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Composting abbattoir/feedlot waste solids

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SUMMARY

This report discusses the application of a temperature-controlled aerated pile composting technique for stabilizing meat processing solid wastes and feedlot manure. Six pilot-scale composting trials were undertaken by MIRINZ and the CSIRO Meat Research Laboratory, Brisbane, under the terms of MRC project M.051.

In addition to demonstrating and evaluating the composting technique, a major purpose of the trials was to introduce MIRINZ composting expertise to the CSIRO, and thereby transfer the technology for development and implementation in Australia.

The different solid waste types investigated in the trials consisted predominantly of the following:

- Paunch contents of grass-fed cattle (Trials 1 and 2)
- Paunch contents of lot-fed cattle (Trials 3 and 6)
- Screened, aged feedlot manure (Trial 4)
- Freshly scraped feedlot manure (Trial 5)

Each trial (except Trial 4) involved the construction of a 20-50 m^3 pile of the waste material (sometimes mixed with a bulking agent) over an aeration base. The material was stabilized by forced aeration controlled by temperature feedback for a period of 3-4 weeks. The compost was then re-formed into a non-aerated curing pile, which was turned occasionally. This curing stage lasted at least two months. In Trial 4 the aeration stage was omitted; i.e. turned windrow composting was used.

Trial 1 was conducted in New Zealand. The other trials were undertaken at two sites in Queensland, Australia.

The paunch contents of grass-fed cattle produced a well-stabilized compost, with good structure and appearance and an earthy odour. The addition of save-all bottom solids containing meat scraps was found to speed the decomposition of the paunch grass fibres and enhance the nutrient content of the product.

The paunch material from lot-fed cattle composted more slowly than from grass-fed cattle, due to the refractory nature of its grain fibres. In addition, the waste in these trials had a high concentration of fat (34% dry weight; from a gut cutting process).

The heat produced by the breakdown of this fat during the aeration stage caused excessive drying of the compost, slowing the composting process. The composting of wastes with a highly biodegradable organic content requires both a high initial moisture content and the addition of water during the curing stage.

All the aerated composting trials were conducted without creating nuisance odours due to the maintenance of aerobic conditions and rapid removal of the highly biodegradable component of the wastes.

Forced aeration composting was found to be inappropriate for stabilizing feedlot manure. Windrow composting using specialized windrow composting machines, with regular turning during the initial stage of the process, is recommended for this material.

1. INTRODUCTION

Composting is potentially a cost-effective and environmentally acceptable means of treating organic waste solids, and is increasingly being used world-wide for stabilizing a variety of organic waste solids including sewage sludges, municipal refuse and agricultural and food processing wastes.

Since 1986 the Meat Industry Research Institute of New Zealand (MIRINZ) has been investigating composting as a means of stabilizing solid wastes from meat processing plants (van Oostrom *et al.*, 1988), and more recently the Institute has investigated the composting of municipal primary sewage sludge (van Oostrom *et al.*, 1989). A temperature-controlled aerated static pile process based on the Rutgers composting process (Finstein *et al.*, 1983) was used in these studies, and was found to stabilize the wastes effectively and remove excess moisture without producing nuisance odours. The composting process recovers the fertilizer value of the wastes and the compost produced is an excellent plant growth medium or soil conditioner.

The Meat Research Corporation (MRC), formerly the Australian Meat and Livestock Research and Development Corporation (AMLRDC), commissioned MIRINZ to demonstrate and refine this composting technique for application to abattoir and feedlot wastes in Australia, by undertaking pilot-scale trials. In addition to demonstrating the process, a major purpose of these trials was to train an employee of the CSIRO Meat Research Laboratory, Brisbane, in the principles and methods of the process, and thereby transfer the technology for development and implementation in Australia.

This final report brings together all the findings of the trials and elaborates on the interim reports for this project (McPhail and van Oostrom, 1990; van Oostrom, 1990; van Oostrom and McPhail, 1990). An overview of composting is given and the appropriate application of this technology for stabilizing meat processing wastes and feedlot manure is discussed by reference to the pilot-scale composting trials. In addition, composting of feedlot manure is discussed by reference to an independently funded visit to a feedlot manure composting operation in the United States.

2. OVERVIEW OF COMPOSTING

2.1 Definition

Composting is the stabilization of organic solid waste material by microorganisms and fungi in aerobic (oxygen present) and moist conditions, and at elevated temperatures. During composting, the readily biodegradable component of the waste is oxidized (converted to carbon dioxide, water and heat), leaving an organic residue (e.g. humus), which is relatively stable (eq. 1). Composting is a special form of aerobic decomposition in that metabolic heat generated by the microorganisms elevates the temperature of the compost. The elevated temperature, if not too high (<60°C), promotes rapid decomposition rates.

$$\text{Fresh organic matter} + O_2 \xrightarrow[\text{metabolism}]{\text{Microbial}} \begin{array}{c}\text{Stabilized organic residue} \\ + CO_2 + H_2O + \text{heat}\end{array} \qquad (1)$$

2.2 Advantages

The advantages of composting an organic waste are as follows:

- Composting and sale of the product may be more cost effective than other solid waste management options.
- Composting can have considerably less impact on the environment than most other solid waste management alternatives.
- A biologically stable compost does not generate offensive odours and can be stored without nuisance.
- Unlike many fresh organic wastes, mature compost does not contain or produce phytotoxic substances (compounds that inhibit plant growth and seed germination).
- The heat generated during the composting process promotes moisture removal, making the product easier, and therefore less costly, to handle than the raw material.
- The heat generated during composting destroys pathogens and most common weed seeds.
- Plant nutrients in the organic material become more concentrated as the readily biodegradable carbon compounds are removed and the waste volume is reduced.
- The structure and appearance of the organic material is improved, making it more easily spread on crop-land or more attractive for marketing as a soil

conditioner or potting mix base for home gardeners and commercial plant nurseries.

2.3 Process Control

Given appropriate initial conditions of moisture, pH and nutrients in the organic material, the most important factors influencing the rate and success of composting are oxygen supply and temperature.

Oxygen is required by the composting microorganisms to oxidise the biodegradable component of the organic material. The higher the content of readily biodegradable material, the greater is the potential requirement for oxygen (oxygen demand). If insufficient oxygen is supplied, anaerobic conditions result. Anaerobic conditions should be avoided as they reduce microbial activity, heat generation and the stabilization rate, and lead to the production of nuisance odours.

In the absence of deliberate heat removal, and provided oxygen is not limiting, composting temperatures can exceed 60 to 65°C (and may reach 80°C), which severely limits process activity and delays stabilization. Temperatures within the range of 40 to 60°C promote maximum activity; therefore temperature control is an important aspect of composting.

The composting of highly biodegradable wastes, with their high oxygen demand and heat generation potential, requires considerable process control over both temperature and oxygen supply, to allow nuisance-free and rapid stabilization.

2.4 Composting Methods

Composting systems can vary greatly in complexity, sophistication and capital cost. At one extreme is the unenclosed static windrow system, with little process control and a long stabilization period; at the other extreme is the totally enclosed composting reactor, with a high capital cost, complex design, and high level of process control.

The selection of the type of composting system will depend on the nature of the waste, site considerations, capital costs and the availability and cost of bulking agents.

There are two main approaches to composting: windrow composting, which relies on turning and passive aeration; and forced aeration composting. These are described below, in terms of their level of control of process temperature and oxygen conditions. The suitability of each method is briefly discussed in terms of waste characteristics such as porosity and content of highly biodegradable material.

2.4.1 Windrow composting

Static windrow

The static windrow method relies on passive aeration to provide oxygen. Oxygen enters the pile passively, through a combination of simple diffusion and convective movement of air through the compost pile (caused by heating within the pile).

The size of the windrow and the porosity of the composting material affect how well passive aeration works. These factors also affect heat loss, and thus the internal pile temperatures. Stabilization is enhanced by controlling the size and porosity of the windrow so that it is both small enough (cross-sectional area) and loose enough to allow adequate oxygenation, yet large enough to retain some heat.

Static windrow composting is suitable only for wastes with a low content of readily biodegradable substrate and an open structure (such as leaves). Wastes with greater oxygen demand may be composted by this technique if they are diluted with a coarse, porous, inert bulking agent. Addition of a bulking agent also produces an open structure in the mixture. Nevertheless, with static windrows, anaerobic conditions and sub-optimal temperatures are unavoidable, and stabilization periods may range from 6 months to 2 or more years.

Turned windrow

Turned windrows are similar to static windrows, except the material is turned or agitated as a means of re-oxygenating and cooling the compost, and loosening its structure to facilitate passive aeration and heat removal. A front-end loader or specialized turning machine is commonly used. With turned windrows, wastes with higher oxygen demand can be composted more rapidly and larger windrows can be used, than is the case for static windrows. However, mechanical turning cannot control compost temperatures precisely, and unless the material is turned frequently, anaerobic conditions are unavoidable.

The frequency of turning required to prevent nuisance odours and achieve rapid stabilization, will depend on the waste's oxygen demand and porosity, and the type and amount of bulking agent used (if any). Stabilization periods of less than three months are achievable for some wastes.

2.4.2 Forced aeration composting

In this technique oxygen is supplied by forcing air through the compost (by a fan and air distribution system). The composting material may be either in an open pile placed over an air distribution base (aerated static pile method; Fig. 1) or partially or fully enclosed in a variety of configurations (in-vessel systems).

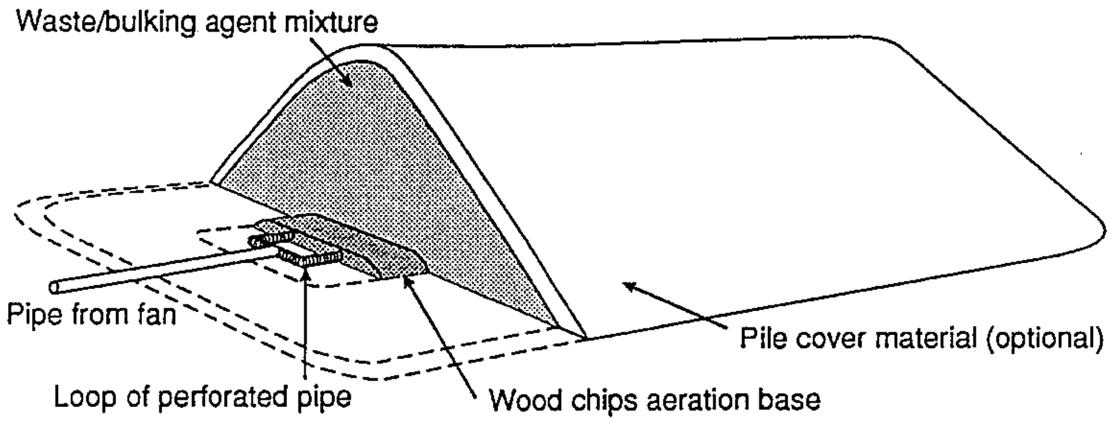


Figure 1. Aerated static pile configuration.

In early forced aeration systems, such as the Beltsville Aerated Static Pile Method (Willson *et al.*, 1980), the main control objective was to regulate the aeration fan (by a timer) to maintain an oxygen concentration of 5-15% within the pile. Low aeration rates were sufficient to supply the oxygen. However, excess heat was not removed and high temperatures (60-80°C) persisted, inhibiting microbial activity, and slowing stabilization. To help control the odours that resulted from high temperatures and slow stabilization, the air was drawn through the pile (induced aeration) and passed through an odour filter pile of mature compost.

In the late 1970s a temperature-controlled forced aeration technique was developed (Rutgers Composting Strategy; Finstein *et al.*, 1980; 1983). In this method the aeration rate is regulated to remove excess heat and maintain a compost temperature ceiling of 60°C, by feedback temperature control of the aeration fan. The rate of airflow required to remove excess heat is about nine times that required to supply oxygen; thus temperature control ensures good aeration. Forced aeration is normally used with this process as, among other advantages, it produces better temperature distribution than induced aeration (Miller *et al.*, 1982).

Temperature controlled, forced aeration composting has the following advantages:

- Decomposition rates are high and stabilization periods are short (normally three to four weeks).
- Highly biodegradable wastes can be stabilized effectively without requiring frequent handling or turning.
- Odours are minimized because putrescible odour-causing compounds are rapidly degraded, and anaerobic conditions are prevented.
- Less bulking agent is required to modify the pile structure and aid aeration of the waste. (Too much bulking agent downgrades the final compost product by diluting the nutrients required for plant growth.)
- Excess moisture is removed during the process, since the principal mechanism of heat removal is evaporative cooling.
- Process activity can be determined by monitoring the amount of aeration needed to remove excess heat.

Temperature-controlled forced aeration composting is best suited to stabilizing organic wastes that contain highly biodegradable material and thus have a potential for high oxygen demand and heat generation.

This process control strategy is now being widely used for stabilizing wastes such as sewage sludge, and has been employed in the current study.

Forced aeration composting normally lasts about 3-4 weeks, during which time most of the readily biodegradable material is broken down. This aeration stage is normally followed by curing the material in non-aerated piles for several weeks, with periodic turning to ensure a uniform structure and moisture content. Sufficient activity normally occurs in the early part of curing to generate high temperatures,

2.5.2 Addition of bulking agents

The structure and moisture content of a solid waste determines how easily it can be aerated, and the type and quantity of bulking agent required (if any) to enhance porosity and absorb excess moisture. The method of mixing the waste and bulking agent will also be determined to some extent by the structure of the waste. Bulking agents must maintain their structural integrity during the composting process. Commonly used bulking agents are:

- Woodchips
- Sawdust
- Crushed pine bark or any bark with a granular structure when crushed
- Organic wastes with structural integrity such as leaves, paunch grass, straw, etc.
- Recycled compost

Bulking agents can be used singly or in combination, and if coarse bulking agents such as woodchips are used, the bulking agent can be screened from the compost and re-used.

Factors, other than the structure of the waste, that affect the selection of a bulking agent are:

- Availability and cost of bulking agents.
- Product quality requirements (e.g. crushed pine bark normally produces a compost with a better appearance than when sawdust is used).
- Product volume constraints. [Recycling the compost or bulking agent (after separation by screening) reduces the volume of product.]

2.5.3 Mixing

The waste solids and bulking agent are mixed (e.g. by front-end loader) in a ratio that both ensures that the composting material has an open structure to facilitate complete aeration of the composting pile, and confers a suitable structure to the finished product. The mixture should generally have a moisture content of about 60-70%.

Waste solids, such as cattle paunch-grass, stockyard waste and other matter of vegetable origin, tend not to produce unacceptable levels of odour during short periods of storage. For these wastes the mixing process and pile formation may be done once a week.

which aids the destruction of any weed seeds or pathogens that might remain after the initial aeration stage.

2.5 Aerated Pile Composting Operations

2.5.1 Overview

Most solid or semi-solid wastes produced by the meat processing industry can be treated by the composting process. These include:

- Paunch contents
- Sheep and cattle yard solids
- Save-all bottom solids
- Save-all and dissolved air flotation (DAF) top scrapings
- Effluent secondary treatment sludges

Although this section outlines operations associated with composting meat processing wastes by the temperature controlled aerated pile method, many of the operations are also applicable to other composting processes and wastes.

The processes required to transform organic waste solids into a stable compost using an aerated pile method are shown schematically in Figure 2.

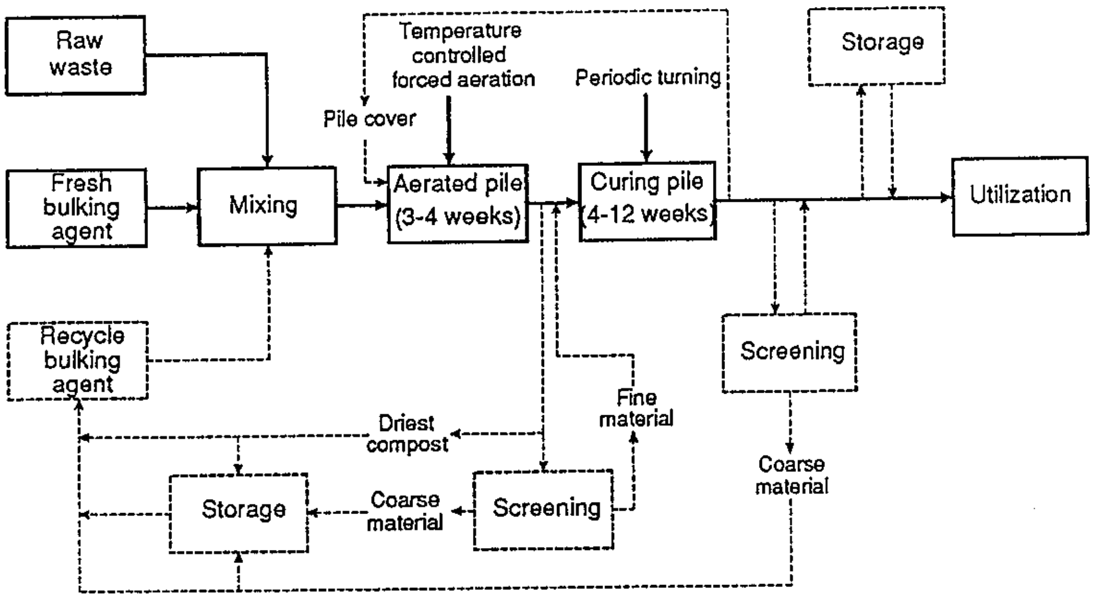


Figure 2. Operations flowchart for temperature-controlled aerated pile composting. Optional operations are indicated by dashed lines.

If week-long storage in uncovered piles proves unsatisfactory, the storage piles may be covered with a layer of bulking agent, or mixed with the bulking agent and placed onto the composting base on a daily basis.

2.5.4 Pile formation

The compost pile is formed over an aeration base on a reasonably flat, firm area. The base can consist of flexible or rigid perforated pipes (100 or 150 mm dia.) either set in the ground or laid on the surface. The pipes are then covered with a permeable material such as woodchips, pine bark or gravel. The width of the aeration base should be about one-quarter the width of the pile (see Figure 1).

Using a front-end loader, the pile is formed centrally over the aeration base to a height of about 2 m on a base width of about 5 m. The pile may be up to about 30 m long depending on fan capacity and the design of the aeration base.

The aeration pipes are connected to the outlet of a centrifugal fan. A temperature sensor, located near the centre of the pile, is connected to a controller that regulates the fan such that most of the pile is maintained within the optimum temperature range of 40 to 60°C.

For waste volumes of less than 100 m^3 per week, one pile can be formed each week and aeration should continue for 3-4 weeks. In the event of nuisance odours from the compost pile or an insect problem, a layer of crushed bark or mature compost can be placed over the pile as an odour-filtering cover. Except in regions of high intensity rain, the pile does not normally require protection from rainfall.

2.5.5 Curing

On completion of the aeration stage, the compost is re-formed into a non-aerated curing pile. Formation of the curing pile mixes moist and dry material, and secondary heating takes place as additional stabilization occurs. Temperatures are likely to exceed 70°C for several days, assisting in the destruction of any pathogens and weed seeds that might be present.

The curing pile should be turned periodically (i.e. every 1-2 weeks) to facilitate aeration and produce a compost of uniform moisture content and structure. This maturing phase may continue for several months until the compost is sold.

2.5.6 Utilization

Before utilization or sale, the compost can be passed through a screen to remove large foreign objects such as stones or bulking material. Depending on the structure and properties of the final product, it can be marketed as a soil conditioner, an ingredient for a potting mix or as a complete potting mix or plant growth medium.

3. COMPOSTING TRIALS

3.1 Introduction

Six pilot-scale composting trials were undertaken for stabilizing meat processing wastes and feedlot manure. The first trial took place in New Zealand as an exercise to train a CSIRO employee. The other trials were conducted in Queensland, Australia. MIRINZ supervised the construction of the piles in the first three trials. The rest were constructed by the CSIRO with remote supervision by MIRINZ.

Specifications of the composting trials are summarized in Table 1. Trials 1-3 and 6 composted paunch contents, sometimes mixed with other solid wastes. Trials 4 and 5 composted feedlot manure. The temperature-controlled aerated pile method was used in all but Trial 4, where a turned windrow approach was used.

3.2 Composting Sites and Raw Materials

The composting trials were located on properties belonging to companies producing the solid wastes used in the trials. The locations and raw material for each trial are listed in Table 1.

Table 1. Summary of composting trials.

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
Location	A sheep and beef killing plant in the North Island of New Zealand	Brisbane Metropolitan Regional Abattoir, Queensland, Australia	Australia Meat Holdings Beef City meat processing plant, Purrawunda, Queensland, Australia	Australia Meat Holdings Beef City meat processing plant, Purrawunda, Queensland, Australia	Australia Meat Holdings Beef City meat processing plant, Purrawunda, Queensland, Australia	Australia Meat Holdings Beef City meat processing plant, Purrawunda, Queensland, Australia
Pile formation date	17/01/90	20/03/90	31/05/90	31/05/90	20/08/90	04/02/91
Aeration stage duration	19 days	20 days	27 days	N/A	24 days	23 days
Waste material	Screened grass-fed cattle and sheep paunch contents, stockyard and truck washings and save-all bottom solids	Screened grass-fed cattle paunch contents	Screened lot-fed cattle paunch contents and gut cutting waste	Screened stockpiled feedlot manure	Freshly scraped feedlot manure	Screened lot-fed cattle paunch contents and gut cutting waste
Bulking agent	Radiata pine bark <12 mm particle size	Slash pine bark <12 mm particle size	none	none	none	peanut shells
Aeration base size, (LxWxH), m	8.3x1.3x0.2	6.3x1.3x0.2	2.8x1.3x0.2	N/A	3.3x1.3x0.2	3.3x1.3x0.2
Pile size, (LxWxH), m	12x5x2	10x5x2	6.5x5x1.8	6.5x5x1.5	7x5x1.6	7x5x2
Approximate pile volume (m^3)	50	40	23	18	19	25

Trial 1

The solid waste consisted mainly of the paunch (stomach) contents of grass-fed cattle slaughtered at a mixed sheep and cattle meat processing plant in the North Island of New Zealand. The waste also contained material from stockyard and truck washings and save-all bottom solids, consisting of gut content and meat scraps. The materials were screened from the liquid stream and then stockpiled for up to seven days before composting.

Trial 2

The waste consisted of screened, stockpiled (up to 7 days) paunch contents from grass-fed cattle slaughtered at the Brisbane Metropolitan Regional Abattoir. This material had a looser, more open structure than the waste used in Trial 1, as it did not contain save-all bottom solids and the paunch grass had a more straw-like structure than the paunch grass in Trial 1.

Trials 3 and 6

The waste used in these two trials consisted of screened paunch contents of lot-fed cattle slaughtered at the Beef City plant of Australia Meat Holdings at Purrawunda near Toowoomba, Queensland. The material consisted mainly of semi-digested grain and roughage, but also contained significant fat from the tallow added to the feed, and from the gut cutting and washing operations. The screened waste was stockpiled for 3-4 days before use.

Trial 4

The feedlot manure used in Trial 4 had been stockpiled for several years at the Beef City feedlot. This material was screened (approx. 12 mm screen), and was quite dry and had an offensive odour from being stored under anaerobic conditions.

Trial 5

The feedlot manure in this trial was transported directly from the pens to the composting site adjacent to the Beef City feedlot. A front-end loader was used to scrape up the manure. The manure contained many large lumps (up to 300 mm thick) of compacted material, but was used in the trial nevertheless.

3.3 Bulking Agents

The solid wastes used in the trials consisted mainly of fibrous material (e.g. grass or gain and roughage) that had an open and porous structure. After screening and stockpiling, during which some passive dewatering occurs, these wastes were sufficiently porous to allow composting without adding a bulking agent. However, in Trials 1, 2 and 6, bulking agents were added (in a ratio of 5 parts waste to 1 part bulking agent by volume) to improve the structure and appearance of the final product rather than aid the aeration process.

Crushed and screened (12 mm screen) pine bark was used in Trials 1 and 2, as bark confers a dark colour and good texture to the product. Peanut shells were tried as a bulking agent in Trial 6.

No bulking agent was added to the manure in Trials 4 and 5, as the manure was sufficiently dry and friable. If the manure had been wetter, a bulking agent would have been required.

3.4 Mixing

The raw materials were thoroughly mixed by front-end loader.

3.5 Pile Construction

The compost piles were formed on dry and fairly level soil or pasture surfaces. Each aerated pile was aligned precisely over the aeration base, which consisted of a loop of slotted 150 mm diameter drainage pipe buried in a bed of bark or wood chips. This pipe was connected to an aeration fan by means of a 150 mm diameter pipe.

The compost piles were 5 m wide and ranged between 6.5 and 12 m long at the base and 1.6-2 m high (Table 1), being between 19 and 50 m^3 in volume. The design of the aeration base, and its geometry relative to the pile base, is given in Figure 3. The aerated pile is shown schematically in Figure 1, but the piles used in the trials did not have a layer of cover material. A photograph of the fan and aeration base arrangement used in Trial 2 is given in Appendix 5 (Plate A1).

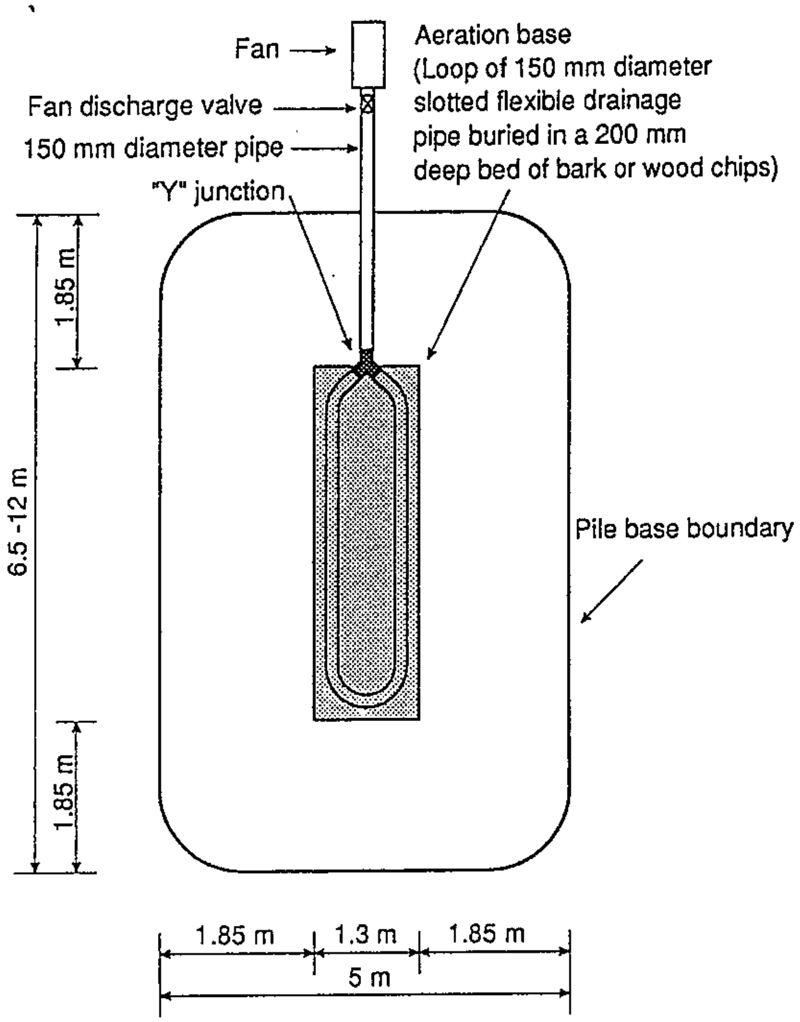


Figure 3. Aeration base design. Plan view.

To minimize air channelling through any part of the aerated pile, the following precautions were taken:

- The location of the aeration base and the dimensions of the pile base were carefully marked out.
- The raw materials were placed symmetrically and precisely over the aeration base and within the marked boundaries.
- Compaction of the raw material (by front-end loader wheels or by standing on the pile) was avoided.
- The raw materials were mixed in a consistent ratio. If the raw materials were mixed in several batches, the pile was formed with alternate bucket loads taken from each batch.

3.6 Fans'

The aeration fan used in Trial 1 was a Richardson VB3 centrifugal fan powered by a 4.1 kW motor. In the other trials a FANENG OHMC 153 2.2 fan was used. This fan was powered by a 2.2 kW motor.

The discharge on each fan could be regulated with a sliding plate valve. Before the trials began, the discharge rate/static pressure head relationship for each aeration fan was determined for various positions of the sliding-plate valve. The fan calibration procedure and the resultant calibration curves are given in Appendix 1. Using the calibration curves, the fan discharge rate at any time during the process could be determined simply from the discharge static pressure head and the position of the discharge valve.

3.7 Temperature Control

The process control objective for the aerated stage of each trial was to maintain temperatures in the pile at a maximum of 60°C, by blowing air through the pile at a rate regulated by on/off feedback temperature control of the fan. This strategy aims to attain a compost temperature range of ambient at the aeration base to 60°C near the outer regions of the pile.

A temperature controller regulated the ventilation fan to maintain a pre-set temperature (50°C) at a sensor located in the centre of the pile, 750 mm above the aeration base. (This sensor was a thermistor for the controller used in Trials 1, 2 and 3. The controller used in Trials 5 and 6 had an RTD sensor.) An overriding control mechanism (a timer) was also used, to ensure that the compost was aerated for a minimum percentage of the time (about 10%). This timer activated the fan for one minute at 11-minute intervals. The process control logic is shown diagrammatically in Figure A3, Appendix 2.

3.8 Curing Stage

After the aeration stage, a non-aerated curing pile was formed from each aerated pile. During formation of the curing pile, the wet and dry regions of each aerated pile were mixed thoroughly. The curing piles were approximately conical in shape and were turned at least four times over a period of 8 to 20 weeks.

3.9 Monitoring

3.9.1 Aeration rate and process activity

A good indicator of process activity during the aeration stage is the rate of aeration needed to remove excess heat generated in the process.

During the aeration stage of the trials the aeration rate was closely monitored at least once daily by recording the fan on-time (run-time meter). The fan discharge rate was determined from the calibration curve of static pressure vs position of the discharge valve.

The average aeration rate (aeration demand) over a given period was determined from the fan on-time and fan discharge rate, divided by the base area of each compost pile. The pile base area rather than pile volume was used in the calculation, as the aeration demand at the site of the control sensor is independent of pile height.

The process monitoring programme in summarized in Appendix 3.

3.9.2 Temperature

Temperature profiles through the centre of each aerated pile were determined using T-type thermocouples attached to wooden probes as shown in Figures 4 and 5. The thermocouple wires were connected to a Grant Squirrel 1205 Meter/Logger, which recorded temperatures at one-hour intervals for each thermocouple site. Figure 4 shows the arrangement for Trial 1; the additional temperature probes at each end of the aerated pile were not used in Trials 2, 3, 5 and 6.

In the curing piles of Trials 2, 3, 5 and 6, and the windrow of Trial 4, a single temperature probe was inserted in the centre of each pile to record temperatures at depths of 250, 750 and 1250 mm.

3.10 Raw Material and Compost Characterization

Samples of the raw materials and curing composts were analyzed. Each of these samples consisted of a composite of at least five grab samples. Samples of the compost at the end of the aeration stage of each trial were also analysed. These samples were taken at specific locations within the pile; 250, 500 and 750 mm above the aeration base in the centre of the pile. These locations were the same as those for which temperatures were monitored (Figure 5, centre probe).

Analyses were performed by the MIRINZ Environmental Management Laboratory for Trial 1, and the CSIRO Meat Research Laboratory for Trials 2 to 6.

4. RESULTS AND DISCUSSION

4.1 Meat Processing Wastes

This section discusses the results obtained in Trials 1 and 2 (paunch contents of grass-fed cattle) and Trial 3 and 6 (paunch contents of lot-fed cattle).

4.1.1 Temperature control

In Trials 1 and 2 the temperature at the site of the control thermistor was controlled at the set point of about 50°C (750 mm site; Fig. 6), indicating that the fan discharge rates used in these trials were sufficient to remove excess heat. (The set-point temperature was reduced from 50 to 47°C on day 7 of Trial 1 to compensate for an upward drift in temperature at the site of the control sensor, as measured by a thermocouple adjacent to the sensor.)

Temperatures were also well controlled in Trial 3, except during peak activity (between days 4 and 7), when the fan discharge rate was too low to remove excess heat at the site of the control sensor (due to high resistance to airflow). (The build up of excess heat is seen as a transient increase in temperature at the 750 mm site in Figure 7). During this period the fan ran for 100% of the time with the valve fully open.

In Trial 6 a faulty fan controller resulted in a loss of temperature control during most of the aeration stage. Despite the wild fluctuations in temperature that occurred, the compost pile remained within the optimum temperature range of 40 to 60°C for much of the aeration stage (Fig. 7). (The cause of the controller failure was established after the trial. The advised settings on this new temperature controller were unsuitable for the duty.)

With good control, the compost temperature increased rapidly at the beginning of the trials and feedback control was automatically initiated on the second day. A vertical temperature gradient was then established, ranging from ambient at the base of the pile to about 60°C near the top of the pile. This pattern is most clearly shown in Figure 6.

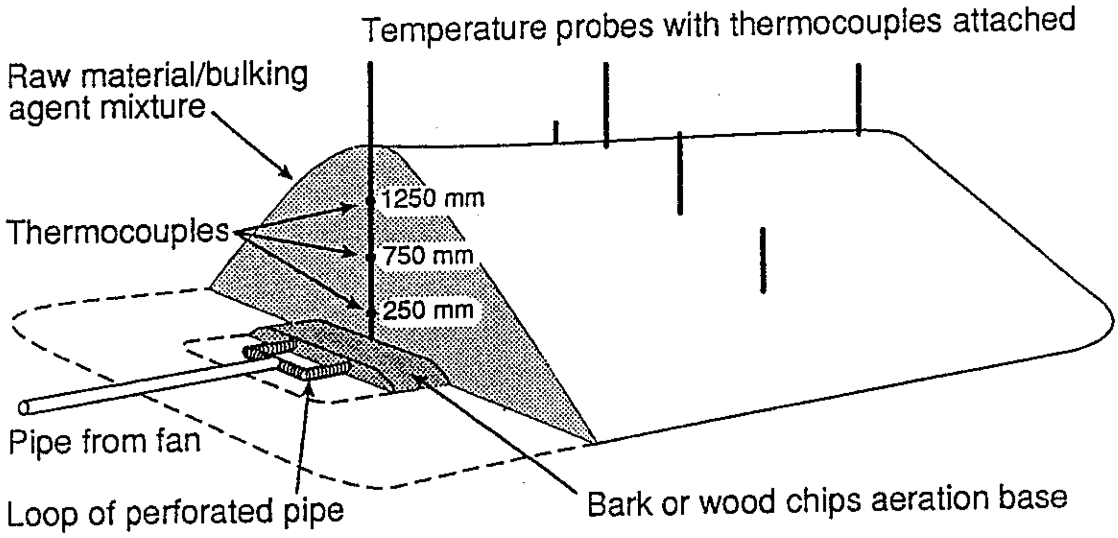


Figure 4. Aerated pile showing location of temperature probes. The probes at each end of the pile were used in Trial 1 only.

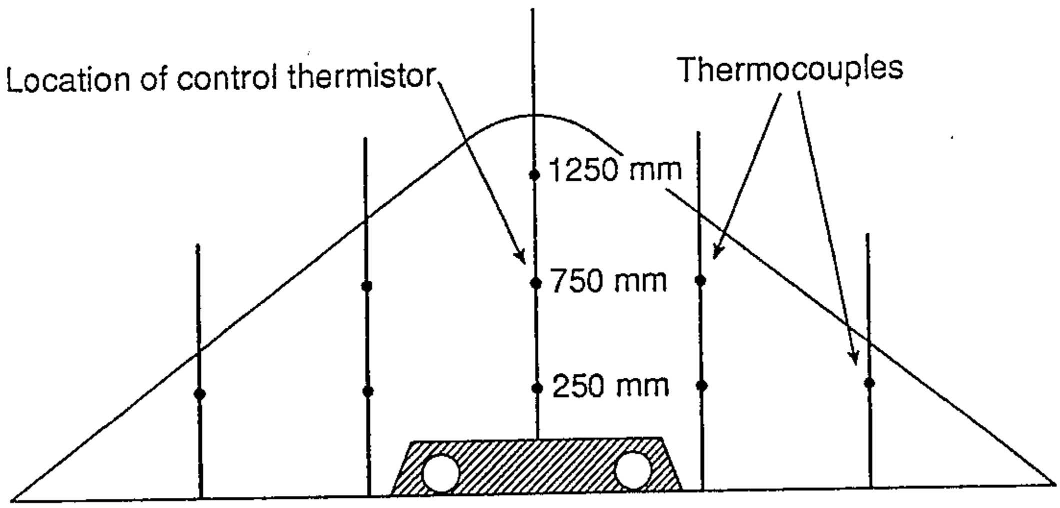


Figure 5. Cross section through the centre of a typical aerated pile, showing the position of the thermocouples. The 750 mm location was also the position of the control sensor.

The samples were characterized by analyses for total solids, volatile solids, pH, total Kjeldahl nitrogen, ammoniacal nitrogen, total oxidized nitrogen and total fat. The methods used are given in Appendix 4.

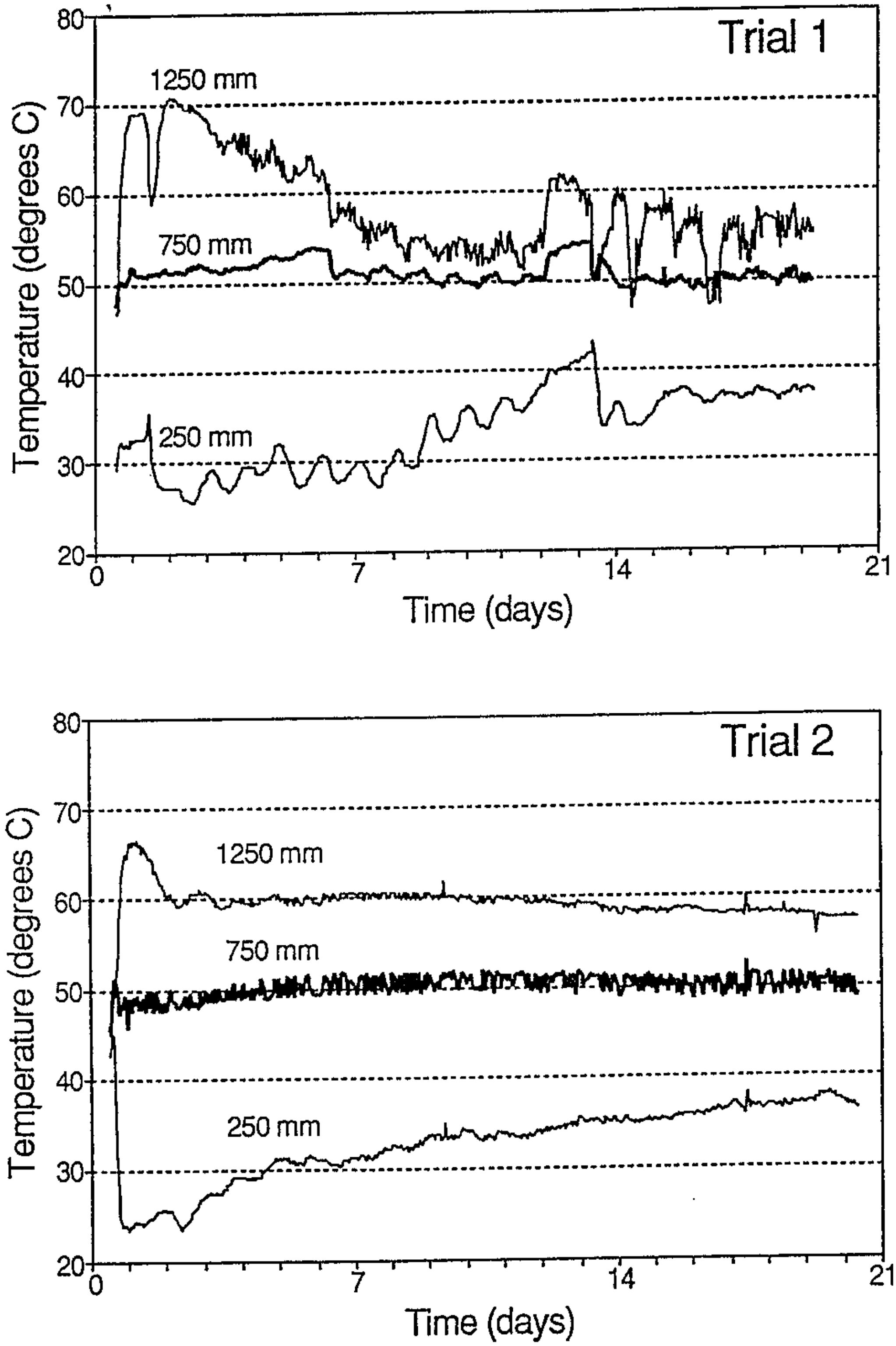
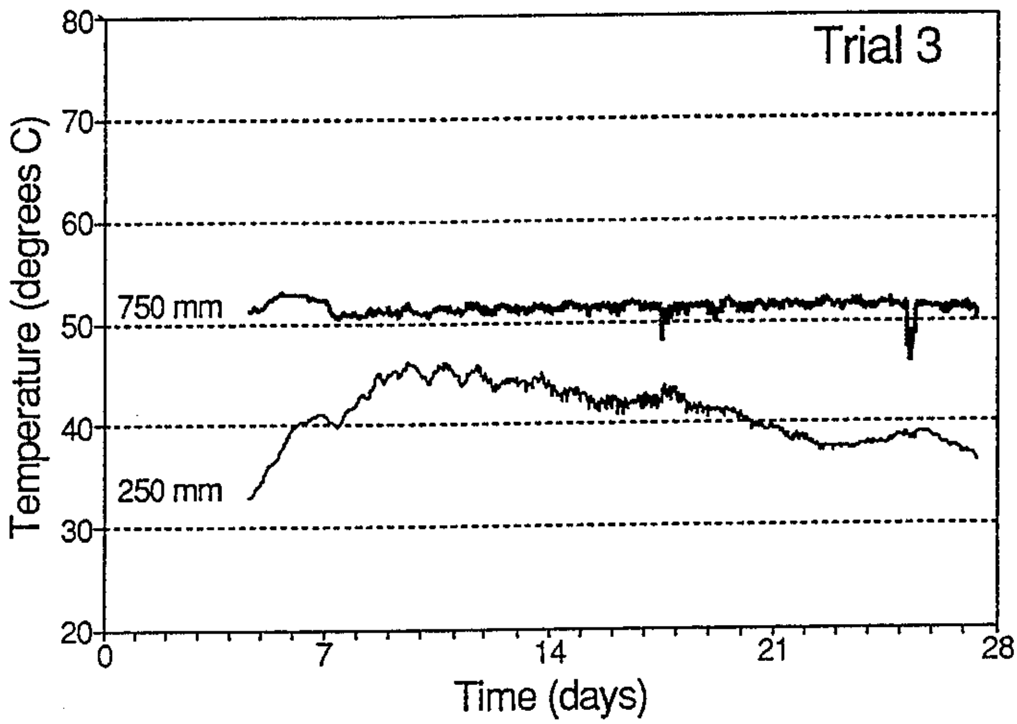


Figure 6. Temperatures recorded at 250, 750 and 1250 mm above the aeration base in the centre of the piles in Trials 1 and 2 (paunch contents of grass-fed cattle). The 750 mm site is also the position of the control sensor.



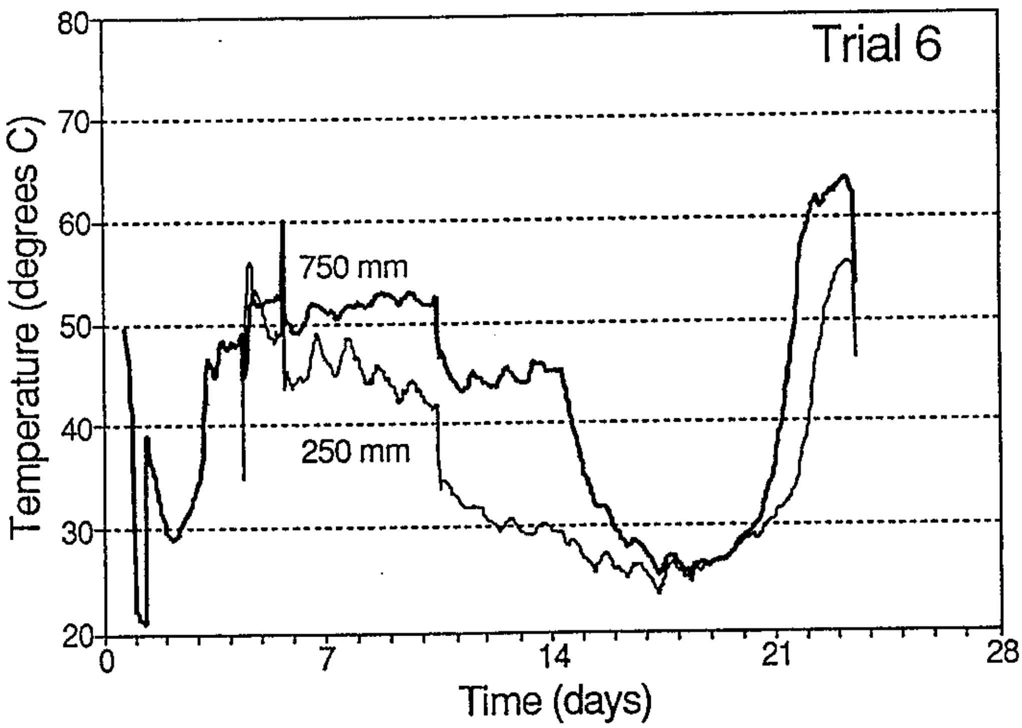


Figure 7. Temperatures recorded at 250 and 750 mm above the aeration base in the centre of the pile in Trials 3 and 6 (paunch contents of lot-fed cattle). The 750 mm site is also the position of the control sensor. The 1250 mm site is not shown due to settling of the piles, exposing the thermocouple to the atmosphere.

Except in Trial 6, the temperature profiles at the various positions within each compost pile showed that most of the compost was controlled successfully within the range of 40 to 60°C. The absence of continuously and excessively hot or cold regions in the piles indicates that significant short-circuiting of air through the piles did not occur, and therefore that each pile was precisely aligned over its aeration base.

4.1.2 Aeration rate and process activity

Assuming even air distribution throughout the pile (minimal channelling), the aeration rate reflects the composting activity and the amount of readily biodegradable organic matter in the composting material. The aeration rate is regulated by feedback control, and therefore corresponds to aeration demand. This measurement applies only to the compost immediately below and surrounding the control sensor, but is a reasonable estimate for the entire pile if the air distribution is even.

In Trials 1 and 2, the maximum composting activity (as determined by aeration demand) occurred during the first day of composting (Fig. 8). Maximum activity in Trial 3 occurred between days 4 and 7 when the fan was running continuously (Fig. 9). Due to the faulty controller, no estimates of activity can be made for Trial 6.

Maximum and total aeration rates were highest in Trial 1 (Table 2), reflecting the high content of readily biodegradable organic matter (fat, protein, carbohydrate) in the waste used in this trial (the save-all bottom solids and the "green" nature of the paunch grass largely contributed to this).

The low activity in Trial 2 reflects the lower quantity of readily biodegradable matter in the waste and the more straw-like structure of the paunch grass.

The maximum activity in Trial 3 was underestimated due to insufficient fan capacity. Total aeration demand in this trial was quite high (Table 2) and reflected the high fat content of the paunch material used in this trial.

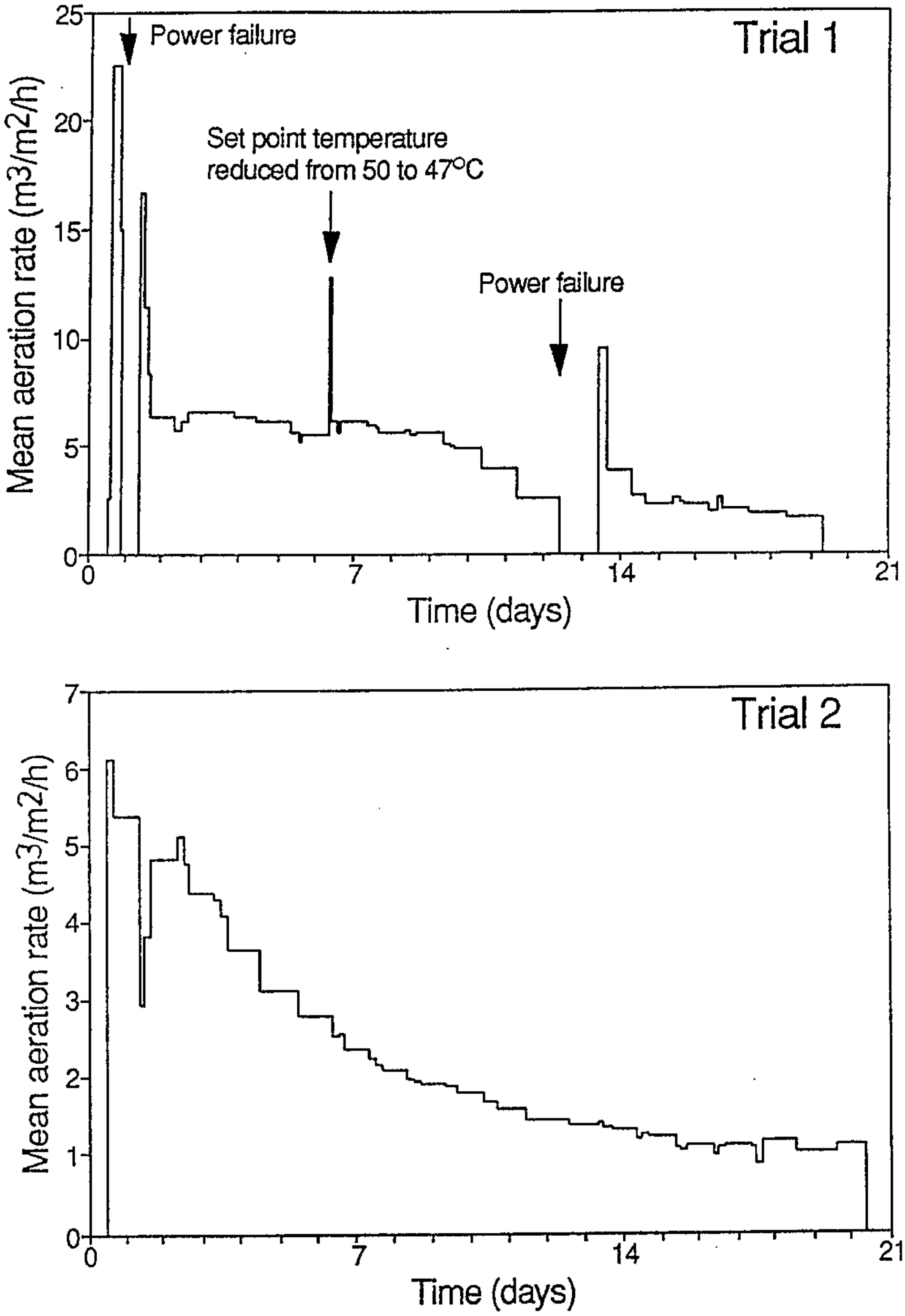


Figure 8. Aeration rates during the aeration stage of Trials 1 and 2 (paunch contents of grass-fed cattle).

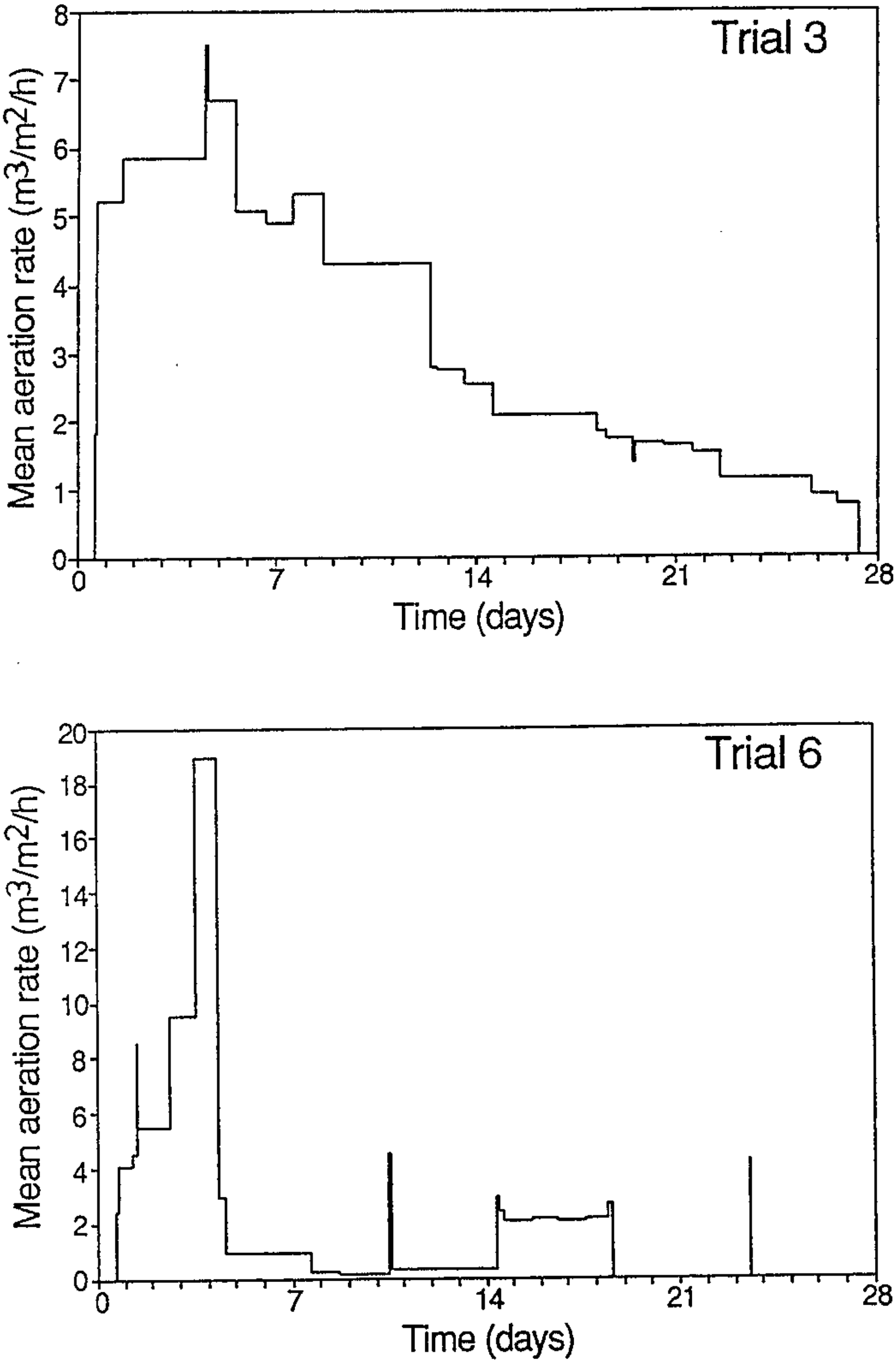


Figure 9. Aeration rates during the aeration stage of Trials 3 and 6 (paunch contents of lot-fed cattle). Aeration was not controlled properly in Trial 6.

Table 2. Maximum aeration rates and total aeration volumes during the first 19 days of the aeration stage. Values expressed as a function of pile base area.

Trial	Maximum aeration rate ($m^3/m^2/hour$)	Total aeration (m^3/m^2)
1	22	2010
2	6.1	1040
3	7.5*	1860*
6	-	-

* Underestimated due to insufficient aeration capacity
\- Not determined due to loss of control

4.1.3 Factors affecting aeration capacity

With on-off feedback control, the fan ideally should be on for more than 50% of the time during the most active stage of composting, to avoid sharp fluctuations in pile temperatures that can result from short and violent bursts of aeration. Therefore, if the fan capacity is too high, the fan discharge may have to be restricted. On the other hand, the discharge rate of the fan should be sufficient to satisfy aeration demand and therefore prevent continuous running of the fan and loss of temperature control (as occurred temporarily in Trial 3).

In the trials with successful aeration control (Trials 1 and 2), the peak aeration rate provides a basis on which to size aeration fans for full-scale composting of the same wastes. As short-circuiting of air was considered minimal in these trials, the aeration rates closely reflected the nature of the wastes and the composting activity. In a full-scale system, to allow for variations in the waste and short-circuiting, aeration systems capable of delivering up to twice the peak aeration rates measured in these trials may be required.

The size of the fan required also depends on the pressure drop across the air distribution system and through the pile during peak aeration demand. The pressure drop across the aeration system would depend on the design of the system, whereas the pressure drop across the compost pile can vary significantly with the porosity of the mixture being composted. Allowances for these factors must therefore be made when determining the capacity of an aeration system.

In Trial 1, during peak composting activity, when the fan discharge rate was 1.3 times greater than required to remove excess heat (76.5% fan on-time), the static pressure in the fan discharge duct and in the aeration base was 176 and 89 mm water gauge, respectively. The pressure drop across the aeration system was therefore a major component of the total pressure loss. When the discharge rate of the fan was reduced during the trials, to increase the fan on-time, the static pressure dropped accordingly (Fig. 10).

The pressure drop across the aeration base and compost pile was also determined by measuring the static pressure in the fan discharge duct before and after the pile was formed over the aeration base. For example, in Trial 6, these values were 100 and 148 mm water gauge, respectively.

Based on previous MIRINZ experience with composting various materials, the static pressure drop across a reasonably porous compost pile (same configuration as in these trials) is unlikely to exceed about 100 mm water gauge during maximum aeration demand.

The aeration base design used in the trials was chosen because it is easily constructed. In a full-scale composting system, a grid-covered plenum chamber (flush with ground level), and larger diameter pipework connecting the fan and aeration base, could be used. Such a system would have a lower pressure loss, and the flush aeration base would also make dismantling of the aerated pile easier.

4.1.4 Curing stage

Sufficient heating occurred during the curing stage to maintain high temperatures (Figs. 11 and 12; not determined in Trial 1). High temperatures during the curing stage are desirable as they facilitate the destruction of weed seeds and pathogenic microorganisms.

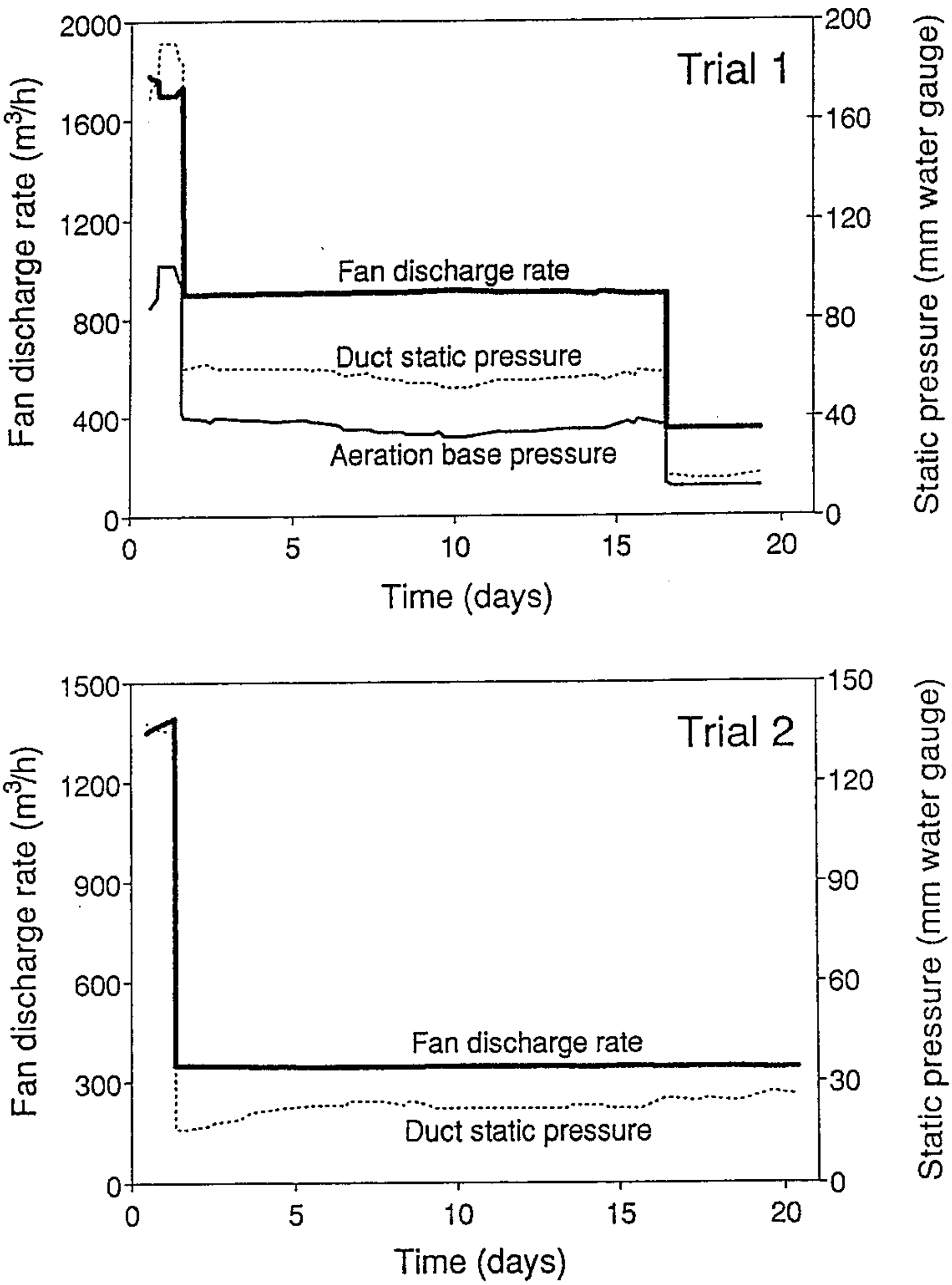


Figure 10. Fan discharge rates and static pressures in the aeration systems of Trials 1 and 2. Fan discharge rates were reduced by partially closing the fan discharge valves.

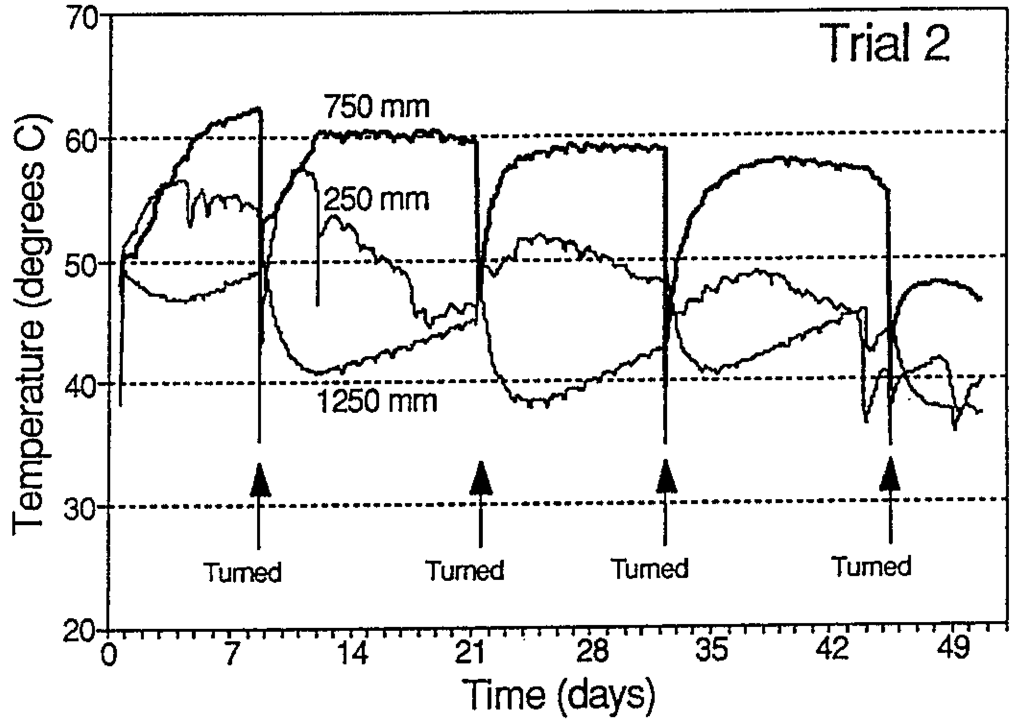
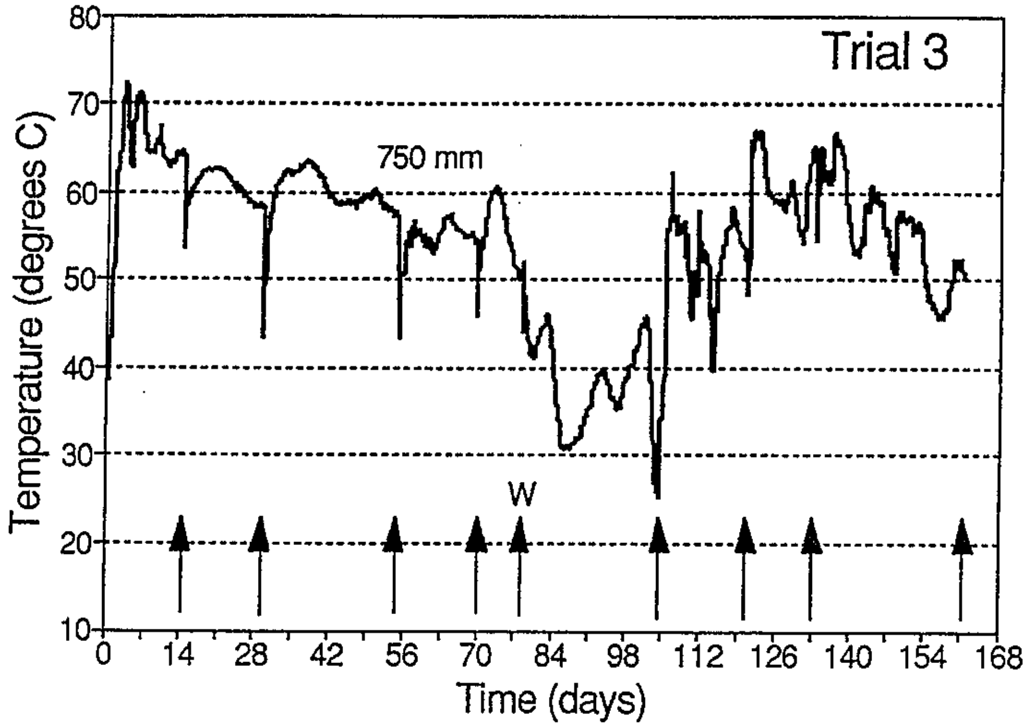


Figure 11. Temperatures recorded at depths of 250, 750 and 1250 mm into the curing pile of Trial 2 (paunch contents of grass-fed cattle). Turning times are indicated by arrows.

During curing, the compost characteristics improved: the colour became darker, the odour became more earthy, and the structure became finer. The improvement in structure resulted from the slow decomposition of the fibrous material. Also, the turning of the pile helped break up lumps of material.

The rate of compost improvement during curing differed markedly between trials. After 10 weeks of curing, the compost from Trial 1 was considered ready for use, based on its appearance. In contrast, the compost from Trial 2 required about 10 more weeks of curing to darken in colour and for its original grass-like structure to be broken down.

The compost in Trials 3 and 6 became very dry during the aeration stage (see Section 4.1.5), retarding the break-down of the fibrous material during the curing stage.



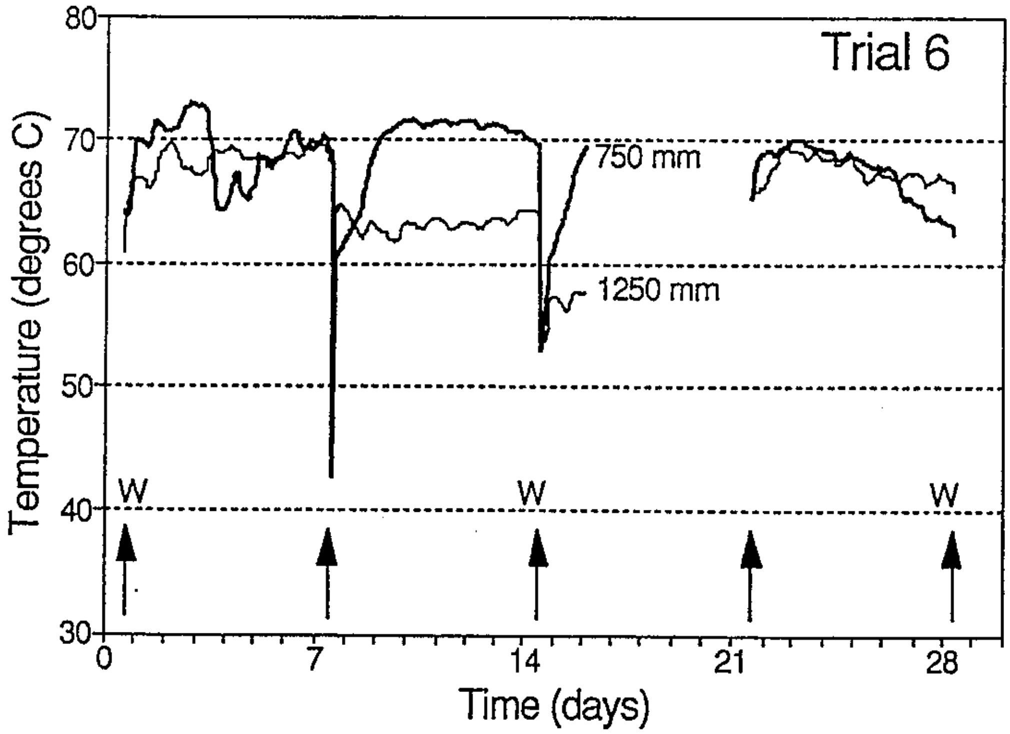


Figure 12. Temperatures recorded at indicated depths into the curing piles of Trials 3 and 6 (paunch contents of lot-fed cattle). Turning times are indicated by arrows. The addition of water is denoted by "W".

4.1.5 Waste and compost characteristics

The characteristics of the raw material and the compost at various stages of each trial are summarized in Table 3.

Visual characteristics and odour

The greatest source of odour during composting was the initial mixing process and pile formation. These odours were detected only within 50-100 m of the mixing operation. Once each pile was formed, the aeration maintained aerobic conditions and thus kept odours to a minimum. The odour during the aeration stage was predominantly a musty odour (like mouldy hay) and no putrid odours occurred.

Flies were not considered a nuisance in the trials. However if flies become a problem, MIRINZ has found in other trials that spreading a thin (25-50 mm) layer of bulking agent or mature compost over a pile prevents flies being attracted to it.

At the end of the aeration stage of each trial the compost was visibly drier than the raw material (except for a 200-500 mm layer of wet compost on the outside of the pile). No regions of "green" unstabilized material remained, indicating that air distribution was reasonably even.

In Trials 1 and 2 (paunch contents of grass-fed cattle) the compost at the end of the aeration stage had a mild, earthy odour, whereas in Trials 3 and 6 (paunch contents of lot-fed cattle) the compost had a slight sweet odour, which was probably due to the grain and molasses in the diet of the lot-fed cattle.

Slight anaerobic odours, detectable only when standing next to the pile, developed in the interior of the curing piles of Trials 1 and 2, suggesting that an extra week of aerated composting to promote further stabilization would have been beneficial. As curing progressed, and after the curing piles had been turned several times, this slightly sour odour disappeared. The sweet odour in the compost from Trials 3 and 6 also reduced slightly during curing.

After 10 weeks of curing in Trial 1 and 20 weeks in Trial 2, the composts had an excellent, dark, earthy appearance and retained little of their original structure. An independent plant growth trial using the compost from Trial 2 showed that the material produced better results than peat moss, as a base in a potting mix.

Table 3. Characteristics of raw materials and compost samples. Sampling dates are given. Trials 1 and 2, paunch contents of pasture-fed cattle; Trials 3 and 6, paunch contents of lot-fed cattle.

	Total Kjeldahl nitrogen (% d.w.)	Ammoniacal nitrogen (mg/kg d.w.)	Total oxidised nitrogen (mg/kg d.w.)	Moisture (% wet weight)	Volatile solids (% d.w.)	pH	Total fat (% d.w.)
Trial 1							
Raw material (17.01.90)							
Waste/bark mixture	2.4	9600	-	76.2	85.7	7.1	-
End aeration stage (05.02.90)							
250 mm above base	2.8	4000	420	64.2	75.3	7.8	-
750 mm above base	3.2	5400	180	53.2	81.6	7.9	-
1250 mm above base	3.0	5200	350	73.1	78.8	8.3	-
Curing stage							
05.04.90	3.2	3400	70	56.0	72.9	8.0	-
21.05.90	3.3	5200	680	64.8	69.5	6.9	-
Trial 2							
Raw material (20.03.90)							
Raw waste	1.6	670	-	72.2	88.1	6.3	-
Waste/bark mixture	1.3	740	-	71.5	88.1	5.6	-
End aerated stage (09.04.90)							
250 mm above base	-	-	-	51.8	-	6.0	-
750 mm above base	-	-	-	51.7	-	6.2	-
1250 mm above base	-	-	-	77.9	-	6.7	-
Curing stage							
19.06.90	1.3	412	-	73.7	72.8	6.4	-
10.10.90	1.4	68	-	64.8	69.8	4.6	-

Table 3 cont.

	Total Kjeldahl nitrogen (% d.w.)	Ammoniacal nitrogen (mg/kg d.w.)	Total oxidised nitrogen (mg/kg d.w.)	Moisture (% w.w.)	Volatile solids (% d.w.)	pH	Total fat (% d.w.)
Trial 3							
Raw waste (31.05.90)	2.00	333	-	62.5	96.0	4.4	34.7
End aeration stage (26.06.90)							
Dry centre zone	-	-	-	6.0	97.9	6.3	30.4
Moist outer zone	-	-	-	30.6	96.2	5.2	27.7
Curing stage							
26.07.90	-	-	-	24.9	-	5.8	30.2
20.08.90	2.53	3851	-	19.6	-	6.3	26.5
13.09.90	2.58	2360	-	13.9	95.0	5.7	17.9
20.11.90	-	2680	-	23.4	90.1	5.3	-
Trial 6							
Raw material (04.02.91)							
Waste/peanut shells mix	1.09	891	-	63.0	95.4	5.2	34.0
End aeration stage (27.02.91)							
250 mm above base	1.19	-	-	10.7	-	6.6	-
750 mm above base	1.11	1415	-	12.7	94.6	6.8	18.8
1250 mm above base	1.07	-	-	10.5	-	6.2	20.8
Curing stage							
06.03.91	1.37	1156	-	34.2	94.0	6.7	21.5
13.03.91	-	-	-	23.9	-	6.6	22.0
20.03.91	1.20	1292	-	20.4	92.3	6.3	18.3
27.03.91	-	-	-	27.9	-	6.4	-
10.04.91	1.50	1010	-	29.6	92.3	6.2	18.4
28.05.91	1.40	992	-	30.8	91.5	5.9	17.4

d.w. Dry weight; w.w. Wet weight; - Not determined.

The composts from paunch contents of lot-fed cattle retained much more of their structure. This is attributed to both insufficient moisture being present during composting, and the more refractory nature of the grain fibres. With more water added than was added in these trials, it is estimated that this material would be sufficiently decomposed after about 5 months of curing.

pH

Compost should have a pH within the range 5.0-8.0 to be compatible with plant growth (Zucconi and deBertoldi, 1989). A pH within the range 5.5-6.5 is desirable if the compost is to be used as the sole component in a general potting medium, because within this range nutrients are most readily available to plants. As well, a pH below 8.0 is desirable to prevent an ammonia odour from the compost.

The pH of the finished compost in each trial was in the range suitable for use as a plant growth medium.

In Trial 1 the pH at the end of the aeration stage and during the first two months of the curing stage was high (7.8-8.3), but then decreased to 6.9 after a further six weeks of curing, as the compost matured. This pattern occurred in Trial 2 and has been observed in other MIRINZ composting trials, suggested that pH change may be a good indicator of compost maturity. However, the pH change was much less pronounced in the other trials, suggesting that pH as a maturity indicator would need to be correlated for each specific waste type.

Nitrogen

Nitrogen is normally the most important nutrient required by microorganisms for the breakdown of carbonaceous substrates. Insufficient nitrogen impairs composting activity, whereas excess nitrogen results in loss of nitrogen to the atmosphere by volatilization of ammonia, which may cause odour problems. An "ideal" carbon:nitrogen ratio of 25-30:1 is often quoted. However, the nutrient status of a waste is determined by the availability (to microorganisms) of the nitrogen and carbon. Therefore, the ideal nitrogen content may be very different for different wastes.

Due to the presence of save-all bottom solids (containing meat scraps), the waste in Trial 1 had a higher total nitrogen content than the waste in the other trials. The concentration of ammoniacal nitrogen, which is a nitrogen form readily available to microorganisms, was also substantially higher in Trial 1. However, despite the relatively high concentration of nitrogen, ammonia odours were at low levels in Trial 1 and were discernible only when standing adjacent to the pile.

The slower breakdown of the plant fibres in the compost of Trial 2 was probably partly due to the lower nitrogen content of the waste in this trial. Therefore, if available, high-nitrogen wastes such as dissolved air flotation (DAF) top solids and save-all bottom solids should be included when composting paunch wastes.

Under aerobic conditions, ammonia may be converted to oxidized nitrogen forms (nitrate and nitrite) by nitrifying microorganisms. Oxidized nitrogen normally increases in concentration as a compost matures and is therefore sometimes used as a maturity indicator.

Moisture

Moisture removal is a good indicator of process activity because evaporative cooling is the major mechanism for the removal of excess heat generated during the aerated stage of the composting process. In addition, moisture removal is often a composting objective because many wastes contain excess moisture and a drier product is easier to handle and store.

At the end of the aerated stage each pile was dismantled in sections to visually assess the extent of drying and to obtain samples for analysis. In all trials the inside of the pile was dry to touch and light brown in colour, whereas a distinct layer of compost on the outside of the pile was significantly wetter and darker in colour due to rainfall and condensation of water vapour (Fig. 13). The depth of the wet layer was about 200-300 mm in Trials 1, 3 and 6 and 500 mm in Trial 2. The deeper wet layer in Trial 2 reflects the high rainfall during the aeration stage of this trial (246 mm; c.f. 17 mm Trial 1, 23 mm Trial 3, 120 mm Trial 6).

High rates of moisture removal were observed in all trials (Table 4). By far the highest rates were observed in Trials 3 and 6 and reflect the high content of readily biodegradable fat in the raw material used in these trials (i.e. high rate of heat generation). In fact, the moisture content of the composting material was reduced to such low levels in Trials 3 and 6 (6 and 10.5%) that low moisture was probably limiting biological activity. Water was added to the curing piles of these two trials (Fig. 12), but in insufficient quantities to thoroughly moisten the compost throughout.

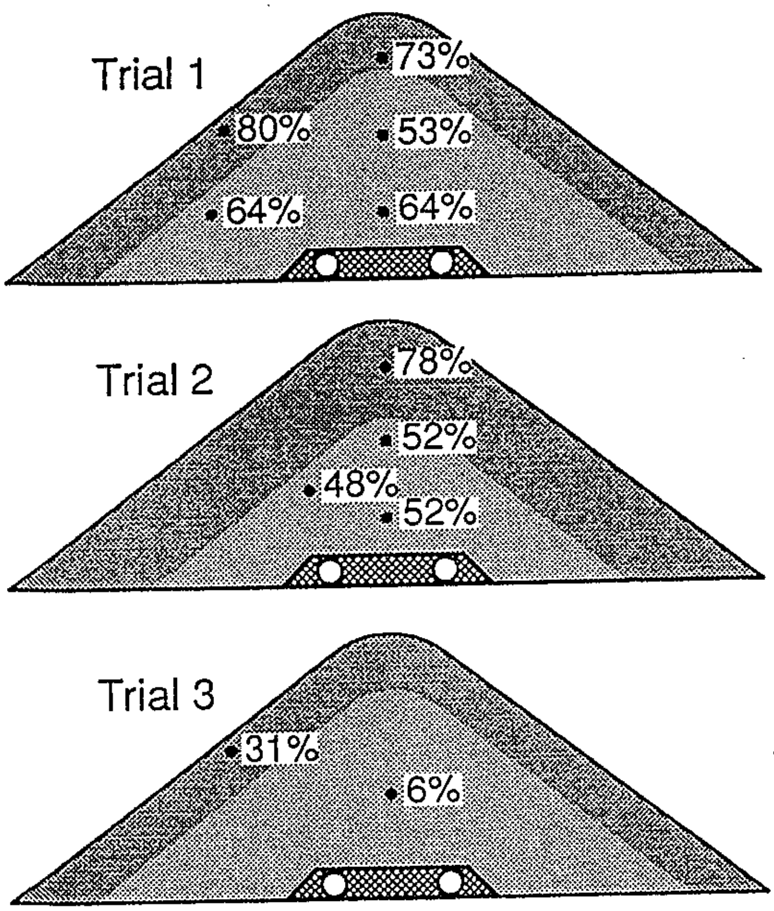


Figure 13. Cross-sections through the centre of the piles at the end of the aerated stage showing the approximate location of the wet outer layer of compost (most densely shaded region) and moisture contents at specific locations (% wet weight). The three vertically spaced moisture values in Trials 1 and 2 correspond to the sites for which temperatures were monitored.

Table 4. Maximum moisture removal during the aeration stage (assumed 20% total solids decomposition).

Trial	Initial moisture content (% wet weight)	Lowest final moisture content (% wet weight)	Moisture reduction (%)
1	76.2	53.2	71.6
2	71.5	47.8	70.8
3	62.5	6.0	96.9
6	63.0	10.5	94.5

Due to its high organic content and its fibrous structure, a compost made from paunch contents is manageable at a relatively high moisture content. The desirable moisture range is between 50 and 65%. Below about 50% moisture, the compost becomes too light and dusty, and above about 65% excess free moisture is present, which makes the compost unsuitable for bagging or use as a potting medium. However, even at 70% moisture the compost is still friable enough to be easily used as a soil conditioner.

Heavy rainfall (290 mm) during the first 10 weeks of curing in Trial 2 saturated the compost (73.7% moisture). In contrast, despite 364 mm of rainfall during the 14 weeks of curing in Trial 1, the finished compost in this trial had a lower moisture content (64.8%) because the compost at the end of the aerated stage was drier on average.

A compost containing excess moisture can be left in curing piles until dry weather reduces its moisture content to a suitable level. (In fact, additional curing would generally improve the appearance of the compost.) Smaller piles or windrows may be required to promote drying, and once dry enough, the compost could be stored under cover (a roofed structure with no walls, to allow air circulation) until required.

No leachate visibly drained from the compost piles, as excess liquid had drained from the raw materials before the piles were formed. Also, the piles has a high capacity to absorb rainfall. To secure against potential groundwater or runoff contamination during heavy rainfall, however, composting should be undertaken on a water-impermeable base, which is sloped and drained to allow runoff collection for subsequent treatment (e.g. in a pond) or storage before recycling onto the compost piles in drier weather. Likewise, the raw materials should be stockpiled on a drainage pad prior to composting.

Fat

The raw material in Trials 3 and 6 contained high concentrations of fat (about 34% d.w.). The fat came from both the feedlot ration and the gut cutting operation. (After changes to the gut cutting operation, the total fat content of the paunch waste was only about 3.7-5.6% d.w.)

Composting reduced the fat concentration by about 50%. The aerobic decomposition of fat during composting generates more heat than decomposition of other organic substrates such as carbohydrates and proteins. The high fat content in Trials 3 and 6 was therefore largely responsible for the high degree of drying during the aeration stage of these trials. In fact, moisture probably became limiting before much of the fat had decomposed; hence the addition of water during curing to promote further fat decomposition and stabilization. Insufficient water was added and much fat still remained after many weeks of curing.

When there are high concentrations of fat in a waste, a high initial moisture content facilitates fat breakdown during the aeration stage of composting. Therefore, for this type of waste the initial moisture content should be maximized without compromising process aeration. Furthermore, facilities to apply large volumes of water during the curing stage may be required.

Volatile solids

The volatile solids (weight loss on ignition at 550°C) content of a compost is a reasonable estimate of its organic content. The change in volatile solids content of organic material during composting may therefore be used to measure the extent of waste decomposition, but should be used with caution as it is sensitive to errors. For example, a change in volatile solids concentration from 99 to 98% (a doubling of fixed solids from 1 to 2%) represents a 50.5% loss of volatile solids. The method is more precise at lower volatile solids concentrations. For example, a change in volatile solids content from 49 to 48% represents a 3.9% loss of volatile solids.

In all trials, the volatile solids content of the compost decreased significantly during composting, reflecting the loss of organic matter and a corresponding increase in the concentration of conserved minerals and nutrients.

4.2 Feedlot Manure

4.2.1 Windrow composting trial

In Trial 4 high temperatures persisted in the non-aerated pile of screened, aged feedlot manure (Fig. 14), indicating that significant aerobic biological activity occurred.

The most noticeable transformation in the compost was the reduction in odour. Initially the manure had a putrid odour from being stored anaerobically for some years, but this rapidly disappeared and was absent after about two months of turned windrow composting.

The raw material had a very high ammonia concentration. After two months of composting, the ammonium concentration was much reduced (Table 5). Because total Kjeldahl nitrogen concentrations increased, the ammonia was largely conserved rather than volatilized. Volatile solids decreased showing that significant biological decomposition of organic material had occurred.

The composted manure had a high pH. Therefore it would have to be mixed with soil or other media to reduce the pH to levels more suitable for plant growth.

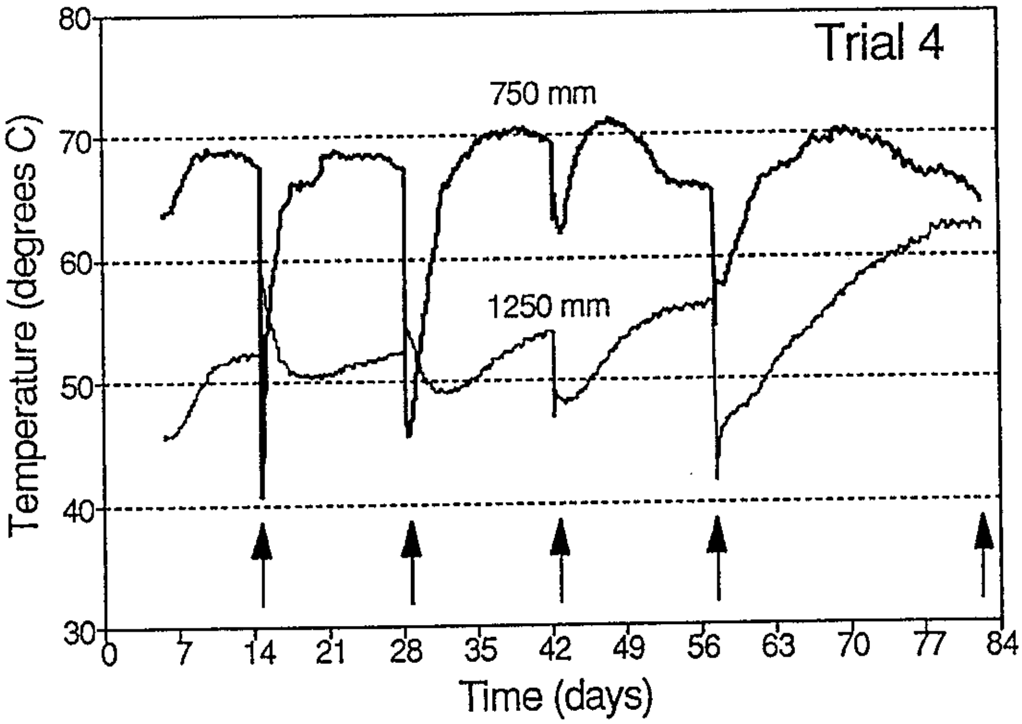


Figure 14. Temperatures at indicated depths in the windrow of aged, screened manure of Trial 4. Arrows indicate times when the windrow was turned.

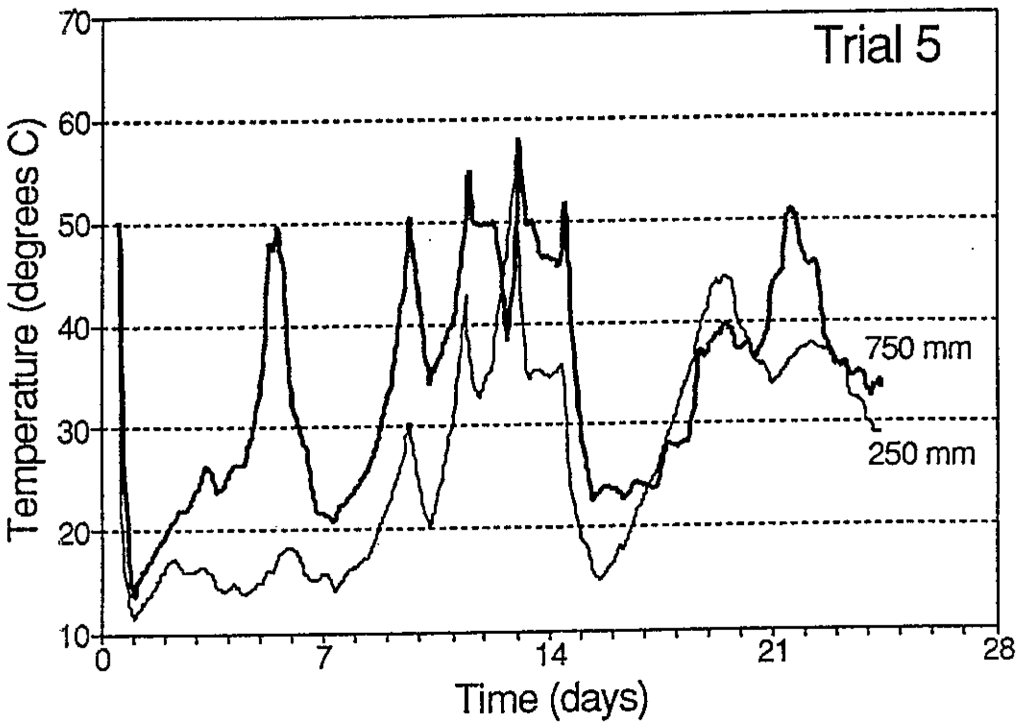
4.2.2 Forced aèration trial

Forced aeration composting of the freshly scraped feedlot manure in Trial 5 proved unsuccessful. The manure had a low moisture content (Table 5) and contained large lumps of compacted material (Plate A4, Appendix 5). The coarse manure structure resulted in a small pressure drop across the pile.

Table 5. Characteristics of raw feedlot manure and compost. Results are expressed on a dry weight (d.w.) or wet weight (w.w) basis.

	Total Kjeldahl nitrogen (% d.w.)	Ammoniacal nitrogen (mg/kg d.w.)	Moisture (% w.w.)	Volatile solids (% d.w.)	pH
Trial 4 (windrow)					
Raw material (31.05.90)	2.37	13700	33.4	62.4	7.5
27.06.90	-	-	27.3	-	7.4
11.07.90	-	-	24.1	-	8.1
26.07.90	-	-	23.7	-	7.7
20.08.90	2.83	5250	20.0	57.8	8.2
04.09.90	-	-	24.7	-	8.4
13.09.90	2.93	4350	21.7	56.8	8.4
09.10.90	2.8	4380	20.8	55.2	8.4
28.10.90	-	4570	18.6	55.2	8.0
Trial 5 (forced aeration)					
Raw material (20.08.90)	3.13	5466	36.9	83.9	8.1
End aeration stage (13.09.90)					
250 mm above base	2.78	2970	21.7	66.8	8.5
750 mm above base	3.16	3370	19.2	66.8	8.5
Curing stage					
09.10.90	2.99	-	22.4	-	8.3
07.11.90	-	3445	23.2	68.5	8.2
20.11.90	-	2823	18.5	-	8.1
05.12.90	-	2933	15.5	64.4	7.9

d.w. Dry weight; w.w. Wet weight; - Not determined.



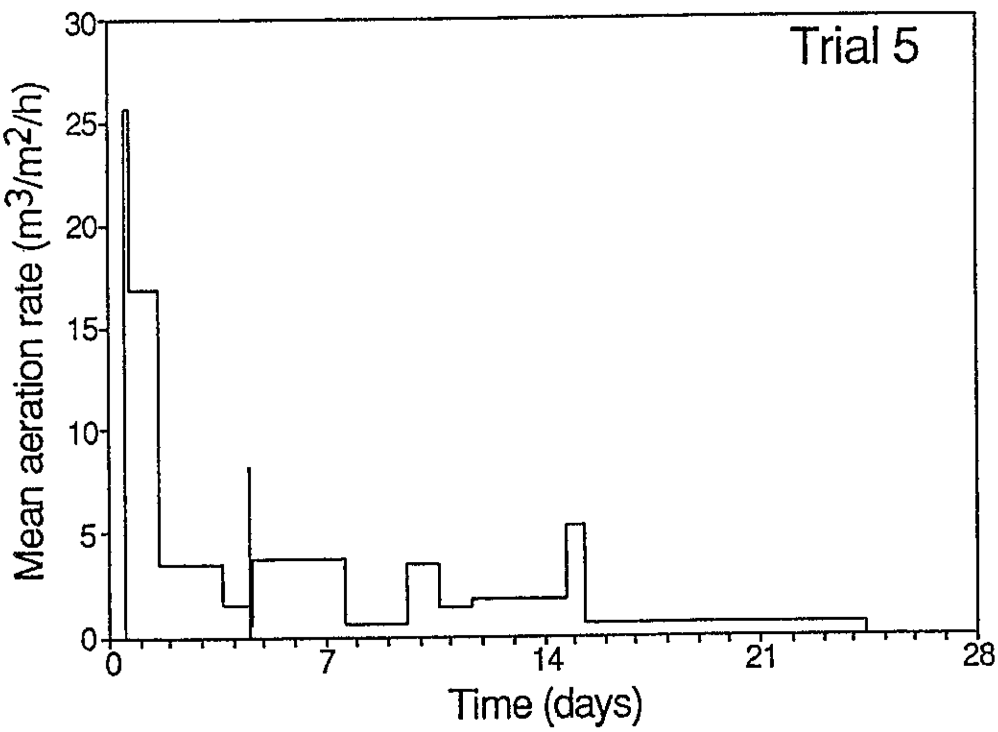


Figure 15. Temperatures and aeration rate during the aeration stage of Trial 5.

In fact, the discharge static pressure with the discharge value fully open (138 mm water gauge) was the same before and after the pile was formed over the aeration base. (In previous trials an increase in pressure drop of at least 40 mm water gauge was normally observed.) Clearly, the air mainly passed between the lumps of compost without penetrating to the bulk of the material in the pile, where it was most needed.

Temperature and aeration control

Although significant heating occurred during the aeration stage, the heat generation and composting activity could not be quantified (by aeration demand), as the controller used in this trial malfunctioned (Fig. 15). However, significant aeration did occur (albeit erratically), and the resultant aerobic activity rapidly removed the offensive odour of the fresh manure. Significant moisture removal also occurred (Table 5).

Curing

During the curing stage elevated temperatures persisted, with transient increases in temperature immediately after turning of the compost (Fig. 16). These increases suggest that oxygen deficiencies occurred within the curing pile.

Turning of the compost improved the structure of the compost only to a small degree. The abrasion of turning was insufficient to break up the highly compacted lumps of manure.

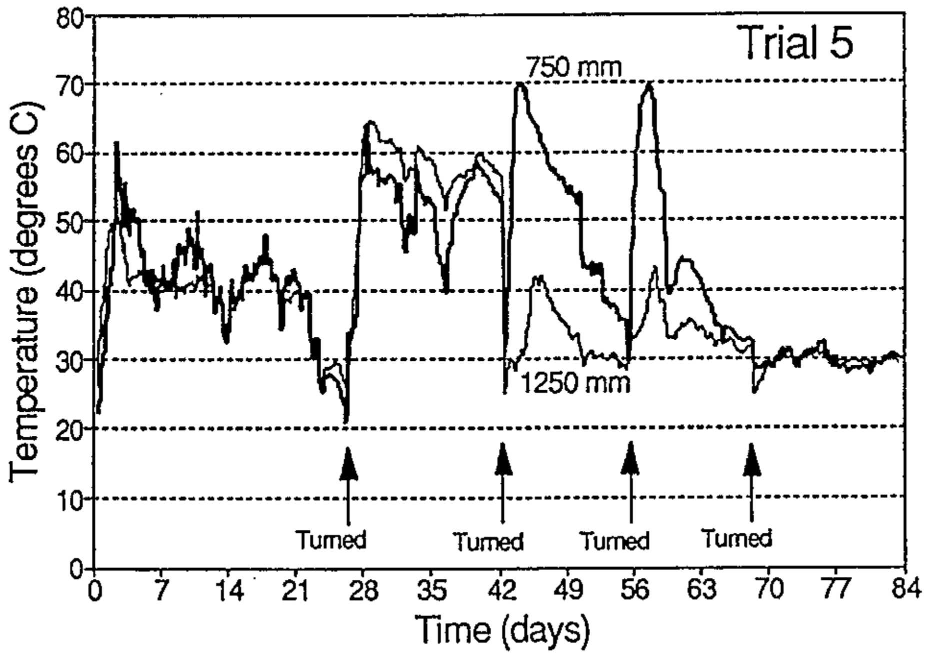


Figure 16. Temperatures during the curing stage of Trial 5 (fresh feedlot manure).

4.2.3 Suitability of forced aeration for feedlot manure

For forced aeration composting to be successful, the waste must meet the following criteria:

- The structure must be open to facilitate aeration and to minimize air pressure drop.
- The structure must be even and free of lumps so that oxygen can diffuse into all or most of the waste particles.
- The waste must have a high content of readily biodegradable organic matter to justify a high level of process control.
- The moisture content must be sufficient to sustain a high rate of biological activity. (The moisture content of the waste material must be about 60% or more, so that the compost does not dry out before it is biologically stable - unless dryness rather than biological stability is the major objective.)

Feedlot manure does not satisfy the criteria listed above, and therefore forced aeration composting for this material is not justified. The reasons for this are as follows:

- Feedlot manure is normally removed from the pens at a moisture content below 45%, which is too low to promote sustained biological activity under forced aeration composting. If the manure is removed from the pens at a higher moisture content, or wetted once removed, the porosity of the manure would then be too low to apply forced aeration without adding a bulking agent. Adding a bulking agent would not be practical as it would increase processing costs, reduce the nutrient quality (by dilution), increase product volume, and exacerbate the problem of product disposal.

- The manure often contains large consolidated lumps, which cannot be composted without first being broken apart.

- The manure is partially stabilized in the pens and does not necessarily require a high level of oxygen and temperature control to prevent odour problems during its subsequent composting. The extent of manure stabilization in the pens will depend on the pen cleaning frequency, the manure moisture content as determined by weather conditions, and the degree of compaction.

4.2.4 Suggested windrow composting process for feedlot manure

Windrow composting is commonly used in the United States for stabilizing and conditioning feedlot manure, and a facility using this technique is described in detail in Appendix 6. With windrow composting, the manure is placed in windrows, typically 1.5 m high and 4 m wide. The windrows are regularly turned using front-end loaders or windrow composting machines designed specifically for this purpose. These composting machines are much more efficient than front-end loaders. Turning re-oxygenates and cools the compost, loosens its structure to facilitate passive aeration and drying, and breaks up lumps of manure.

The information that follows is largely based on observations and discussions during a study tour of composting facilities in the United States, by the principal investigator.

<u>Windrow composting machines</u>

Windrow composting machines typically have a horizontal drum (with a series of tines or flails attached) that rotates as it moves through the compost, turning, mixing, aerating and re-forming the windrow as the machine moves along. There are about eight manufacturers of windrow turning machines in the United States. The cost of self-contained units ranges from US$100,000 to US$220,000. PTO-powered (tractor powered) systems for smaller operations range from US$50,000 to US$70,000 (Glenn, 1990).

<u>Advantages and limitations</u>

Windrow composting using composting machines is ideally suited to stabilizing and conditioning feedlot manure, for the following reasons:

- Consolidated lumps of manure are broken up, producing a fine-structured compost that looks like a screened topsoil.
- Little or no site preparation is required. An open field with an even, dry surface (preferably with a gentle slope) is all that may be needed. Control of runoff is recommended.
- Wet manure can be composted without the addition of a bulking agent.
- A composting machine and front-end loader are the only machines required.
- The composting machine can be readily transported, so one machine can be used to compost the manure from several feedlots (or wastes from different sources).

A limitation of composting machines is that the flails wear rapidly if the manure has a high sand and stone content. The flails typically may need to be replaced every 40-100 hours of operating time. The machines are inappropriate if the manure contains many large rocks.

Processing

The mixing action of the windrow machine results in a fine-textured product and promotes aeration and drying. The degree of product stability achieved depends primarily on the moisture content of the material during composting. A high initial moisture content (about 50%), or addition of water to the windrows will be required to produce a stable compost. (Feedlot manure has a wet consistency at a 50% moisture content).

If the main objective is to produce a compost for spreading thinly over cropland, then low moisture content and fine structure (to minimize transport costs and allow easy spreading) may be much more important product characteristics than biological stability. In this situation a high moisture content during processing may not be necessary.

If, however, the compost is to be marketed in bags or bulk for home or nursery use, then it would be necessary to produce a more moist and biologically stable product by controlling the process moisture levels.

The frequency of turning the compost, and the duration of the composting process will depend on the moisture content of the manure, weather conditions, and the degree of stabilization required. Very few passes of the windrow machine would be required if the manure is quite dry and if only a small degree of stabilization is required. If a high degree of biological stability is required, the composting process may take up to 12 weeks and require between 10 and 20 passes of the composter. Turning should be most frequent during the early stages of process. Addition of water may also be necessary.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Meat Processing Wastes

- Temperature-controlled aerated pile composting effectively stabilized the meat processing solid wastes used in the trials and improved their appearance and structure. This was achieved without creating nuisance odours.

- Trials composting the paunch contents of grass-fed cattle produced a more stable, darker and finer-structured product than the trials composting paunch material from lot-fed cattle. The lower-quality product in the latter trials was due to the high fat content (34%) in the raw material (which generated a high aeration demand, excessively drying the compost), and the more refractory nature of the grain fibres in this material.

- Wastes containing high concentrations of fat can be composted successfully if the initial moisture content of the raw material is high (about 70% so long as porosity remains suitable for aeration purposes), and if large volumes of water are added during the curing stage.

- Highly biodegradable save-all bottom solids added to the paunch grass in Trial 1 increased the aeration demand and moisture removal and improved the nutrient content, structure and appearance of the compost. Paunch contents should therefore be composted with highly biodegradable wastes such as dissolved air floatation top solids and save-all bottom solids, where these are available. Fat concentrations in excess of about 30% d.w. should be avoided in the initial composting mixture.

- The maximum aeration demand during the aeration stage of the trials ranged between 6 and 22 m^3/hour per m^2 of pile base area. To account for variations in air short-circuiting and in the nature of the waste, full-scale composting of the same wastes may require aeration systems capable of delivering up to twice these maximum aeration demands. The aeration system should be designed for a maximum pressure drop across the compost pile of 100 mm water gauge (excludes pressure drop through aeration pipes).

- The three-week aeration stage used in Trials 1 and 2 should have been extended to four weeks to promote further stabilization prior to curing.

5.2 Feedlot Manure

- Forced aeration composting was found to be inappropriate for composting feedlot manure, due to its lumpy structure, low moisture content when removed from pens, and requirement for bulking agent when sufficiently high in moisture.

- Windrow composting using a compost turning machine is the best available technology for this material. In addition to supplying the aeration required for stabilization, these machines break up the lumps of manure. Windrow machines cannot be used if the manure contains many large stones and rocks.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

APHA (1989) Standard methods for the examination of water and wastewater, 17th edition, American Public Health Association, Washington, D.C.

Finstein, M.S., Cirello, J., MacGregor, S.T., Miller, F.C. & Pasarianos, K.M. (1980) Sludge composting and utilization: rational approach to process control. Final report to USEPA, NJDEP, CCMUA. Rutgers University, New Brunswick, N.J. (USEPA Report No. C-340-678-01-1).

Finstein, M.S., Miller, F.C., Strom, P.E., MacGregor, S.T. & Psarianos, K.M. (1983) Composting ecosystem management for waste treatment. *Bio/Technology* **1**(4), 347-353.

Glenn, J. (1990) Yard waste collection and composting equipment. *Biocycle* **31**(9), 70-72.

Keeney, D.R. & Nelson, D.W. (1982) Nitrogen-organic forms. In: A.L. Page; R.H. Miller, & D.R. Keeney, (eds). Methods of soil analysis part 2 (2nd Edition). American Society of Agronomy Inc., Madison, Wisconsin.

McPhail, N.G. & van Oostrom, A.J. (1990) Use of a composting technique for stabilizing meat processing waste solids and feedlot manure. Meat. Ind. Res. Inst. N.Z. Publ. No. CR 259.

Miller, F.C., MacGregor, S.T., Psarianos, K.M., Cirello, J. & Finstein, M.S. (1982) Direction of ventilation in composting wastewater sludge. *J. Wat. Pollut. Control Fed.* **54**(2), 111-113.

van Oostrom, A.J. (1990) Options for composting feedlot manure. Meat Ind. Res. Inst. N.Z. Publ. No. CR 263.

van Oostrom, A.J., Cooper, R.N. & Adamson, D. (1989) The stabilization of primary sewage sludge by temperature controlled, aerated static-pile composting: a pilot-scale study. Proceedings Waste Management Institute New Zealand Inc., 1st Annual Conference, Wellington.

van Oostrom, A.J., Cooper, R.N. & van Rossem, J.E. (1988) Temperature-controlled, aerated static-pile composting of slaughterhouse waste solids. In: R. Bhamidimarri (ed.), Alternative waste treatment systems. Elsevier Applied Science Publishers, London.

van Oostrom, A.J. & McPhail, N.G. (1990) Demonstration of a composting technique for stabilizing meat processing waste solids. Meat Ind. Res. Inst. N.Z. Publ. No. CR 247.

Willson, G.B., Parr, J.F., Epstein, E., Marsh, P.B., Chaney, R.L., Colacicco, D., Burge, W.D., Sikora, L.J., Tester, C.F. & Hornick, S. (1980) Manual for composting sewage sludge by the Beltsville aerated-pile method. USDA and EPA Report, EPA-600/8-80-022.

Zucconi, F. & deBertoldi, M. (1989) Specifications for solid waste compost. In: The biocycle guide to composting municipal wastes. J.G. Press Inc., Emmaus, Pennsylvania.

APPENDIX 1. CALIBRATION OF FAN DISCHARGE RATE

Prior to the trials, the discharge rate of each fan used was calibrated against various positions of the discharge valve (a sliding plate) and against a range of aeration pressure heads at each position of the valve. The resulting calibration curves are shown in Figures A1 and A2.

The fan discharge rate was measured in a smooth-walled pipe attached to the outlet of the fan, using a rotating-vane or hot-wire anemometer. The static pressure head was measured using a water-filled U-tube manometer connected to the discharge pipe, 1.2 m from the fan outlet.

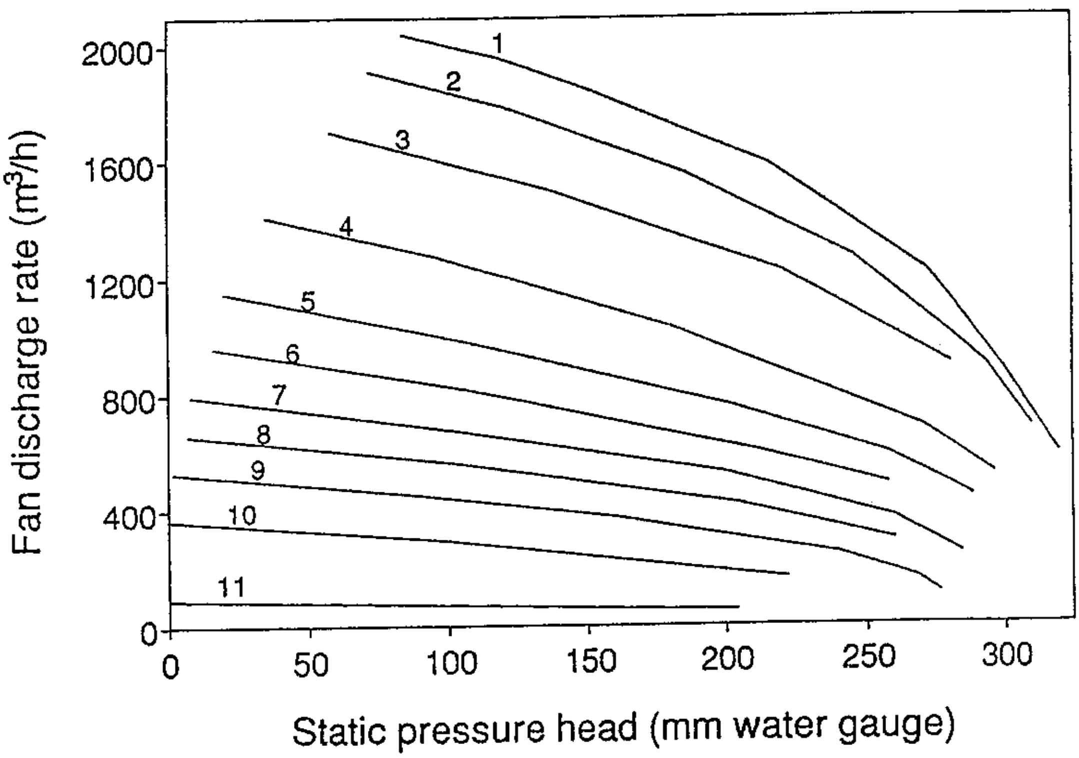

Figure A1. Fan discharge characteristics for various positions of the discharge valve (1-11; position 1 fully open) and for a range of aeration pressure heads. Fan used in Trial 1.

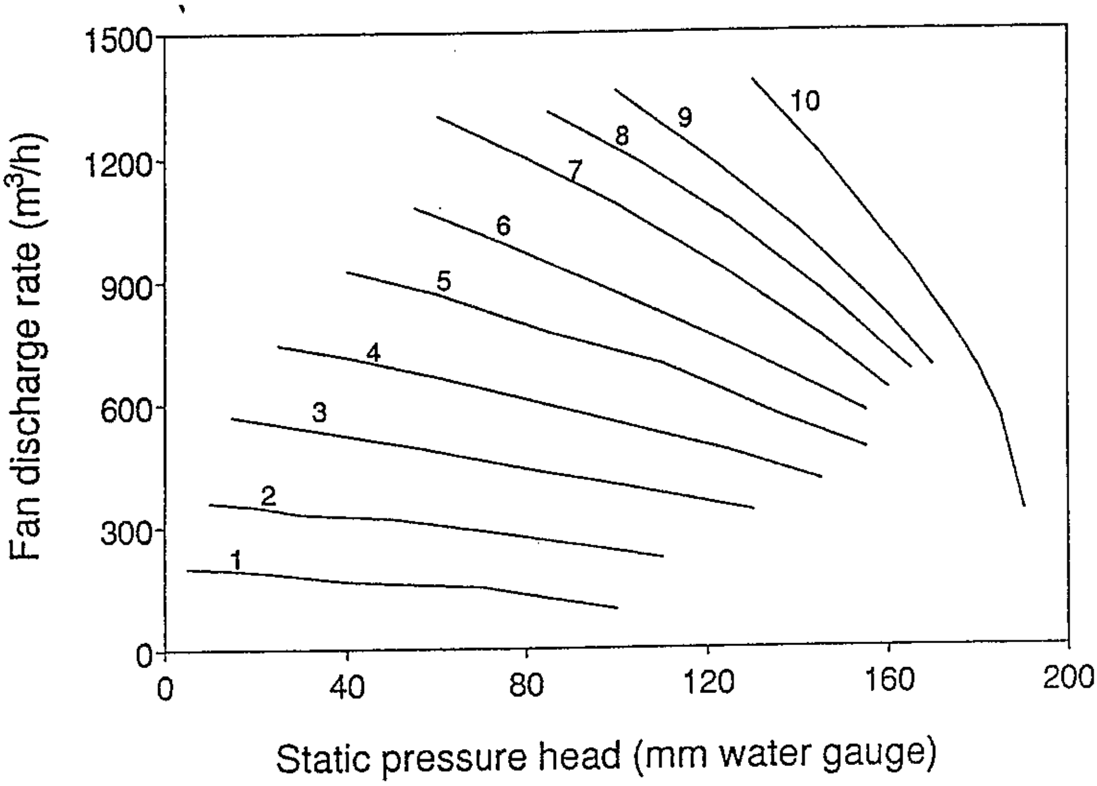

Figure A2. Fan discharge characteristics for various positions of the discharge valve (1-10; position 10 fully open) and for a range of aeration pressure heads. Fan used in Trials 2, 3, 5 and 6.

APPENDIX 2. PROCESS CONTROL LOGIC

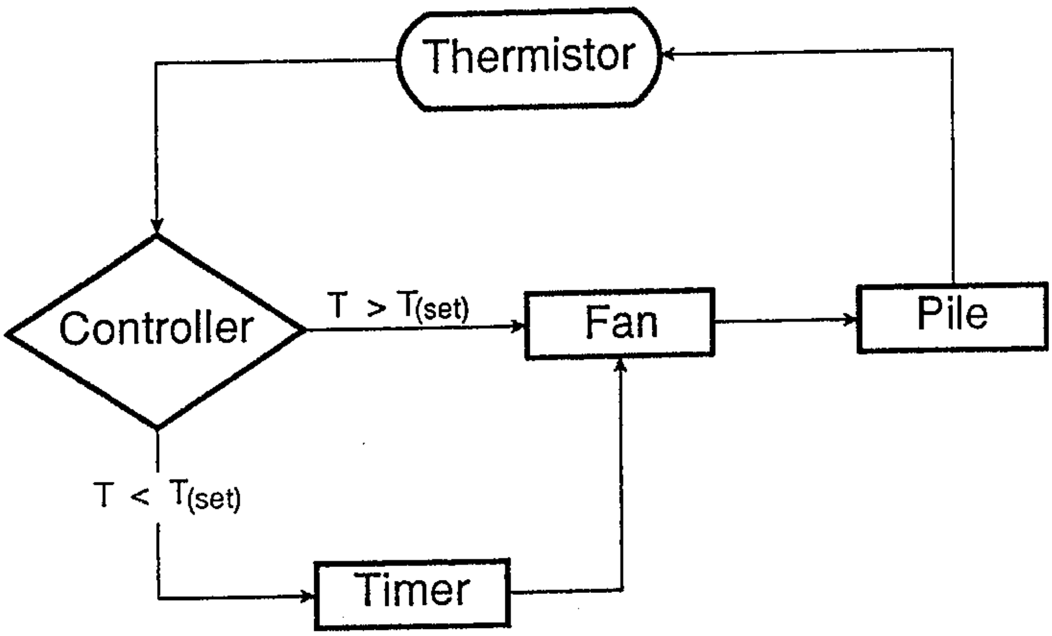

Figure A3. The process control logic used in the trials, where T is the temperature at the site of the control sensor in the compost pile, and T(set) is the set-point temperature.

APPENDIX 3. MONITORING PROGRAMME

Aeration Stage

The following data were recorded during the aeration stage:

- Hourly
  - temperatures at 9-15 positions a in pile (logged automatically)

- Once daily
  - rainfall

- Once to three times daily
  - time
  - fan hour-meter reading
  - control thermistor temperature
  - fan-start counter reading
  - static pressure head in aeration system when fan is running
  - fan discharge rate (determined from calibration curve of static pressure vs position of discharge valve)
  - static pressure head in aeration base (Trial 1 only)

- At the beginning of the trial and when adjusted
  - timer setting
  - temperature set-point
  - fan discharge valve position

Curing Stage

The following data were recorded during the curing stage:

- Rainfall
- Temperatures at three positions in pile (logged hourly)
- Dates pile was turned
- Dates water was added

APPENDIX 4. ANALYTICAL METHODS

The methods used for analysing composts and solids in this study were based on established methods for examining wastewaters and solids. References for each method, and special considerations are given below.

1. **Moisture and volatile solids**

   Method 2540 G, APHA, 1989.

   Percent moisture was determined as 100-% total solids.

2. **pH**

   Procedure

   Calibrate a pH meter according to manufacturer's instructions.

   Weigh 10 g of a thoroughly mixed portion of sample into a 100 ml beaker and add 50 ml of distilled water. Mix thoroughly and allow to stand for 30 minutes. (Longer standing times, as often used in soil pH determination, are not recommended for composts and organic solids as biological activity can significantly alter the pH.)

   Immerse the pH electrode into the slurry and, without stirring, record the pH. Report the result to one decimal place.

3. **Ammoniacal nitrogen**

   Exchangeable ammonium was extracted using a method based on Keeney and Nelson (1982). A 25 g sample (wet weight) was shaken with 250 ml of 2M KCl solution for one hour. The solution was then filtered.

   The ammonium in the filtrate was determined titrimetrically after distillation (APHA, 1989), but using an automated Tecator Kjeltec apparatus.

4. **Total oxidized nitrogen**

   Total oxidized nitrogen was determined on the same extraction solution as that on which ammonium was determined.

   Two methods for determining oxidized nitrogen were used:

   (i) An automated cadmium reduction method using a Tecator Aquatec 5200 Analyzer, according to the manufacturer's instruction.

   (ii) MgO-Devarda Alloy method according to Keeney and Nelson (1982).

5. **Total Kjeldahl nitrogen** (ammonical + organic nitrogen)
Digestion procedure: A 0.1 g dried, ground sample was digested with 10 ml H_2O_2 and 10 ml concentrated suphuric acid at 365 to 380°C for 1.5 to 2 hours. The digested solution was cooled and then diluted with 50 ml distilled water and made alkaline with 10 ml of 50% NaOH.

The solution ammoniacal nitrogen concentration was then determined titrimetrically after distillation, as in method for ammonium nitrogen.

APPENDIX 5. PHOTOGRAPHIC REVIEW OF TRIALS

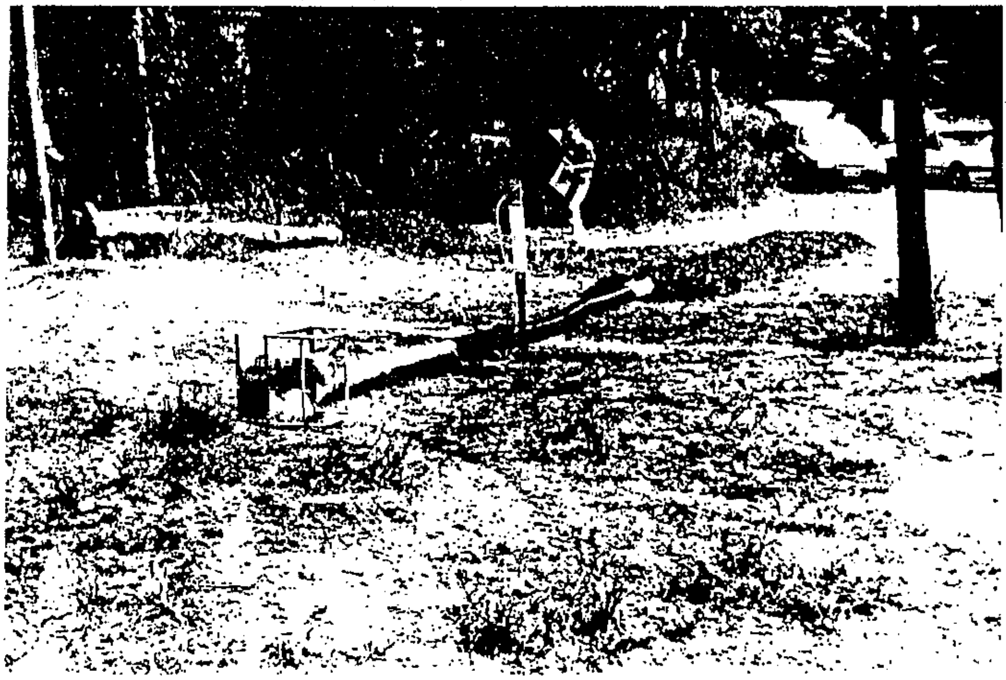

Plate A1. The fan and aeration base, Trial 2.

Plate A2. Newly formed pile, Trial 2.

Plate A3. Finished compost made from paunch contents of lot-fed cattle (Trial 3).

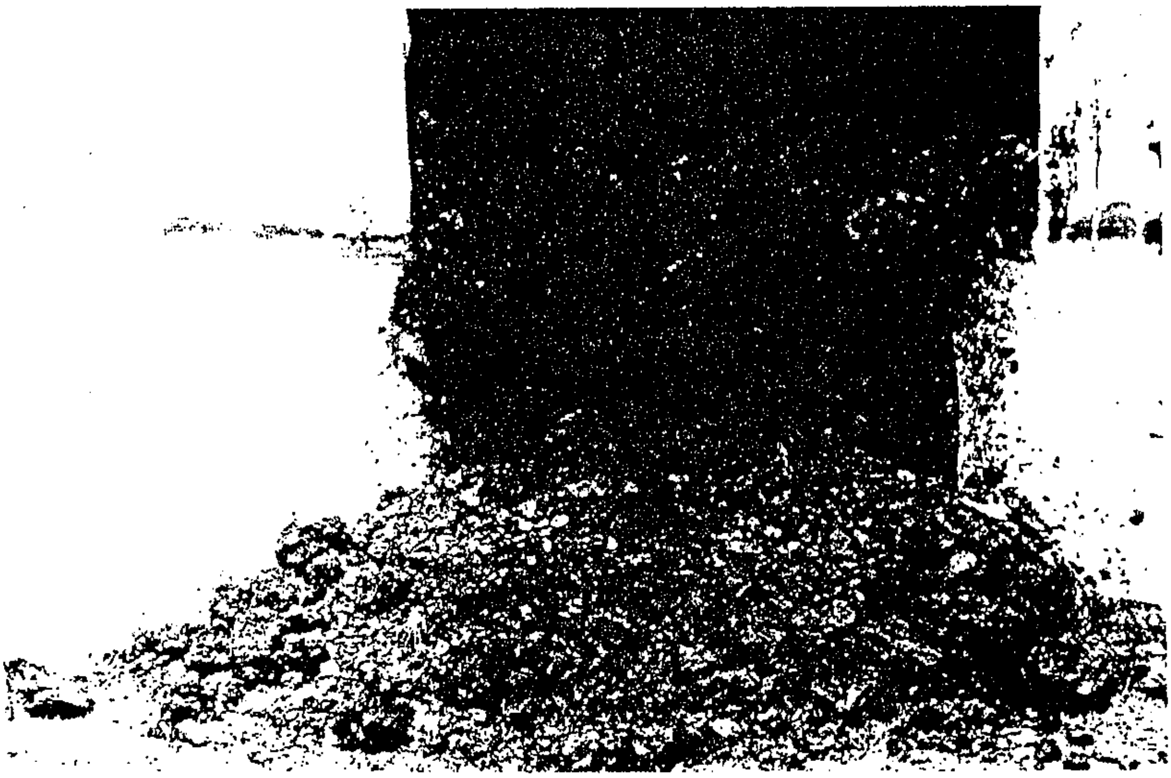

Plate A4. The lumpy feedlot manure used in Trial 5.

APPENDIX 6. WINDROW COMPOSTING OF FEEDLOT MANURE IN NEBRASKA, U.S.A.

Introduction

This Appendix describes a manure composting operation at a feedlot in Nebraska, U.S.A., and is based on information obtained during a visit to the feedlot by the principal investigator, Mr Albert van Oostrom (MIRINZ), in October 1990. The visit was part of a two-week study tour of composting facilities in the United States.

The feedlot and adjacent composting operation are part of a 2000 acre farm located at Glenvil, Nebraska (about 200 km south-west of Omaha), and owned by the Kissinger family (R Lazy K, Inc.).

The feedlot raises about 25,000 cattle each year. Corn grown on the farm supplies some of the feed, and an additional 3-4 million bushels of corn is bought each year from other suppliers.

Each year 14,000-20,000 tons of manure compost is produced and spread over most of the 2000 acre farm (10-12 tons/acre). This practice has been going on for 15 years. Supplementary nitrogen is the only artificial fertilizer used on the farm and crop yields are claimed to be as good as or better than the average for the district. The Kissingers estimate that the compost saves them at least US$30,000 p.a. in chemical fertilizers.

Cleaning of Pens

Most of the manure is deposited on concrete feeding aprons that run alongside the feeding trough fenceline of each cattle pen. These feeding strips are 4.6 m wide and serve as a base for the area where the cattle spend most of their time. The rest of each pen does not have a concrete base. Instead, the base consists of a layer of compacted manure over the indigenous soil.

Only the manure deposited on the concrete aprons is removed from the pens. It is scraped up when wet (after rainfall during the spring rainy season) using front-end loaders, and then trucked to the composting site. By early summer the pens have been cleaned out.

When dry, the surface layer of manure in the rest of each pen is occasionally scraped up and mounded in the centre of the pen. The mound becomes compacted by the cattle, and serves to reduce the pooling of water in rainy weather.

Composting Site

The composting occurs on a gently sloping site adjacent to the feedlot. No special site preparation was required.

Composting Method

The wet manure is formed into parallel windrows, each 4 m wide x 1.5 m high x more than 50 m long. They are positioned parallel to the slope on the site, to allow rainfall runoff between the windrows. Composting of the manure is facilitated using a Resource Recovery System of Nebraska Inc., KW 614 windrow turning machine. This machine passes over each windrow, turning, aerating, and "chopping" the manure, and re-forming the windrow as it moves along. The composting process takes about 8 weeks. During this period the manure is turned at least 10 times, depending on rainfall and the moisture content of the compost. If wet, the compost is turned more frequently. The process is judged to be complete when the material has the structure and appearance of a dry, light-brown, finely structured topsoil. The compost is dried out as much as possible to minimize weight and transport costs. The compost is turned only during dry weather, as the machine requires a dry surface for adequate traction.

Machine Maintenance

The main maintenance on the windrow machine is replacement of the flails. These need to be replaced every 40-100 hours, depending on the abrasiveness of the manure. Wet manure generally requires more frequent flail replacement. Manure containing many stones cannot be composted using a windrow machine.

Although the machine occasionally encounters large rocks or lumps of concrete in the manure, this rarely causes significant damage as long as the driver stops the machine right away.

Operating and maintenance costs for the machine are estimated by the manufacturer to be about US$30/hour, excluding the driver's wages. The machine is rated to turn 2,000 tons/hour.

Compost Application

The composted manure is spread on the land in autumn, as this time of year has the lowest rainfall. Two 10-ton trailers (bulk lime spreaders) are used to transport and apply the compost. Spreading the compost using both trailers takes about one month each year.