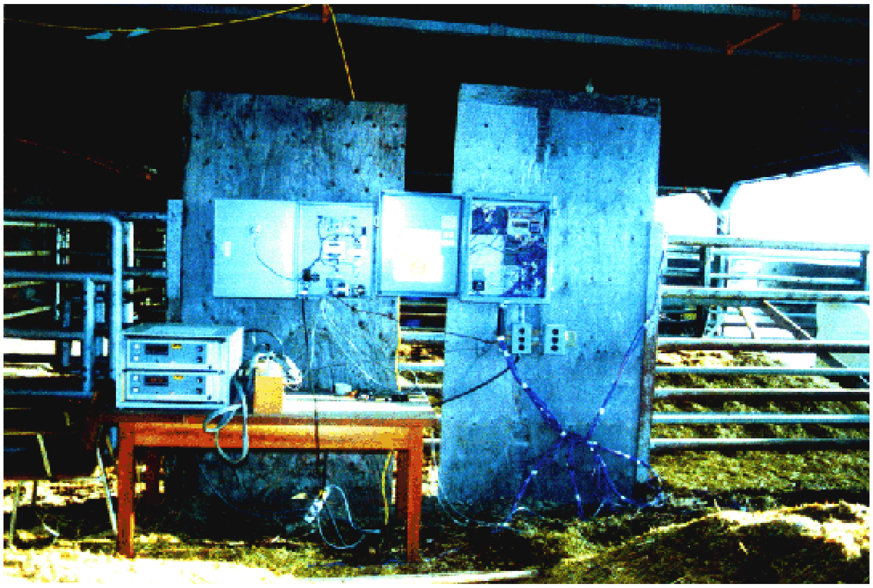

Photo 8. View of the data logger and controller system used to continually monitor temperatures and gas in the four piles, and to trigger the slurry pumps for pile irrigation.

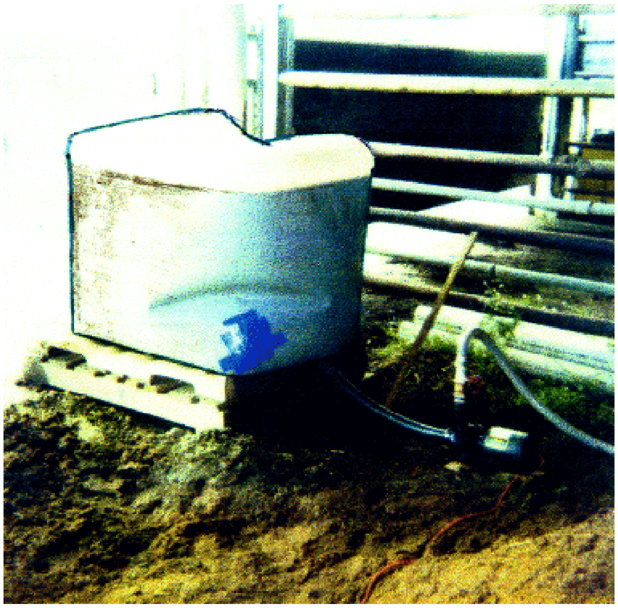

Photo 9. View of the 200-gallon slurry storage tank and the centrifugal pump. One such unit was used for each of the two treatment piles.

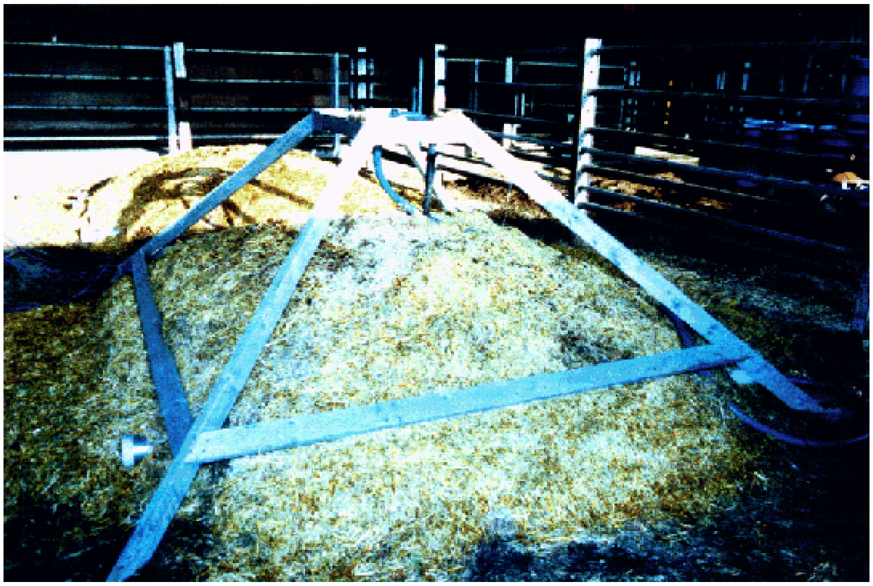

Photo 10. View of the compost piles of straw and swine manure at the end of the 60-day composting period. Initial size of the pile is indicated by the wooden frame.

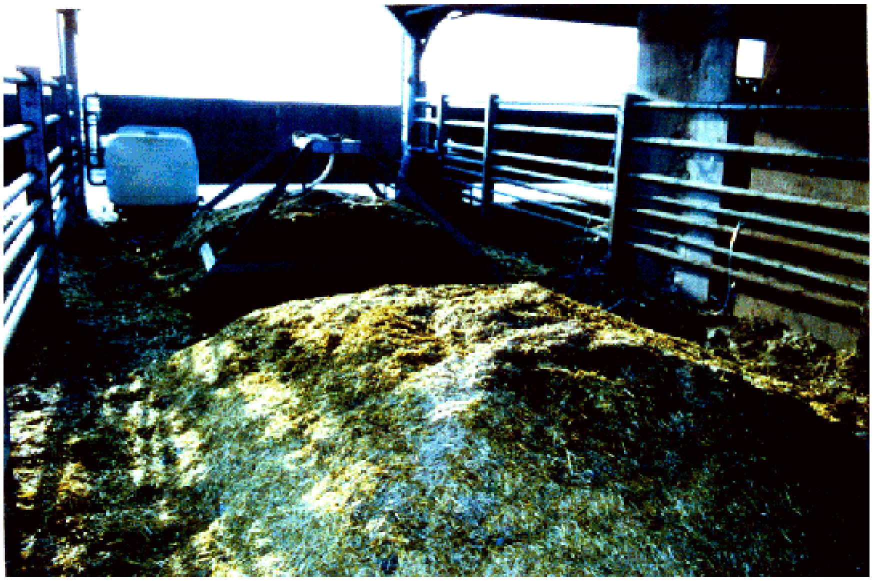

Photo 11. View of two piles in one pen. The control pile is in the foreground. The system control and monitoring panels are on the other side of the plywood boards (not visible in this photo) on the right.