COMPOST CONVECTIVE AIRFLOW, N AND C CONSERVATION WITH PASSIVE AND ACTIVE AERATION.

by

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ABSTRACT

An experimental laboratory study was undertaken to investigate the convective airflow which develops in compost masses and the effect of passive and active aeration on nitrogen (N) and carbon (C) losses of compost at three different levels of dry matter (d.m) with four different C sources (pine shavings, grass hay, oat straw and wheat straw). Each bulking agent was individually mixed with swine slurry and composted at 40, 32 and 28% d.m.. Duplicate mixtures were aerated for 21 days (14 days for one of the pine shavings trials) both in active and passive conditions in 100L composters and their temperature was monitored every 3 hours. A mass balance on the compost N and C allowed for the calculations of N and C losses. The passively aerated compost demonstrated temperature regimes similar to that of the actively aerated compost reaching and exceeding 55^{0}C for 3 days. The initial airflow resistance of the composts was found to be lower than the final. The convective airflow of the compost was correlated with time and to the difference in ambient and compost temperature. The 32% d.m. content and the wood shavings compost produced higher convective airflows. The statistical significance of the effects of aeration method, d.m. level, and C source on N conservation was tested. Only the C source had a significant effect ($P \leq 0.05$). The hay amended with urea had the lowest N losses (22.4%), followed by oat straw, hay, wood shavings amended with soybeans, wheat straw and wood shavings with losses of 41.4, 53.4, 53.6, 55.2% and 68.5% respectively. The C losses were strongly related to the N losses, except for the hay amended with urea compost. The oat straw loss the most C (51.4%), followed by hay, wheat straw, wood shavings amended with and without soybeans, and hay amended with urea with losses of 37.4, 35.8, 25.4%, 13.5% and 12.19% respectively.

RÉSUMÉ

Une étude expérimentale en laboratoire a été entreprise pour étudier le taux de ventilation par convection se developpant dans les masses de composte, ainsi que l'effet d'aeration passive et active sur les pertes en N et C en composte à trois differents niveaux de matière sèche (m.s.) et avec quatre differentes sources de C (le copeaux de pin, foin, et paille d'avoine, et paille de blé). Chaque agent en vrac a été mélange individuellement avec du lisier de porcs et composté a 40, 32, et 28% m.s. Des melanges appariés ont été aérés pendant 21 jours (14 jours pour un des essais utilisant le copeaux de pin), dans des conditions actives et passives, dans des cellules de compostage de 100L. Leurs temperatures ont été enregistrés à tout les 3 heures. Une balance de masse de N et C sur les compostes a permis le calcul des pertes de N et C. Le composte aéré passivement a demontré des regimes de temperature semblables à ceux du composte aéré activement. Ils ont tous atteint et excédé 55°C pour une durée de trois jours. La resistance du passage d'air initial était inférieur à celui du passage d'air final. Le passage d'air convecteur du composte était relié à la difference entre la temperature ambiente et celle du composte ainsi que du moment qu'il a été mesuré. Le compost à 32% m.s. et le composte de copeaux de pin ont produit le passage d'air convecteur le plus élevé. Une test de signification quant aux effets du la méthode d'aération, du niveau de m.s. et de source de C sur les pertes d'azote a été accompli. Seulement la source de C a été significative ($P \leq 0.05$). Le foin mêlé à l'urée a demontré la perte la plus basse de N (22.4%), suivi par la paille d'avoine, le foin, des copeaux de pin mêlé avec du soya, la paille de blé, et des copeaux de pin avec des pertes de 41.4, 53.4, 53.6, 55.2 et 68.5%, respectivement. Les pertes de C etaient étroitement reliées aux pertes de N, avec l'exception du composte de foin mêlé à l'urée. La paille d'avoine a perdu le plus de C (51.4%) suivi du foin, la paille de blé, des copeaux de pin mêlés avec et sans soya, et le foin mêlé avec l'urée avec des pertes de 37.4, 35.8, 25.4, 13.5 et 12.19%, respectivement.

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1 INTRODUCTION

1.1 BACKGROUND

Composting is a technique which can be used to reduce the amount of organic waste through recycling and the production of soil fertilizers and conditioners. Compost is primarily used as a soil conditioner and not as much as a fertilizer because it contains a high organic content (90%-95%) but generally low concentrations of nitrogen, phosphorus, potassium as well as macro and micro nutrients compared to commercial fertilizers. Compost is comparable to peat moss in its conditioning abilities.

Areas where composting can be beneficial is in the recycling of the organic fraction of the municipal waste. It reduces as much as 30% of the volume, in the form of organic matter, entering our already overcrowded landfill sites. Furthermore the composting process, if performed correctly, transforms wet and odorous organic waste into an aesthetically, dryer, decomposed and reusable product.

Disposal of septic tank sludge, commonly known as biosolids, has benefitted from the composting process. Once the liquid fraction has been separated from the septic sludge, the biosolid is composted with a dry bulking agent. Because of the biosolids high concentration of pathogens, it needs to be stabilized to control the spread of disease. Composting performs the tasks of stabilization and sterilization thus allowing the composted material to be safely reused as a soil amendment. Until now, in Quebec, composting is the only accepted stabilization process for sludge.

The paper industry has also found composting useful in dealing with its sludge. By composting the sludge, not only does it reduce the amount of waste entering the landfill, it also transforms the hard to degrade lignin into a more acceptable form with a lower C:N ratio and more immobilized N. The marketable material is well suited for horticultural and agricultural uses.

Composting is a controlled aerobic decomposition process converting biodegradable solid organic matter into stable humus (Parent 1983). Therefore, composting is a manageable process, and the skill with which it is executed dictates the speed and effectiveness of the process. In its simplest form, the composting of a waste material, serving as a nitrogen source, starts with its mixing with a bulking agent serving several functions. First, it is a source of carbon and energy essential for the microorganisms degrading the material. It is also a dryer material aiding in absorbing excess moisture therefore providing porosity and aeration to the mass and eliminating any potentially unpleasant odours. A bulking agent has the added benefit of adding structure to the mass, thus allowing air movement through the pile.

Ideally, sufficient quantities of a carbon source and nitrogen source along with adequate moisture, aeration and pH is needed for composting. The shape of the temperature curve with time is a prime indicator of how well the composting process is proceeding. High temperatures are the consequence of biological activity: heat is liberated through the respiration of microorganisms decomposing organic matter, thus higher temperatures indicates active composting. The typical cycle is one where, 48 hours after mixing, a sharp rise in the temperature occurs in the pile. This temperature can range from 40 to 60°C, and it may even climb as high as 75°C after 2 to 3 days. Ideally, the temperature should, at some point during the process, remain above 55°C for three days in order to sterilize the waste. However, temperatures above 70°C should be avoided as they are detrimental to the microorganisms important for composting. Depending on the availability of carbon and nitrogen along with the other factors, the temperature will be maintained or begin to decrease after 2 to 3 weeks.

Since composting is an aerobic process requiring aeration, the availability of oxygen during the process is of primary importance. This requirement is accomplished by either passive or forced (active) aeration. Passive aeration occurs as the pile heats up, a temperature gradient is formed between the ambient air and that of the pile. This gradient causes convective forces move air throughout the pile, thus eliminating the need for any sort of mechanical aerating equipment. The air can be supplied by using a pipe and duct system or simply by natural diffusion. Forced aeration is as its name implies, supplying oxygen by pulling or pushing air into the compost pile by a fan or blower set-up.

It is generally recognized that there are two composting systems, open and closed. The open systems are characterized by outside windrows which are aerated by mechanical mixing or through the ventilation of static piles. Static piles are piles which are not turned or mixed during the composting process. Windrow composting is one of the oldest forms of composting known to man. In its simplest form, a windrow compost system can be tailored to any dimensions depending on the size of the turning equipment to be used. The number of turnings is based on the aeration requirement which will vary depending upon the stage of the process. Another version of the windrow system is the aerated static pile design. As opposed to mechanical turning, it allows for much larger windrows and even the use of huge piles. The major difference is that instead of turning the piles, a fan and duct system are used to supply air to the wastes. If the compost is aerated adequately then the active composting phase can be achieved in three to four weeks followed by a maturation phase taking a further 12 weeks (Tchobanoglous et al. 1993). The only disadvantage of static piles is that the outside layers may not be composted as effectively. If not turned or aerated, then the organic waste could take as long as three to five years to decompose and can be responsible for some unacceptable odours.

The second composting process, closed or in-vessel systems, have been devised with every possible shape from circular bed reactors, rectangular reactors and even vertical reactors shaped like a silo (Figures 1A, 1B and 1C). In-vessel composting can be further divided into two major categories: plug flow and dynamic flow. In plug flow design, the process revolves around a first-in, first-out principle but is subjected to compaction and less effective composting. This problem is solved by the dynamic system. The composting material is mechanically mixed during the process, providing essential aeration. The mechanical in-vessel composting system is becoming more widely accepted, the reasons being faster turnover of product, more control over the process, better odour control, lower labour costs, and smaller area requirements. For both in-vessel composting systems, the aeration is achieved by supplying air either by forced or passive means.

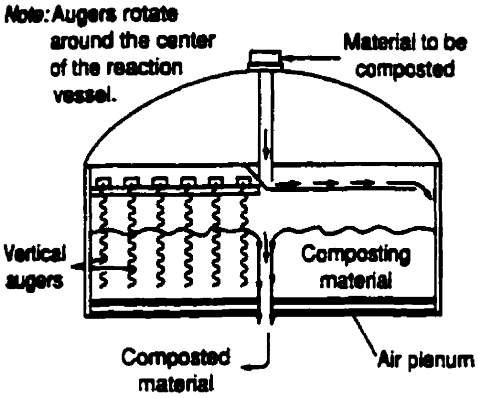


Figure 1A Circular reactor (Tchobanoglous et al. 1993)

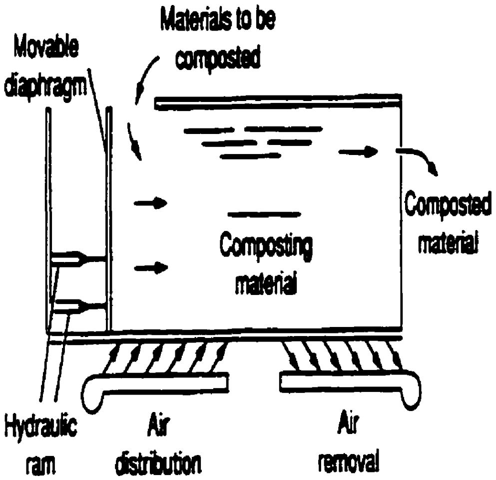


Figure 1B Rectangular reactor (Tchobanoglous et al. 1993)

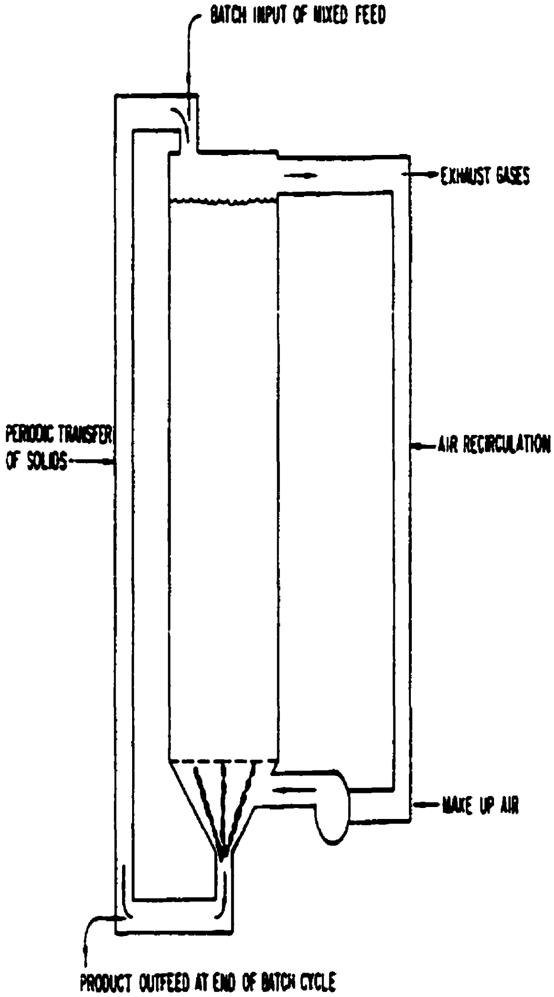


Figure 1C Vertical reactor (Diaz et al. 1993)

Composted material should exhibit good quality: dark brownish in colour, earthy smell, C/N ratio less than or equal to 25, 50 to 60% moisture, loose structure, and low percentages of nutrients (N, P, and K) and a neutral pH. Mature compost has low BOD which would not lead to oxygen deficiencies in the soil and toxicity problems for the plant roots.

The general benefits of composting are 1) to transform the biodegradable organic materials into a biologically stable material and in the process reduce the original volume of the waste; 2) to destroy pathogens, insect eggs, weed seeds and other unwanted organisms that may be present; 3) to produce a stable material for soil fertilization reducing risks of leaching, and 4) to produce a product that can be used to support plant growth and to amend soils.

The factors that are of most concern during the composting process are the loss of nutrients and costs associated with the process. The loss and transformation of nutrients during the composting process influence the final value of the compost. Of the three major nutrients, (N, P and K), nitrogen is by far the most important (Patni and Jui 1990). Nitrogen is the only nutrient that can be lost by volatilization as gaseous ammonia at a level of 50% to 70%.

Composters are interested in handling as much waste in the least amount of time while expending the least amount of energy. Higher energy input results in an increase in the cost of the final product. Turning and aeration equipment represent a substantial investment. Figure 1.1 is a commercially self-propelled compost turner, these units can cost up to $200,000 (Diaz et al. 1993). An alternative to the expensive self-propelled compost turner is a tractor with a front loader attachment that costs between $15 000 to $20 000 (Figure 1.2).

However, passive aeration is the most advantageous of the ventilation processes mentioned earlier, because it requires the least investment. With passive aeration and the open system, the turning frequency of the windrows can be reduced while eliminating the need for ventilation fans. Passive aeration can also be used in supplying the oxygen requirements to the composting materials in closed systems.

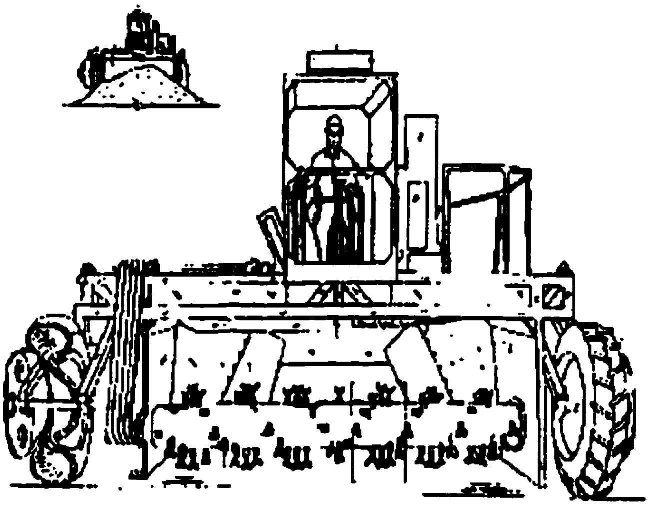


Figure 1.1. Self-propelled mechanical turner
(Diaz et al. 1993)

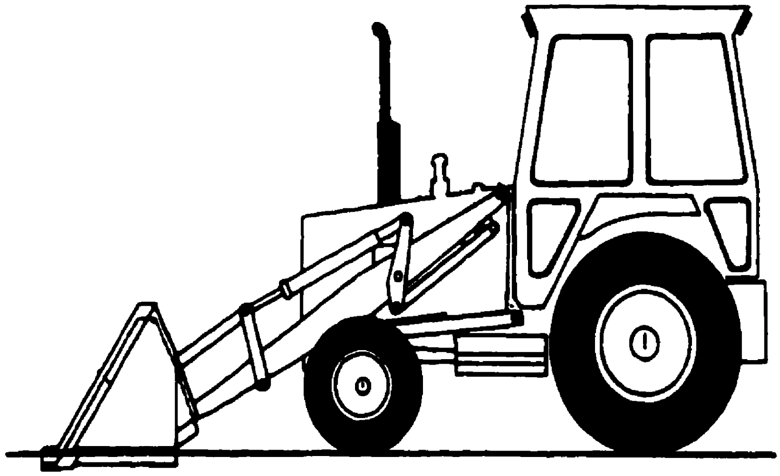


Figure 1.2. Tractor with front loader attachment

However, there is very little information on the efficiency of passive aeration. Thus, a project was undertaken to compare the performance of two composting aeration strategies, passive and forced. Simultaneously, N and C losses were investigated for four bulking agents, straw (oat and wheat), hay and wood shavings, composted at three dry matter levels (40%, 32% and 28%).

1.2 OBJECTIVES

This study aimed primarily at comparing the performance of two different aeration strategies, passive and active, for composting of swine slurries under three different moisture levels and four bulking agents, straw (oat and wheat), hay and wood shavings.

Criteria to compare the performance were:

1. The temperature evolution with time.
2. The air flow through the mass.
3. The nitrogen and carbon losses.

1.3 SCOPE

The results obtained in this experiment are limited to the 4 types of bulking agent, hay, straw (oat and wheat), wood chips, and to specific dry matter levels (40, 32, 28%) associated with the wastes under the two aeration strategies. Furthermore, the N and C balance were determined by taking an initial and final value of the nitrogen and carbon content. No analyses were performed during the experiments. Swine slurries were the only nitrogen rich waste composted. Finally, all experiments were performed on a laboratory scale for a period of 21 days (14 days for wood shavings).

2 LITERATURE REVIEW

2.1 GENERAL

Composting is defined as the biological decomposition and stabilization of organic substances under conditions which allow development of thermophilic temperatures (35 to 50^{0}C) as a result of biologically produced heat. The final product is sufficiently stable for storage and application to land without adverse environmental effects (Huag 1980). The basic biology of composting is relatively well understood, but the metabolic and organic transformations are not so well known. The aerobic composting organisms are those bacteria, fungi, and protozoa naturally occurring in the waste. Materials to be composted should contain at least 25% volatile organics, a moisture content of 50 - 65 %, a carbon-to-nitrogen ratio in the range of 20:1 to 40:1, and a pH between 5 and 8 (Poincelot 1974, Rynk 1992) . To deal with the large volumes of wastes generated by today's society, mankind is endeavouring to come up with viable solutions. However, it was not until recently that research was directed to determining the most important factors that influence the composting process.

2.2 AERATION

From the definition of composting, it is accepted that the process is aerobic, as little activity and self-heating occur under anaerobic conditions (Jeris and Regan 1973, Suler and Finstein 1977, Fermor et al 1985). As such, several experiments have been conducted to investigate the different modes of aeration, natural, passive and forced (active).

The main factors that influence the level of aeration are: bulking agent, moisture content, particle size, porosity and temperature.

2.2.1 Modes of Aeration

The accepted aeration methods for composting are natural, passive and forced (active) aeration. Campbell and Darbyshire et al. (1990) reported that air flow through the compost is the prime factor affecting its temperature development. If too little air is supplied, the temperature may not reach the desired sterilization temperature of 55°C. Likewise, some regions of the pile may turn anaerobic and emit malodours. However, if the pile receives too much air, the pile may heat up thus inhibiting the composting microorganisms. Darbyshire et al. (1989) used forced aeration to compost coniferous bark (Sitka spruce bark - *Picea sitchensis*) in which they were able to operate at optimum conditions by controlling the temperature by adjusting the air flow to the waste. In order to reduce the costs of expensive aeration equipment, passive aeration has been gaining in popularity. Since forced or active aeration requires more expensive equipment, an alternative has been passive aeration. McGarry and Stainforth (1978) were one of the first to report successful composting of human and farm wastes by passive aeration. Mathur et al. (1990), passively composted peat with sheep, cow and poultry manure and achieved temperatures between 55°C and 65°C within 4 days which remained in that range for between 8 - 12 days. Zhan et al. (1992) obtained temperatures between 60°C and 65°C after 3 days when passive aeration was used to compost a mixture of poultry manure and peat. Sartaj (1995) passively aerated sheep manure with peat, demonstrated that the waste could achieve thermophilic temperatures which are so important for the sterilization of the wastes and reported that a good end product can be achieved. Fernandes et al. (1993) reported that when passively composting poultry wastes under high initial moisture conditions of 73 and 80%, the temperature of the pile reached thermophilic conditions (>45°C) within the first two days with a peak temperature of 71°C on day 5 and remained in the thermophilic range for 90 days, thus indicating the effectiveness of passive aeration.

Natural ventilation methods, whereby air is supplied by diffusion through pores in the pile as opposed to air being supplied by means of perforated pipes as in passive aeration, was successfully applied by Ishii et al. (1991) for sewage sludge in static pile composting under 50% initial moisture content. However, the natural aeration system does not include a means to facilitate air delivery and is not recommended for wastes with high initial moisture content (Sartaj 1995). The effectiveness of perforated aeration pipes and their zone of influence in passive aeration under high initial moisture (76%) was investigated by Sartaj (1995). It was concluded that the influence zone of passive aeration pipes was limited to the interior portion of the bottom half of the pile. Seven 0.10m inside diameter perforated ABS pipes with a 0.4m spacing between them were laid horizontally at the base of a 5 m^3 mixture of peat composted with poultry manure. Temperature distribution inside the piles indicated that passive aeration pipes were effective in providing more air than natural aeration. The Passive aeration process finished two weeks earlier than the natural aeration process (Sartaj 1995).

Compared with passive aeration, forced aeration has been reported as capable of accelerating the composting process (Darbyshire et al. 1989). With forced aeration, the temperature of the pile can be regulated allowing for increased and decreased oxygen demands depending on the stage of composting. Oxygen demand is very high during the initial decomposition stage, because of a rapid expansion of the microbial population, a temperature rise and a high rate of biochemical activity (Zucconi and Bertoldi, 1987). Therefore if left to itself, the internal temperature can reach in excess of 65° C which can be detrimental to the microbial population and thus to the composting process. Only a few species of thermophilic microorganisms beneficial for composting show metabolic activity above 70°C (Bertoldi and Zucconi 1987).

Regardless of which aeration technique is utilized, the microorganisms responsible for composting require oxygen to survive and propagate. Theoretically, the amount of oxygen required is determined by the amount of carbon and nitrogen to be oxidized (Peavy et al. 1985). However, it would be impossible to arrive at a precise determination of the oxygen requirement on the basis of the carbon content of the waste, since an unknown fraction of the carbon is converted into bacterial cellular matter and another unknown fraction is so refractory in nature that its carbon remains inaccessible to the microbes (Diaz et al. 1993). For composting swinery wastes, the aeration rate should be between 0.04 to 0.08 l/min-kg (Lo et al. 1993) with the rate a little higher, about 0.1 l/min-kg (Diaz et al. 1993) for the initial 3 or 4 days of composting. For the composting process to develop correctly and not interfere with microbial metabolism, the oxygen level in the atmosphere of the composting material should be in the range of 10 to 18% O_2 (Bertoldi and Zucconi 1987).

2.2.2 Bulking Agent

It is clear that the function of a bulking agent is to add carbon, absorb excess moisture and impart some kind of structure to the waste (Tengman et al. 1995). Since the microorganisms require oxygen (air) to survive and propagate, air channels must be created and maintained in order to facilitate its movement. Since swine manure is typically collected with water and handled as a liquid, it is too wet to be composted on its own. Therefore a suitable bulking agent is required. Choosing an appropriate bulking agent takes on a monumental importance. For example, hay has been found to be a poor bulking agent for composting because it tends to compress and block air flow through the composting pile. Wheat straw works better because it is hollow, providing pathways for air flow (Rynk 1992). Wood shavings, sawdust and peat moss offer good structural strength even at moisture contents of 75% while straw and paper residues tend to collapse when wet, and therefore limit the moisture content to 60% (Mathur et al. 1990, Zhan et al. 1992, Diaz et al. 1993). To date, the most successful composting, in terms of temperature rise and quality of final product, has been achieved using sawdust as the bulking agent, "due to its small particle size, ease of handling, absorbency and high carbon content" (Fullage and Ellis 1994). Each bulking agent contains varying amounts of carbon that are available to the microorganisms. Each time that organic compounds are consumed by microorganisms, two-thirds of the carbon is given off as carbon dioxide. The remaining third is incorporated along with nitrogen into microbial cells, then later released for further use once those cells die (Barrington 1994). Wood, because of its very high lignin content, is one of the most resistant natural substrates for microorganisms to degrade (Lynch 1993). Lignin is reported as having a one month biodegradability of 7% (Russell 1973). Sawdust, depending on the source, may contain between 20-30% lignin, giving a C bio-degradability of 15 to 25% (Lynch 1993, Russell 1973), whereas straw from mature cereals can have a one month C bio-degradability of 30% (Russell 1973).

2.2.3 Particle Size and Particle Size Distribution

The particle size of the bulking agent determines availability of the carbon source. For rapid composting, organic matter must undergo size reduction. Mustin (1987) reported that if the organic waste has a coarse particle size distribution, it must be chopped to optimize its decomposition. The primary purpose of this operation is to increase the surface area of the material, inasmuch as the smaller the particle, the greater is the ratio of the surface area to mass. The speed of biological oxidation is in direct proportion to the amount of surface exposed to the reactive agent. Darbyshire et al. (1989) reported that temperatures registered when composting large unmilled strips of Sitka spruce bark remained low (<28°C). It was not until the bark was milled into pieces of 2 cm in diameter that the temperature rose to 40°C. While theoretically it may be true that the smaller the particle size, the better the biological degradation, in practice, limits exist to size reduction which are a function of the structural strength of the raw materials (Bertoldi and Zucconi 1987). Besides structural strength, the length to width ratio of the particles is probably the most important factor which influences the optimum size. Thus, plant material such as stems and leaves, can be as large as 15 cm whereas woody material should not exceed 6 cm in length and 1 cm in width (Diaz et al. 1993). For composting, in general the particles should range between 2 to 5 cm

(Tchobanoglous et al. 1993).

2.2.4 Moisture Content

The composting microorganisms, along with oxygen, require moisture to survive and propagate. Microbial activity takes place in a liquid film on the surface of waste particles. Moisture provides the means of transporting soluble nutrients and effecting the chemical reactions of the process (Tchobanoglous et al. 1993). If too much moisture is present, this would fill the pore space and block the movement of oxygen. As a result, the microorganisms would not receive an adequate supply and die off. The pile environment would thus enter into anaerobic conditions and thus produce malodorous emissions resulting in an inefficient composting stage. All microbial activity ceases when the moisture content is less than 8 to 12% (Diaz et al. 1993). Generally, the recommended moisture content for composting is in the range of 50 to 60% (Poincelot 1974, Lau and Wu 1987, Schuchardt 1987).

2.2.5 Porosity

To allow adequate air movement there has to be sufficient air channels in the pile. Fernandes et al. (1993) reported that the optimum porosity level for composting animal waste slurries is between 30-50 %. The pore space of the compost helps store and diffuse oxygen to the microbes (Diaz et al. 1993) and is influenced by the structural strength of the bulking agent.

2.2.6 Temperature

Temperature plays an important role in static passive aeration. Miller et al. (1989) reported that during composting of mushroom stacks they noticed a "chimney effect". Once the core temperature heats up to thermophilic temperatures, a temperature gradient occurs. This gradient, between the core temperature and ambient air temperature will induce air movement. The "chimney effect" is credited with pile oxygenation; with the achievement of elevated temperatures, mass air flow by natural convection results (Gerrits 1972; Vedder 1978; Fermor et al. 1985). Zhan et al. (1992) reported that while composting poultry manure with peat, temperature changes during composting process were a function of the recording locations. They noted that close to the exterior surfaces, temperature rose sharply to 62°C in 3 days but also dropped off to 25°C in about 10 days. Comparatively, the temperature in the interior of the pile gradually rose to 43°C in about 15 days and remained at that level for more than 45 days before it fell to ambient temperature.

2.3 NITROGEN CONSERVATION

During composting, the greatest nitrogen losses are caused by gaseous emissions (Martins and Dewes 1992). Nitrogen lost during composting can range from 20 -50% and is related to the initial compost content (Eghball et al. 1997, Eghball and Power 1994). Depending upon seepage quantity and the original compost dry matter, of the nitrogen lost, over 90% is lost by ammonia volatilization (Eghball et al. 1997). Therefore, one of the main purposes of composting is to conserve nitrogen and minimize its losses to the atmosphere in the form of ammonia. Ideally the total carbon should decrease and total nitrogen increase, and therefore the C/N ratio should decrease after the compost process. This is due to the conversion of organic carbon to releasing CO_2 gas and conservation of nitrogen in living cells during the organic matter decomposition.

2.3.1 Bulking Agent

The use of woody material, rich in lignin can lead to significant losses in nitrogen during the composting process. Lignocellulosic materials can be transformed biologically into valuable products in spite of the presence of a lignin barrier. In nature, wood is decomposed by wood rot fungi belonging to *Basidiomycetes*. For example, sawdust as a bulking agent leads to high N losses because of its high lignin content and low C bio-degradability (Barrington et al. 1997). The C bio-degradability of sawdust ranges from 15 to 25% (Lynch 1993). Therefore, a sawdust compost with an initial C/N ratio of 30 and a C bio-degradability of 15 to 25%, may lose 80 to 60% of its initial N content respectively.

2.3.2 pH

It is generally true to say that matter over a wide pH range (from 3 to 11) can be composted (Bertoldi and Zucconi 1987). However, optimum values range between 5.5 and 8. Most microorganisms thrive poorly under acid conditions or may even be killed. The ideal pH level for most microorganisms is 7.0, a level that corresponds to neutrality. Most piles become somewhat acid during the onset of decomposition, but this condition is not detrimental as it is usually temporary. As bacteria and fungi digest organic matter, they release organic acids. In the early stages of composting, these acids often accumulate. The resulting drop in pH encourages the growth of fungi and the breakdown of lignin and cellulose. Usually the organic acids become further broken down during the composting process (Jeris and Regan, 1973). At alkaline levels (>7.0), the ammonium radical leaves its ionized state and is volatilized. Thus, as pH increases, more ammonia will be observed over the composting pile. Combining this volatilization with the high temperatures characteristic of actively composting mass leads to extensive loss of nitrogen in the form of ammonia (Diaz et al. 1993).

2.3.3 Carbon to Nitrogen Ratio

Carbon is an essential macronutrient and takes part in energy metabolism. It is the major energy source for microorganisms and must be available to the microbes in large quantities. Nitrogen is also an essential macronutrient for growth and production of microbial cells. The amount of nitrogen needed per unit of carbon varies with the type and concentration of organisms (Tchobanologous et al. 1993).

Ideally the total carbon should decrease and total nitrogen increase, and therefore the C/N ratio should decrease after the compost process. This is due to the conversion of organic carbon to releasing CO_2 gas and conservation of nitrogen in living cells during the organic matter decomposition (Zhan et al. 1992). Elwell et al. 1996 reported that when composting mixtures of food residues, yard trimmings and chicken manure the C/N ratios were reduced from the 13 to 20 range initially, down to 11 to 12 for all three mixes. Bernal et al. (1996) reported similar results when composting sweet sorghum bagasse with either sewage sludge or a mixture of pig slurry and poultry manure. The C/N ratio in the two components decreased from 24.0 and 15.4 to values between 12 and 10.

The C/N ratio is an important indicator of the compostability of a waste. It is generally agreed that a C/N ratio of between 20 to 40, with the optimum of 25, is acceptable for composting (Bertoldi and Zucconi 1987). At ratios less than 20, nitrogen is lost to the atmosphere in the form of ammonia. Under those conditions there is not enough carbon to provide the energy to convert all available nitrogen into protoplasm. Hansen et al. (1993) reported that ammonia loss during composting of poultry manure in reactor vessels was three times greater with a C/N ratio of 15 compared to 20.

The C/N ratio recommended for composting falls within the range of 20 to 40. Nevertheless most microorganisms require a C/N ratio of 20, in spite of the fact that most of the microorganisms have a body composition with a C/N ratio of 5 to 10 (Alexander 1977). The discrepancy between the body composition of the microorganisms and their C/N requirement is explained by the loss as CO_2 of 60% of the carbon consumed (Barrington et al. 1997). The discrepancy between the recommended C/N ratio for composting and that required by the microorganisms is explained by the fact that some of the carbon of the organic wastes is not easily biodegradable. Thus, a C/N ratio of 20 to 40 is based on the fact that 100% to 33% respectively of the carbon contained by the waste is biodegradable (Barrington et al. 1997).

On the other hand, excessively high C/N ratios causes a decline in the production and growth of the microorganisms in proportion to the decrease of nitrogen in the substrate thus resulting in a slower composting activity (Tchobanologous et al. 1993, Diaz et al. 1993).

3 MATERIALS AND METHODS

3.1 MATERIALS

The composting trials were conducted using four bulking agents: pine shavings, four year old grass hay, oat and wheat straw complemented with pig slurry. The pig slurry was obtained from the farrowing and grower hog barn of the Macdonald Campus farm of McGill University located in Ste-Anne-de-Bellevue. The hog barn utilizes a scraper system to handle the manure. As such, the solids content of the pig slurry ranged from 16 to 20%. Soybeans were utilized as an amendment and added only to the wood shaving compost trial to reach a C/N ratio of 20. Urea was used with the hay, however it was found to increase the pH of the oat straw and wood shavings above 9.0 and arrest the temperature regime at 30°C. It's use was discontinued. Tap water was used to vary the d.m. (dry matter) level of the compost mixtures made of the same bulking agent. All materials were characterized for their d.m., T.N. (Total Nitrogen), pH, ash, C and particle density (Table 3.1).

Table 3.1. Characteristics of the Experimental Materials

Material	Characteristic					
	d.m. %	T.N. g/kg	pH	Ash %	C** %	Density g/ml
Straw	86.9 (0.45)	9.79 (0.247)	6.3 (0.60)	8.96 (0.423)	49.8	0.50 (0.039)
Hay	87.2 (1.11)	11.0 (1.80)	5.2 (0.10)	6.5 (0.26)	51.1	0.66 (0.088)
Pine shavings	92.4 (0.33)	0.64 (0.0375)	4.4 (0.13)	0.38 (0.128)	54.4	0.78 (0.098)
Pig slurry*	16.8 (0.86)	75.1 (5.54)	7.2 (0.16)	19.8 (1.38)	43.8	1.30 (0.131)
Soybeans	90.0 (0.46)	6.8 (0.25)	--	2.3 (0.15)	53.4	--

Note : the T.N., C and ash content are expressed on a dry matter (d.m.) basis.
: numbers in the parentheses refer to the standard deviations.
* typical values obtained, for the pig slurry, among all 6 tests.
** the C content was equated to (100% - ash (%)) / 1.83 (Lo et al.1993).

3.2 COMPOSTERS

The experimental composters consisted of 100 L cylindrical plastic containers, 0.76 m high and 0.45 m in diameter. The vertical perimeter of each container was insulated with 100 mm of mineral wool to reduce heat loss. An air plenum, 100 mm in height, was created at the bottom of each container using a supported metal mesh, to distribute the air flow uniformly through the material (Figure 3.1). The plenum of the active aerated compost was connected to a distribution chamber receiving air from a compressed air line. The airflow was controlled by an air flow meter and a control valve (Figure 3.2). The passively aerated compost received air through a 2 cm^2 hole which opened to the ambient air and was located at midheight of the constructed plenum. A drainage tube connected from the bottom of the container leading to a collection bottle was used to collect the seepage from the compost. This seepage was later analysed for T.N. content to complete the Nitrogen balance.

The temperature of the compost in each container was monitored by a type T thermocouple (copper - constantine) installed in the centre of the mass, once mixed and placed in the container. The thermocouples were connected to a data logger (Doric 245) which collected the temperature readings at three hour intervals. The thermocouples were initially calibrated in water at 0°C and 85°C which covered the anticipated temperature range for the compost mixture.

To measure the air flow through the compost, a container cap fitted with a seal was utilized. This cap has a central orifice, 5 mm in diameter. An anemometer (Alnor 4000) was fixed to the cap with its sensing wire lying across the centre of the orifice to measure

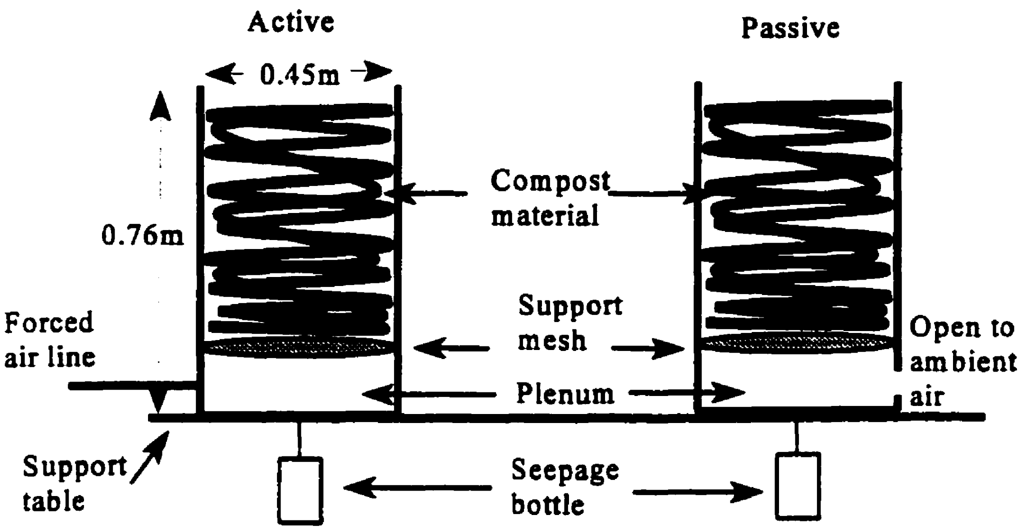


Figure 3.1. Experimental composters.

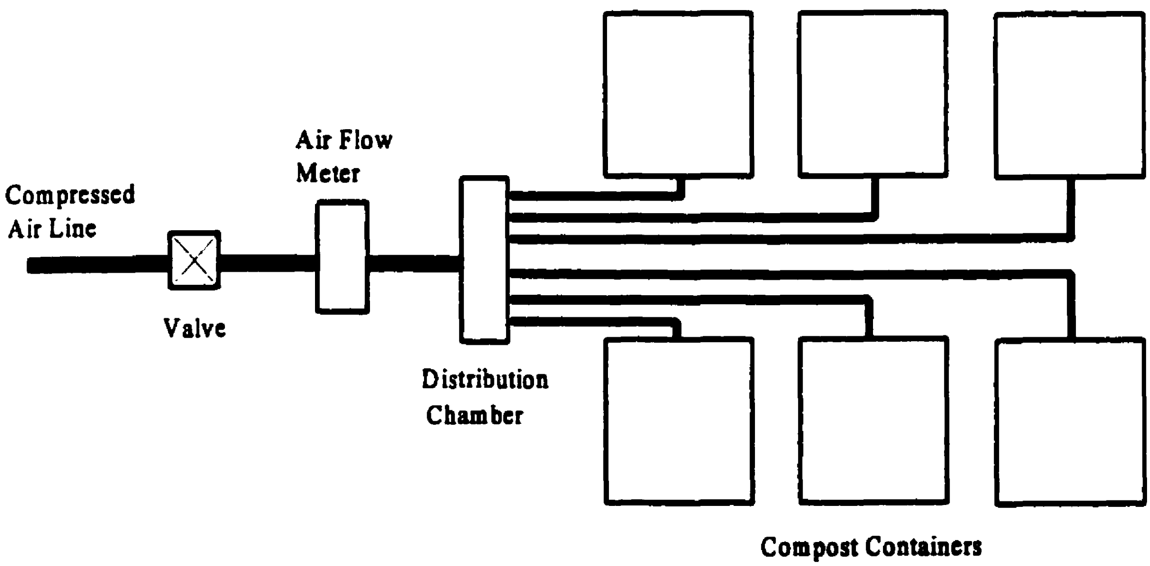


Figure 3.2. Schematic diagram of experimental set-up for active aeration.

its air flow. Prior to the compost test, the discharge coefficient (C_d) of this orifice was measured. The airflow and the orifice air velocity were used to calculate the discharge coefficient, C_d.

$$C_d = Q/V^2A \qquad (3.1)$$

where C_d is the discharge coefficient,

Q is the air flow, m^3/s,

V is the air velocity measured at the orifice, m/s,

A is the area of the orifice, m^2

A known air flow was allowed into one air tight container. Simultaneously, the air velocity at the orifice of the cap was measured along with the static pressure inside the container. The C_d of the orifice was found to range from 0.98 to 0.64 for air velocities varying from 0 to 2.75 m/s and 0.64 for air velocities above 2.75 m/s (98% confidence level). The pressure and orifice air velocity measurements were in agreement with Bernoulli's Law ($P < 0.05$):

$$P = \sigma V^2/2 \qquad (3.2)$$

where P is the static pressure measured inside the container, Pa,

σ is the air density for the ambient temperature, kg/m^3,

V is the air velocity measured at the orifice, m/s.

For the ranges of velocities measured across the cap orifice during the experiment, the convective air flow was measured with a maximum error level of 5 % attributed to the anemometer reading and the air loss through leakage around the edge of the cap.

3.3 EXPERIMENTAL METHODS

Each composting test lasted for a duration of 21 days, except for the first trial (wood shavings) which lasted for 14 days. The composting trials were performed during a period commencing April 1996 and ending December 1996 in a room maintained at 20 - 24°C. One test was conducted for each bulking agent and for each test, three levels of d.m. (40, 32 and 28%) were mixed. For each test, a single bulking agent/pig slurry mixture was used and its d.m. level was varied by adding a different amount of tap water. The 28% d.m. level corresponded to the maximum amount of humidity which the bulking agents could hold. Thus, all mixtures would loose very little seepage initially for a uniform C/N ratio. This also allowed for the measurement of N losses mainly as volatilization. For each test, twelve compost containers were filled, 6 for passive and 6 for active aeration. For each type of aeration, three moisture levels were tested in duplicate.

A mass balance on the N and C allowed for the calculation of losses. Before each test, the bulking agent was sampled and analysed. Then, the bulking agent was mixed with a set amount of pig slurry, water and amendment (soybeans for the shavings and urea for the hay) to give the required d.m. level and C/N ratio (Table 3.2). The final C/N ratio of each test varied slightly because the d.m. and T.N. of the fresh pig slurry had to be estimated beforehand. The pig slurry could not be collected for analysis 24 hours before mixing because its T.N. would drop significantly. Each batch of material was prepared and mixed manually in sufficient quantity to fill two containers, one for the passive and another for the active aeration test. The initial N and C content of the compost was obtained by measuring the weight of all ingredients used for each batch and by characterizing these ingredients beforehand. Each compost batch was divided into two portions of equal weight and each portion was placed in either an active or a passive composter. Thus, each passive compost treatment was replicated in an actively aerated treatment.

To characterize its airflow within one hour of filling the containers and just before emptying the containers, a pressure test was conducted on the material in each container. To characterize its airflow at a measured flow rate of 33, 66, 110, 133, and 166 ml/s, air was introduced in the container plenum. The cap and anemometer assembly was used to measure the outlet air velocity. The air static pressure in the plenum was measured using a Dwyer microtector. The orifice air velocities and air static pressure in the plenum were used to calculate the air flow ,Q, through the compost mass:

$$Q = VA\rho C_d \tag{3.3}$$

where Q is the airflow, kg/s,

V is the air velocity measured at the orifice, m/s,

A is the area of the orifice, m^2,

ρ is the air density for the temperature at the outlet, kg/m^3,

C_d is the discharge coefficient,

The drop in pressure for this airflow to move through the compost is:

$$\Delta P = (\rho V^2/2) - P_p \tag{3.4}$$

where ΔP is the pressure drop, Pa,

P_p is the plenum air static pressure, Pa,

ρ is the air density for the temperature at the outlet, kg/m^3

V is the air velocity measured at the orifice, m/s

During the composting test, the active containers were aerated using forced air at a rate of 33 ml/s and through their sealed plenum. The passive containers were aerated by leaving a side opening in the plenum.

With the cap and anemometer apparatus the convective air flow of each passive container was measured twice a day for the first week and once a day for the second and third week. The convective heat flow in the actively aerated compost was also measured by stopping the forced aeration for 0.5 h before taking the readings and opening an air orifice at the level of the plenum.

The temperature regime in each compost container was monitored over a period of 21 days. The compost was not mixed during the test period in order not to disturb the original porosity. Each container manually received 2 L of water at room temperature, once a week. A drainage tube was installed in each plenum to collect all seepage during the test.

Table 3.2. Compost Composition for the Experimental Tests

Item	Units	Oat Straw	Wheat Straw	Hay	Hay +urea	SS	S
Bulking agent	% d.w.	74	74	76	89	77	77
Pig slurry	% d.w.	26	26	24	10	15	23
N complement	type % d.w.	--	--	--	Urea 1	Soybean 8	--
d.m.	% d.w.	40 32 25	40 34 29	40 35 30	42 34 26	41 35 30	39 31 27
C/N ratio		18	18	26	20	20	25

Note : d.m. - dry matter; d.w. - dry weight.
: SS, S denote wood shavings amended with soybeans and wood shavings respectively.

To characterize the final airflow properties through the compost mass, a pressure test was conducted on the material in each container before emptying the composters. The final N and C content of the composts were obtained by measuring the weight of the composters at the completion of the trial. The contents were then emptied into a mixing cart and thoroughly mixed before samples were taken for analysis. The effect of the different bulking agents, moisture contents and types of aeration on nitrogen conservation was determined by comparing the initial and final C and N content of the bulking compost.

3.4 ANALYTICAL PROCEDURES

The swine manure, bulking agents and the compost mixture were analysed initially and at the end of the composting period for d.m., pH, NH_4-N, NO_3-N, total Kjeldahl nitrogen, particle density and ash content. The ash content was used to calculate organic matter as (1-ash, expressed as a fraction) and C as (organic matter/1.83) according to Lo et al. (1993).

All composts and materials were analysed using Standard Methods (APHA et al. 1990). Dry matter was determined by drying at 80^{0}C for 23 hours and one hour at 103^{0}C. Particle density was determined on oven dried samples by soaking in kerosene (Parent and Caron 1993). TKN was determined after digestion with sulphuric acid and hydrogen peroxide using an ammonia-selective electrode connected to a voltage meter. Ammonia and pH were measured using an ammonia-selective and pH electrodes, respectively, connected to a voltage meter.

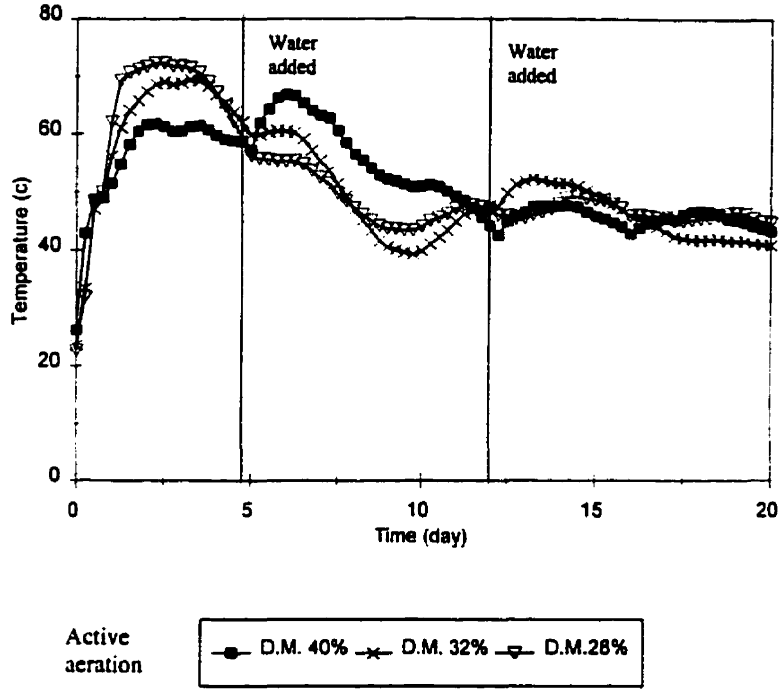
A 2-way analysis of variance (ANOVA) was used to compare the temperature regime between the different aeration treatments (passive and active) and for the three levels of d.m.. The nitrogen conservation between the different aeration treatments, the three levels of d.m. and the three bulking agents was compared by performing a 3-way ANOVA. Where the ANOVA test showed significance, a Duncan Multiple Range test was utilized to compare the means. The convective air flow was correlated with time and temperature differential between the compost and the ambient air using linear regression for the power curve and multiple regression for the polynomial curve.

4 RESULTS AND DISCUSSION

4.1 THE TEMPERATURE REGIME

A sharp temperature rise is a sign of a good composting process once the waste materials are mixed and placed in the reactor vessel. All the temperature regimes, for both active and passive aeration, exhibited this sharp temperature increase, such as that for the wood shavings amended with soybeans (Figure 4.1). Within the first 48 hours, temperatures exceeding 50^0C were achieved.

The sharp rise in the temperature is the result of heat generated by the microbes from their respirational activities. As the process proceeds, the temperature remains high for a certain period and then declines gradually. The temperature plateau is due to an equilibrium existing between the microbe population and available substrate. As the readily decomposable material has been composted, and only that which is more refractory remains, bacterial activity diminishes and the temperature drops.



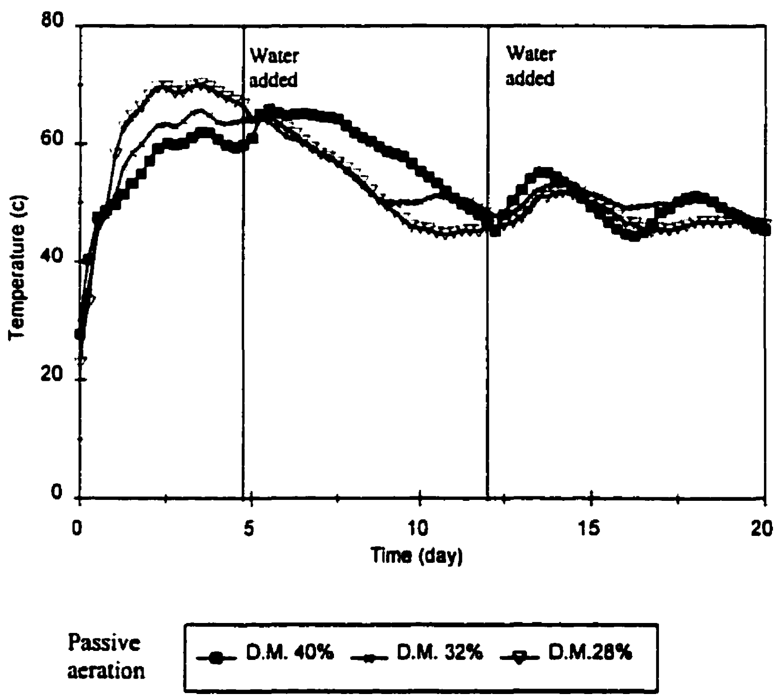


Figure 4.1. Temperature regime for wood shavings amended with soybeans.

For both active and passive aeration and all C sources, the temperature exceeded 55^{0}C for at least three days. This is an important requirement for the sterilization of the compost material. However, if the temperature exceeds 65^{0}C there will be a substantial decline in the microbial population which is reflected by a drop in temperature. This decrease in the microbial population at elevated temperatures adversely affects the overall composting efficiency. The maximum temperature reached for the active aeration technique was 73.5^{0}C for hay amended with urea . The maximum temperature for passive aeration was 69.8^{0}C for the wood shavings amended with soybeans (Table 4.1).

Periodically, water was added to the compost to supply the microbes with moisture. The addition of the water had a desirable effect in that it resulted in the temperatures of the compost for all trials to increase slightly, especially for the 40% d.m. compost. The temperature increase resulting from the water addition at the 40% d.m. level shows that the compost was too dry.

In general, the temperature for the active aeration technique was about 4^{0}C, on average, higher than the temperatures achieved for passive aeration. This difference was due to the supply of constant air for the actively aerated compost while for the passively aerated compost, detrimental temperatures reduced the bacteria population which automatically reduced the heat generation and compost temperature. The passively aerated composters relied on the ability of the convective forces to draw in and supply the necessary air. Despite this, it can be said that the passive aeration technique was capable of providing sufficient convective aeration to sterilize the compost as was demonstrated by the high temperatures achieved.

The maximum moisture content which a compost mass can support is a function of its structural strength. According to Rynk (1992) and Mathur et al. (1990), in terms of providing good structural strength from worst to best is hay, straw and wood shavings. However, from the temperature regimes presented in Table 4.1 no clear trend is apparent. Despite this, the 28% d.m. compost exhibited the higher temperatures for both active and passive aeration techniques (Figure 4.1, Appendix A).

Table 4.1. Summary of temperature data

		S	SS	H	H+U	WS	OS
Days to reach	A	0.75	1	0.75	0.25	0.75	0.5
55^{0}C	P	1.75	1	0.75	0.25	0.75	0.75
Max Temp.	A	67.7	71.7	67.5	73.5	63.8	71.5
(C)	P	65.3	69.8	66.2	64.1	60.5	67.3
Days to Max.	A	1.5	2	1.75	0.75	1.75	1.25
	P	3.0	2.25	2.75	1.75	5	1.25
Temperature	A	43.7	48.8	49.9	39.9	32.8	46.7
at day 14	P	44.7	52.8	50.8	38.8	30.4	48.4
Temperature	A	--	42.4	26.1	26.8	26.4	32.6
at day 21	P	--	46.8	26.3	26.2	26.7	31.8

Note : Table represents averages for the three d.m. levels.
A,P denotes active and passive aeration respectively.
S - wood shavings; SS - wood shavings and soybeans; H - hay; H+U - hay and urea; WS - wheat straw; OS - oat straw.

4.2 COMPOST CONVECTIVE AIR FLOW

Because of an incomplete set of air flow data for the wood shavings amended with soybeans and oat straw, only the results for the wheat straw, wood and hay trials are presented and discussed.

The airflow resistance properties of the compost are characterized by the regression equations presented in Table 4.2. The power regression equation is preferred over the log regression for describing the airflow through the compost mass because of a better correlation factor. When characterizing the compost, the initial airflow resistance was found to be lower than the final as was seen for the hay compost (Figure 4.2). The Figures for wood and straw compost are presented in Appendix B.

Table 4.2. Correlation of the Air Flow Properties for the Compost

Bulking Agent		Regression Equation		
		Log	Power	Porosity
Wood	Initial	$Q = 2.09e^{0.463P}$ $R^2 = 0.477$	$Q = 4.77P^{0.503}$ $R^2 = 0.821$	62
	Final	$Q = 2.32e^{0.398P}$ $R^2 = 0.451$	$Q = 3.98P^{0.398}$ $R^2 = 0.828$	58
Hay	Initial	$Q = 2.708e^{0.483P}$ $R^2 = 0.696$	$Q = 5.73P^{0.499}$ $R^2 = 0.935$	77
	Final	$Q = 3.11e^{0.329P}$ $R^2 = 0.48$	$Q = 2.41P^{0.787}$ $R^2 = 0.911$	68
Straw	Initial	$Q = 2.22e^{0.463P}$ $R^2 = 0.477$	$Q = 5.06P^{0.422}$ $R^2 = 0.90$	80
	Final	$Q = 2.897e^{0.253P}$ $R^2 = 0.496$	$Q = 4.11P^{0.301}$ $R^2 = 0.922$	76

Note : Q denotes air flow, (g/s).
P denotes pressure change, (mm).

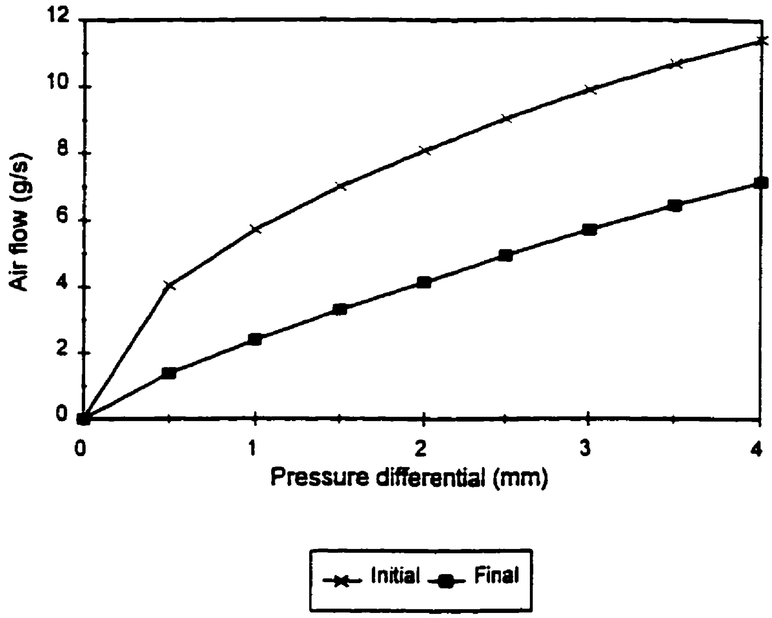


Figure 4.2. Air flow characteristics of the hay compost.

The convective air flows through the composting mass are presented in Table 4.3. The polynomial regression equation is preferred over the power regression for describing the convective air flow because of a better correlation factor.

The convective air flow of the compost varied significantly with the dry matter (d.m.) content and with the bulking agent used. The 32% d.m. humidity produced higher convective air flows than the 40 or 28% d.m.. The wood shavings produced significantly higher convective air flow than the hay or straw compost (Figure 4.3A,B,C). Since the wood shavings were more difficult to degrade, they retained their structure and were not as susceptible to compaction. This resulted in more air channels for freer movement of air.

Table 4.3. Correlation of the Convective Air Flow for the Composts

Bulking agent	D.M.	Regression Equation	
	%	Power	Polynomial
Shavings	40	$Q = 0.78\ T^{0.71}$ $R^2 = 0.78$	$Q = -0.0003T^3+0.0294T^2-0.747T+12.5$ $R^2 = 0.81$
	32	$Q = 0.83\ T^{0.70}$ $R^2 = 0.64$	$Q = -0.0017T^3+0.1693T^2-5.261T+60.39$ $R^2 = 0.72$
	28	$Q = 0.42\ T^{0.87}$ $R^2 = 0.89$	$Q = -0.0005T^3+0.0517T^2-1.404T+17.80$ $R^2 = 0.93$
Hay	40	$Q = 1.17\ T^{0.55}$ $R^2 = 0.56$	$Q = -0.0002T^3+0.0019T^2-0.0335T+3.762$ $R^2 = 0.74$
	32	$Q = 0.92\ T^{0.63}$ $R^2 = 0.61$	$Q = -0.0005T^3+0.0484T^2-1.309T+14.99$ $R^2 = 0.85$
	28	$Q = 1.35\ T^{0.48}$ $R^2 = 0.61$	$Q = -0.0005T^3+0.0361T^2-0.839T-0.5288$ $R^2 = 0.76$
Straw	40	$Q = 1.58\ T^{0.42}$ $R^2 = 0.51$	$Q = 0.0013T^2-0.1504T+2.423$ $R^2 = 0.39$
	32	$Q = 2.54\ T^{0.29}$ $R^2 = 0.32$	$Q = 0.0010T^3-0.0714T^2+1.5172T-2.937$ $R^2 = 0.52$
	28	$Q = 2.46\ T^{0.28}$ $R^2 = 0.43$	$Q = 0.0003T^3-0.0256T^2+0.656T+0.6641$ $R^2 = 0.39$

Note : T denotes temperature, (C).
Q denotes air flow, (g/s).

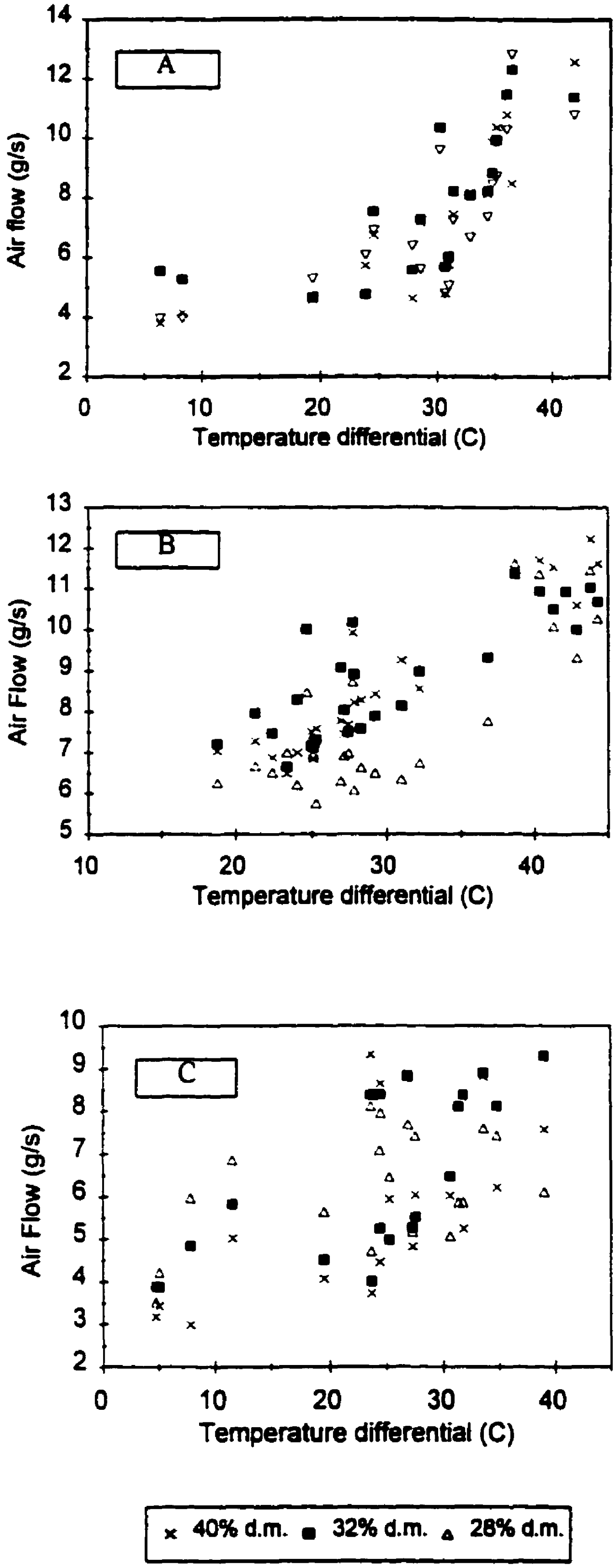


Figure 4.3. Convective air flow for: A) hay compost; B) wood compost; C) straw compost

The convective air flow evolution was correlated with time (Table 4.4). Figure 4.4A,B,C represents the convective air flow evolution for the composts with time. For all treatments the convective air flow of the compost had a higher correlation with time than with the temperature differential between the compost and the ambient air. This probably results from the fact that microbial activity and thus, heat generation, changes more with time than with compost temperature. Convective aeration rate of compost is a function of heat generation and loss with ventilation which is more than a simple relation with time or temperature. This requires further thermodynamic analysis which is beyond the scope of this project.

Table 4.4. Correlation of the convective air flow properties for the compost with time.

Bulking agent	d.m. (%)	Polynomial Regression equation	
Shavings	40	$Q=0.0024t^2-0.3367t+12.5$	$R^2=0.733$
	32	$Q=-0.0028t^2-0.19t+11.581$	$R^2=0.885$
	28	$Q=0.0158t^2-0.6235t+12.612$	$R^2=0.624$
Hay	40	$Q=-0.0076t^2-0.3713t+11.517$	$R^2=0.629$
	32	$Q=-0.0043t^2-0.4041t+11.919$	$R^2=0.641$
	28	$Q=-0.0045t^2-0.3879t+11.171$	$R^2=0.6012$
Straw	40	$Q=-0.0039t^2-0.349t+9.6358$	$R^2=0.741$
	32	$Q=-0.01t^2-0.191t+9.3307$	$R^2=0.683$
	28	$Q=-0.0233t^2+0.2217t+6.6393$	$R^2=0.543$

Note : t denotes temperature (C).
Q denotes air flow (g/s).

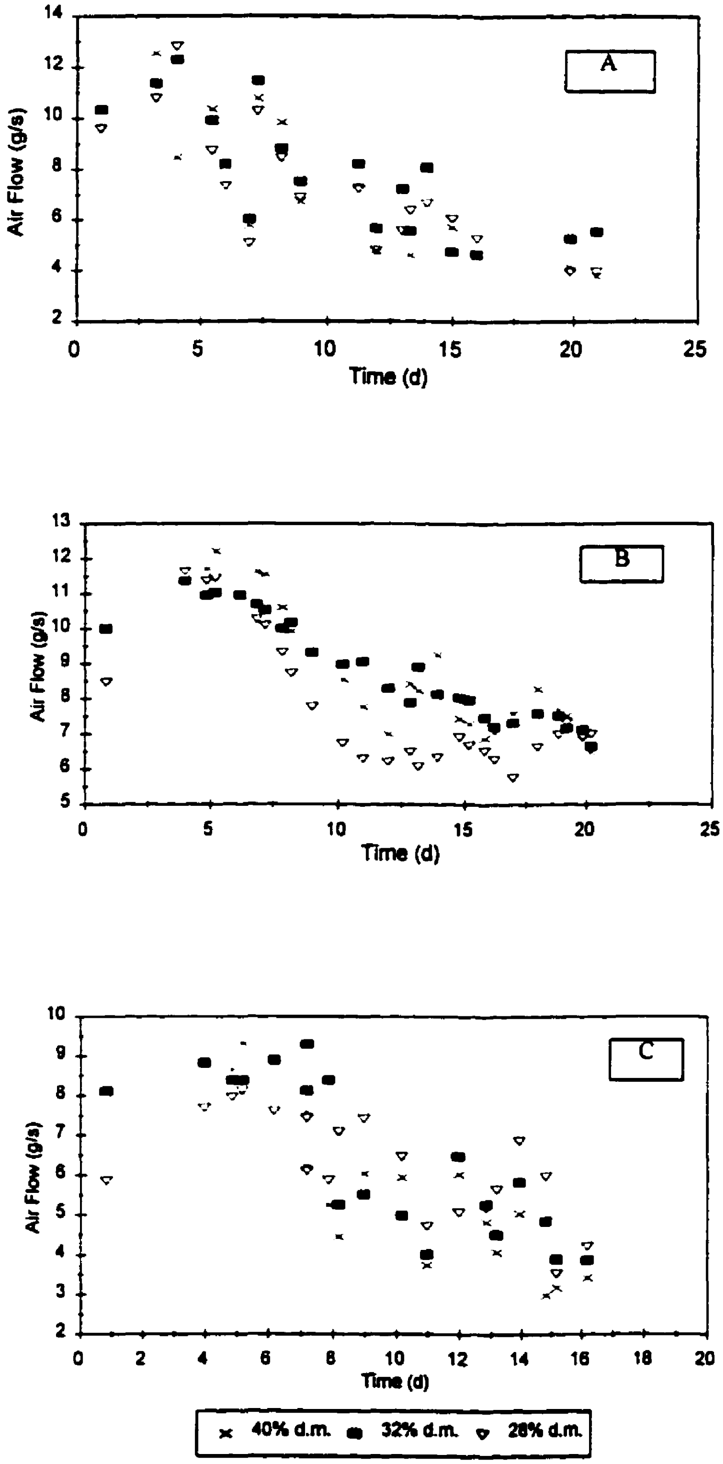


Figure 4.4. Convective air flow versus time for: A) hay compost; B) wood compost; C) straw compost.

4.3 NITROGEN LOSSES

The nitrogen losses due to volatilization are presented in Table 4.4.

Table 4.4. Nitrogen losses* by volatilization for the different materials for two levels of aeration and three levels of dry matter (28%, 32%,40%).

Dry matter	Aeration	N losses, %					
		C source					
%		SS	S	H	H+U	WS	OS
28	Active	56.8 (0.57)	72.65 (3.18)	48.45 (32.58)	22.80 (0.8)	53.28 (19.13)	41.35 (12.37)
	Passive	53.05 (6.01)	74.4 (6.93)	69.5 (4.8)	27.79 (3.47)	67.96 (5.42)	43.1 (2.26)
32	Active	56.35 (1.06)	61.0 (6.22)	52.6 (14.67)	22.82 (4.97)	62.5 (0.28)	37.05 (0.35)
	Passive	45.7 (9.19)	67.25 (1.77)	35.94 (35.5)	20.6 (3.88)	46.77 (18.24)	44.45 (0.92)
40	Active	58.05 (3.32	64.7 (4.53)	54.56 (14.62)	16.56 (2.97)	75.05 (2.76)	28.65 (11.38)
	Passive	51.57 (1.94)	71.15 (6.01)	59.54 (5.03)	24.0 (7.35)	25.6 (32.07)	53.4 (4.67)
	Average	53.58[c]	68.53[d]	53.43[c]	22.4[a]	55.19[c]	41.33[b]

Note : SS - wood shavings and soybeans; S - wood shavings; H - hay; H+U - hay amended with urea; WS - wheat straw; OS - oat straw.
: means with the same letter are significantly different at $P<0.05$ (Duncan's Multiple Range Test).
: * nitrogen losses, represent the total losses for the manure/bulking agent mixture

The N losses were lowest at 22.4% on the average, for hay amended with urea, followed by 41.3%, 53.4%, 53.6% and 55% for oat straw, hay, wood shaving amended with soybeans and wheat straw. A 68.5% N loss, the largest, was reported for the wood shavings compost.

The C source had a marked effect on nitrogen losses by volatilization. The N losses for hay amended with urea were significantly different than all other treatments ($P<0.05$). Ammonia volatilization was obvious during the composting of the hay amended with urea. Within 2 hours of filling, the experimental composters had a strong smell of ammonia indicating that the urea was being degraded into ammonia which in turn was being volatilized. Despite this, the N mass balance for the hay amended with urea showed that more N was conserved than in any other treatment and 41.9% more than the other hay compost. A possible explanation for the variation in N losses between the two hay composts might be attributed to the compost pH. At the onset of the composting process the pH begins to drop due to the activity of acid-forming bacteria which break down complex carbonaceous material to organic acid intermediates. Typically, the acids serve as substrates for succeeding microbial populations but in the case of the hay amended with urea compost, it is possible that the organic acids formed lowered the pH to such an extent as to minimize the amount of ammonium ion released by volatilization and thus conserved more N. Excluding the N loss for the hay amended with urea, the oat straw and wood shavings were significantly different than the hay, wheat straw and wood shavings in conserving N ($P<0.05$, Table 4.5). The N losses were the lowest for the oat straw due to the amount of readily available C. This is further supported by the amount of C that was lost during the composting period (Table 4.6). The oat straw compost loss on average 51.4% of its C content, meaning that the carbon was made more readily available for the microorganisms to utilize. The N losses were lower with the oat straw than with the of wheat because the wheat straw was very coarse and this had an effect on the degradation ability of the microorganisms because large particles have a smaller surface area for the microorganisms to attack. The fact that wood contains high levels of difficult to degrade lignin, accounts for the high N losses and low C losses reported, 68.5% and 13.5% respectively.

Wood shavings amended with soybeans and hay had similar N losses (53.6% and 53.4%) but different C losses, 25.4% and 37.45% respectively. The lower N loss of the hay can be attributed to the higher initial C/N ratio of 26 as opposed to 18. The N losses for all the C sources, except the hay, varied inversely to the associated C losses.

The permissible moisture content and oxygen availability are closely interrelated. If the moisture content of the compost is so high as to occupy most of the pore spaces and as to collapse the structure from its weight, anaerobic conditions develop within the mass. As a result, more N can be lost during this time until sufficient aeration is supplied to the organisms enabling the compost to return to aerobic conditions. Despite this, from the results, the moisture level did not have a significant effect on the N loss through volatilization.

Passive aeration tended to have a slightly lower N loss than the active aeration, 53.96% and 54.87% for passive and active respectively. However, the difference was not significant. Therefore, the aeration technique had no significant effect on N losses by volatilization.

Interactions between aeration and moisture level, aeration and bulking agent, and moisture level and bulking agent were also investigated, however none were found to be significant at $P<0.05$ (Appendix C). A significant interaction, for example, between bulking agent and moisture level will have meant that the effect of the bulking agent on nitrogen is different depending on what bulking agent is used. However it is possible that a true difference, if any, was not detected since we had a limited sample size (Type II error).

4.4 CARBON LOSSES

The carbon losses are represented in Table 4.6.

Table 4.6. Carbon losses* for the different materials for two levels of aeration and three levels of dry matter (28%, 32%, 40%).

Dry matter	Aeration	C losses, %					
		C source					
%		SS	S	H	H+U	WS	OS
28	Active	28.64 (1.79)	12.03 (4.38)	51.17 (8.85)	15.83 (0.46)	36.86 (2.3)	56.12 (3.05)
	Passive	29.24 (7.54)	23.79 (9.92)	52.31 (2.6)	14.08 (1.75)	40.04 (8.86)	58.89 (2.02)
32	Active	21.66 (0.53)	9.5 (1.09)	40.62 (26.19)	13.51 (1.58)	44.35 (1.91)	48.16 (5.61)
	Passive	26.66 (2.72)	8.11 (0.11)	20.12 (20.26)	10.69 (3.47)	32.53 (5.22)	56.0 (1.51)
40	Active	23.5 (4.99)	14.09 (1.69)	25.34 (11.17)	10.13 (1.34)	24.32 (0.86)	45.09 (8.17)
	Passive	22.71 (14.62)	13.71 (5.48)	35.12 (1.57)	8.89 (2.69)	37.07 (11.46)	43.95 (9.11)
	Average	25.4^{c}	13.5^{d}	37.45^{b}	12.19^{d}	35.86^{b}	51.4^{a}

Note : SS - wood shavings and soybeans; S - wood shavings; H - hay; H+U - hay and urea; WS - wheat straw; OS - oat straw.
: means with different letters are significantly different at $P<0.05$ (Duncan's Multiple Range Test).
: * carbon losses, represent the total losses for the manure/bulking agent mixture

The oat straw had the highest C loss of 51.37%, followed by hay and wheat straw at 37.45% and 35.86%, followed by wood shavings with and without soybeans at losses of 25.4% and 13.54% respectively, and 12.19% for hay amended with urea. An ANOVA test was performed at the $P<0.05$ level and found a significant difference between the different bulking agents (Table 4.6).

Because of the high available C content and the fine particle size of the oat straw, it easily degraded, as was reported earlier. On the contrary, wood shavings, with its high lignin content had a much lower amount of available C. The C loss of hay amended with urea was the lowest of all the treatments and can be attributed to the organic acid formation which lowered the pH to less than ideal composting conditions.

The effect of moisture was tested on C loss. The highest C loss was 38.91% for the 28% d.m. level, followed by the 32% and 40% with losses of 30.77% and 28.49% respectively. The only level that was significant was the 28% d.m. level ($P<0.05$, Appendix C). The higher loss of C obtained at higher moisture levels indicated an environment that is better suited to C degradation.

5 SUMMARY AND CONCLUSIONS

5.1 SUMMARY

A laboratory scale experiment was undertaken to investigate two aeration techniques; passive and active, on temperature, convective airflow, and N and C conservation with different C sources at three levels of humidity for each aeration technique. The swine slurry was mixed with different C sources such as hay, straw (oat and wheat), wood shavings with and without soybeans at 3 levels of humidity. All the trials were conducted in duplicate. The airflow properties of the composts were characterized initially and prior to the emptying of the composters by measuring the airflow resistance through the compost mass. To study the convective airflow rate of the composts, the convective air flow was correlated with time, and with the temperature differential between the ambient and compost temperature. A complete N and C balance was performed in order to study the N and C losses of aeration techniques both in active and passive modes.

5.2 CONCLUSIONS

Convective aeration was shown to be a suitable technique for the composting of swine slurry with different sources of C. It was shown to provide sufficient convective aeration capable of raising and maintaining the temperature to levels high enough to sterilize the compost material. The results presented suggest that the peak temperature for the passive aeration technique was on average 4°C less than the active one. Despite this, the passive aeration technique remained in a more favourable temperature range for the microorganisms and never rose above 70°C.

The airflow convective resistance for the composts increased over the 21 days of composting (14 days for one wood trial). The convective airflow was correlated with time and the temperature differential between the ambient and compost temperature and for all treatments demonstrated a higher correlation with time than with temperature differential. Despite this, a further thermodynamic analysis is required to further understand the interactions between heat flux with ventilation.

The aeration technique and the moisture level used did not significantly affect the N losses ($P<0.05$). The N losses were significantly affected by the C source used ($P<0.05$). The mean values of N loss were 22.4, 41.3, 53.4, 53.6, 55.2, and 68.5% for hay amended with urea, oat straw, hay, wood shavings amended with soybeans, wheat straw, and wood shavings respectively.

The C losses were not affected by the aeration technique and were only significant at the 28% d.m. level ($P<0.05$). The mean values of C loss were 51.4, 37.4, 35.8, 25.4, 13.5, 12.2% for oat straw, hay, wheat straw, wood shavings with and without soybeans and hay amended with urea respectively. Considering the N and C losses encountered, a careful consideration would be required in the selection of C source when planning a compost strategy.

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APPENDICES

APPENDIX A

Temperature regimes for all treatments

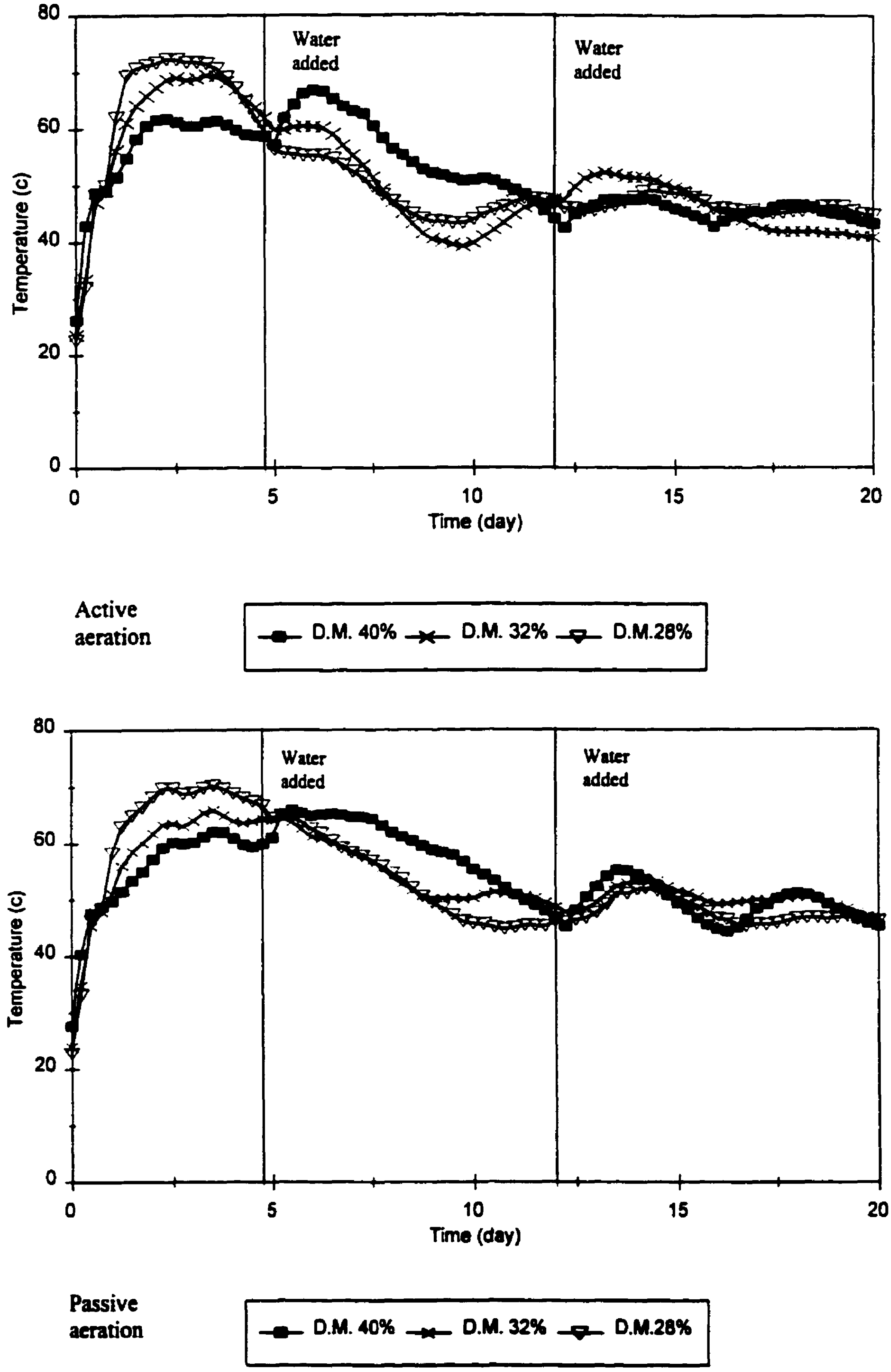


Figure A.1. Temperature regime for wood shavings amended with soybeans.

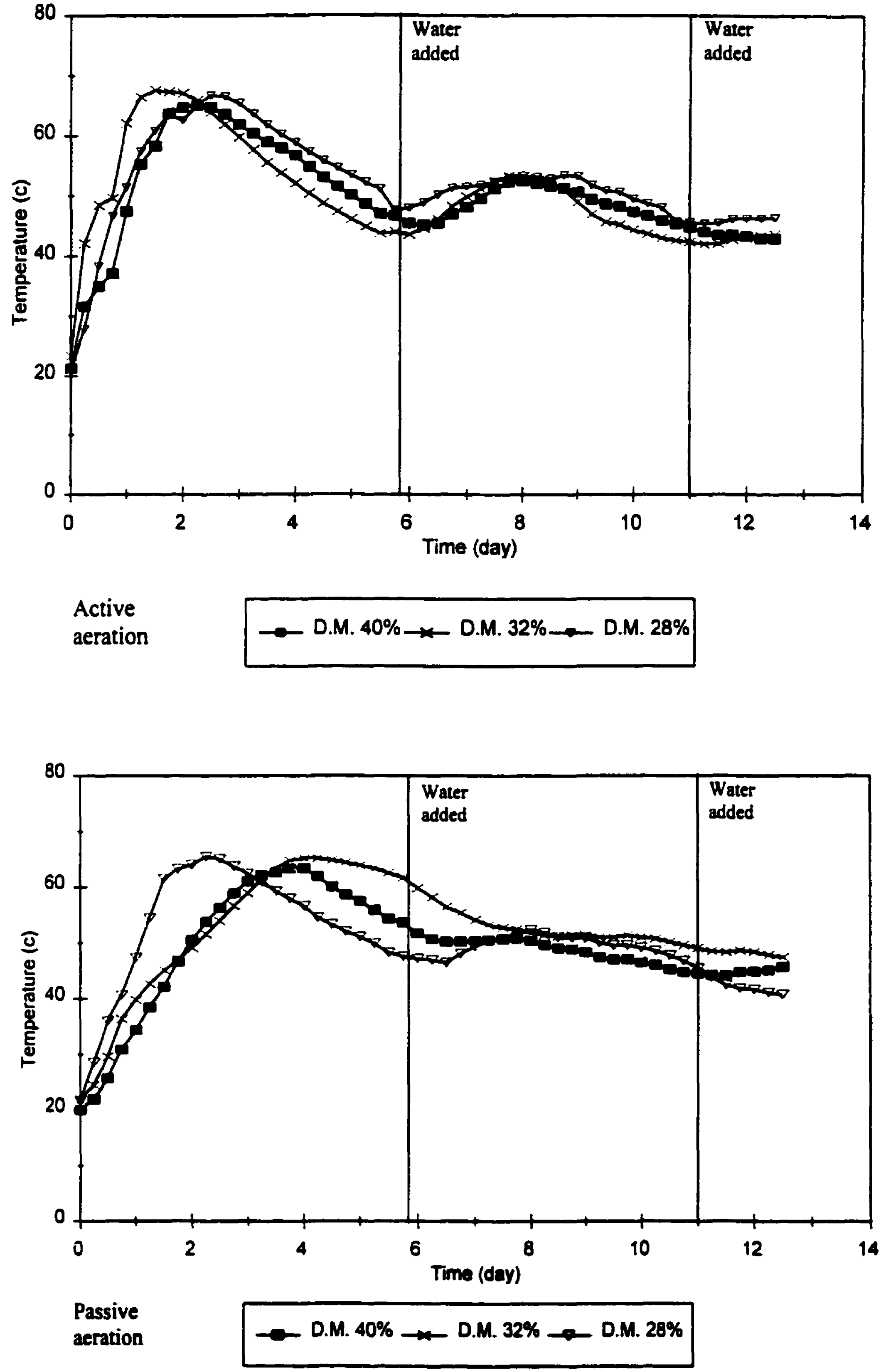
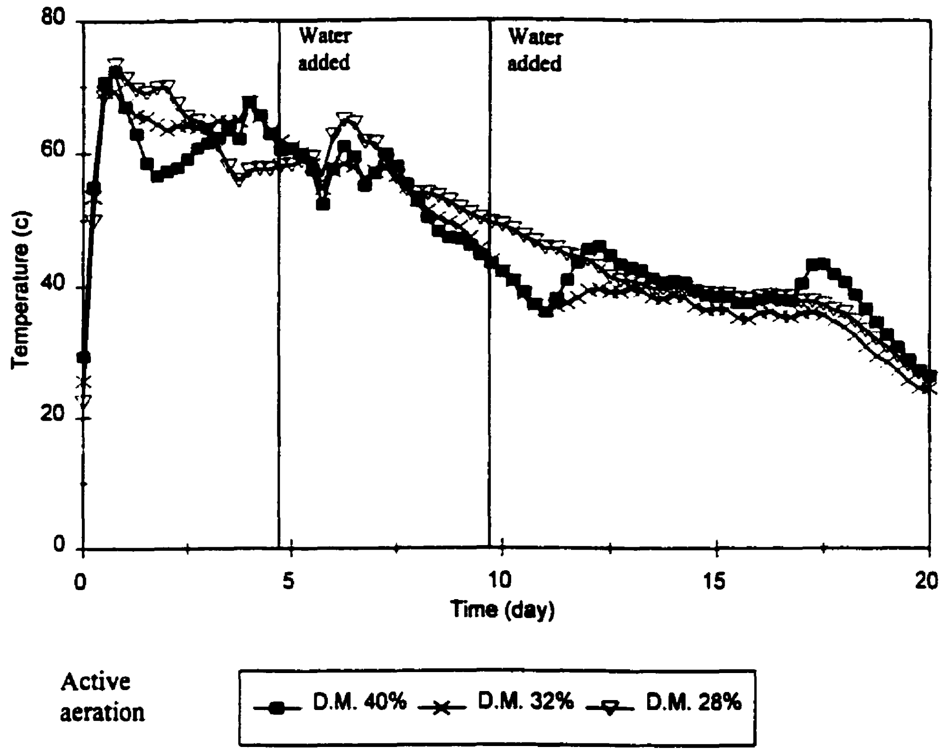


Figure A.2. Temperature regime for wood shavings.



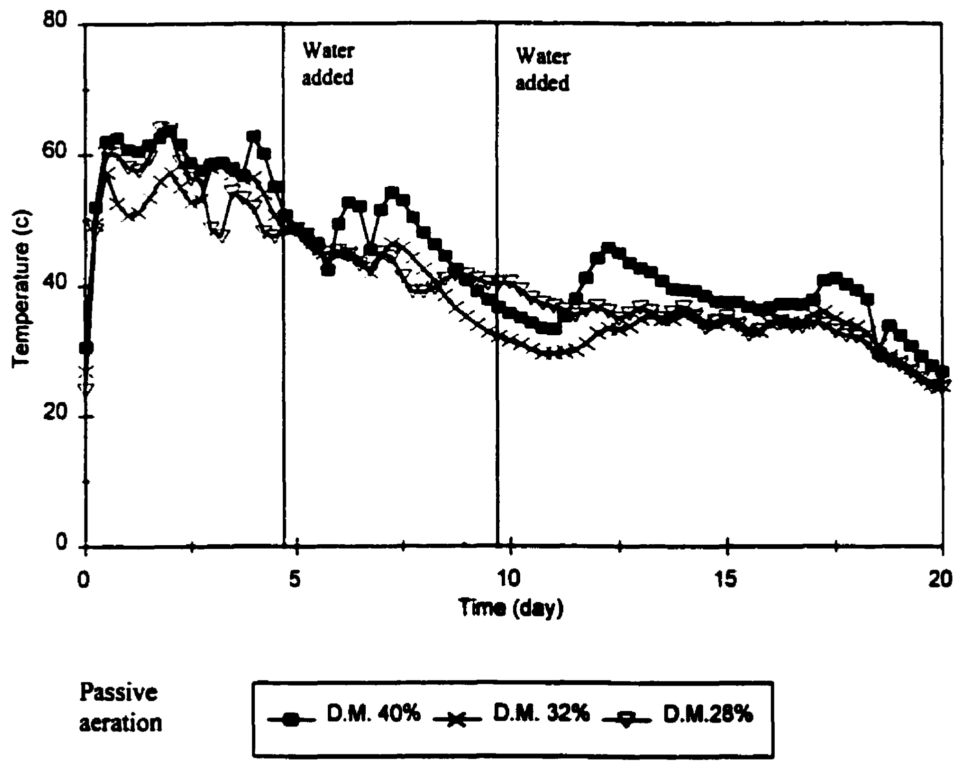
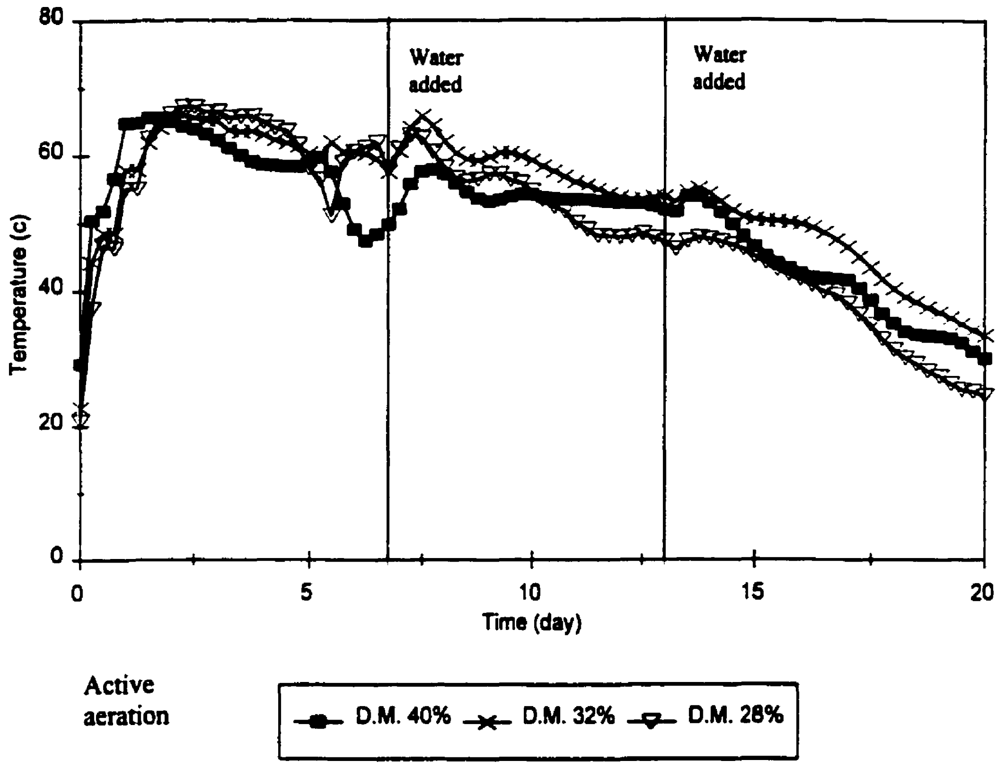


Figure A.3. Temperature regime for Hay amended with urea.



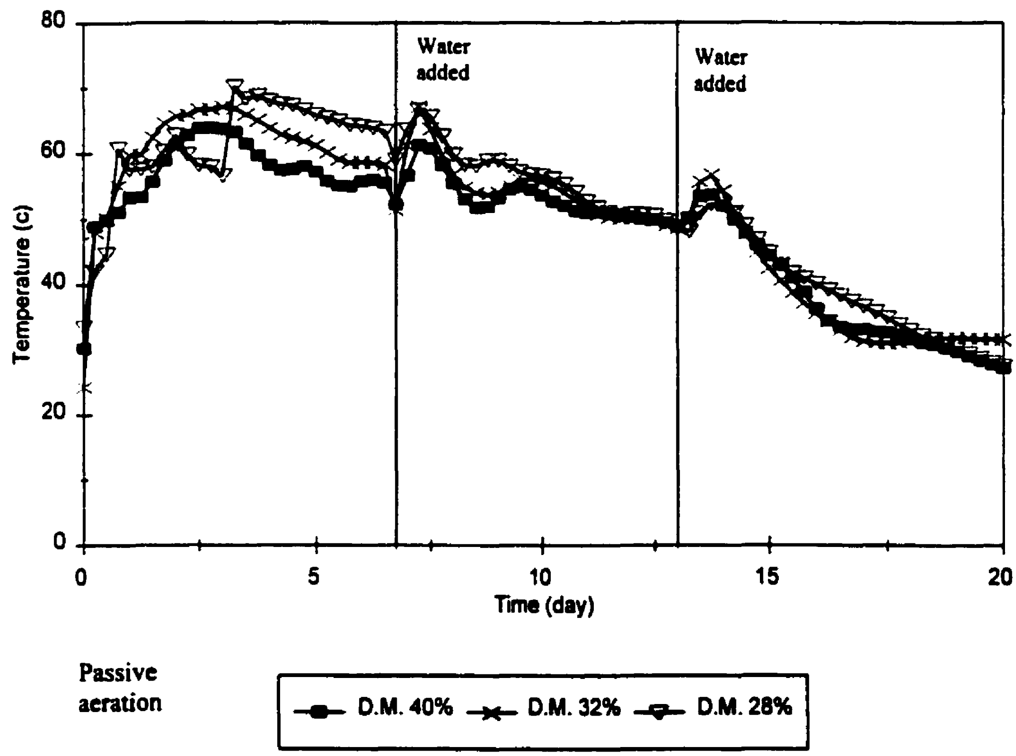


Figure A.4. Temperature regime for hay.

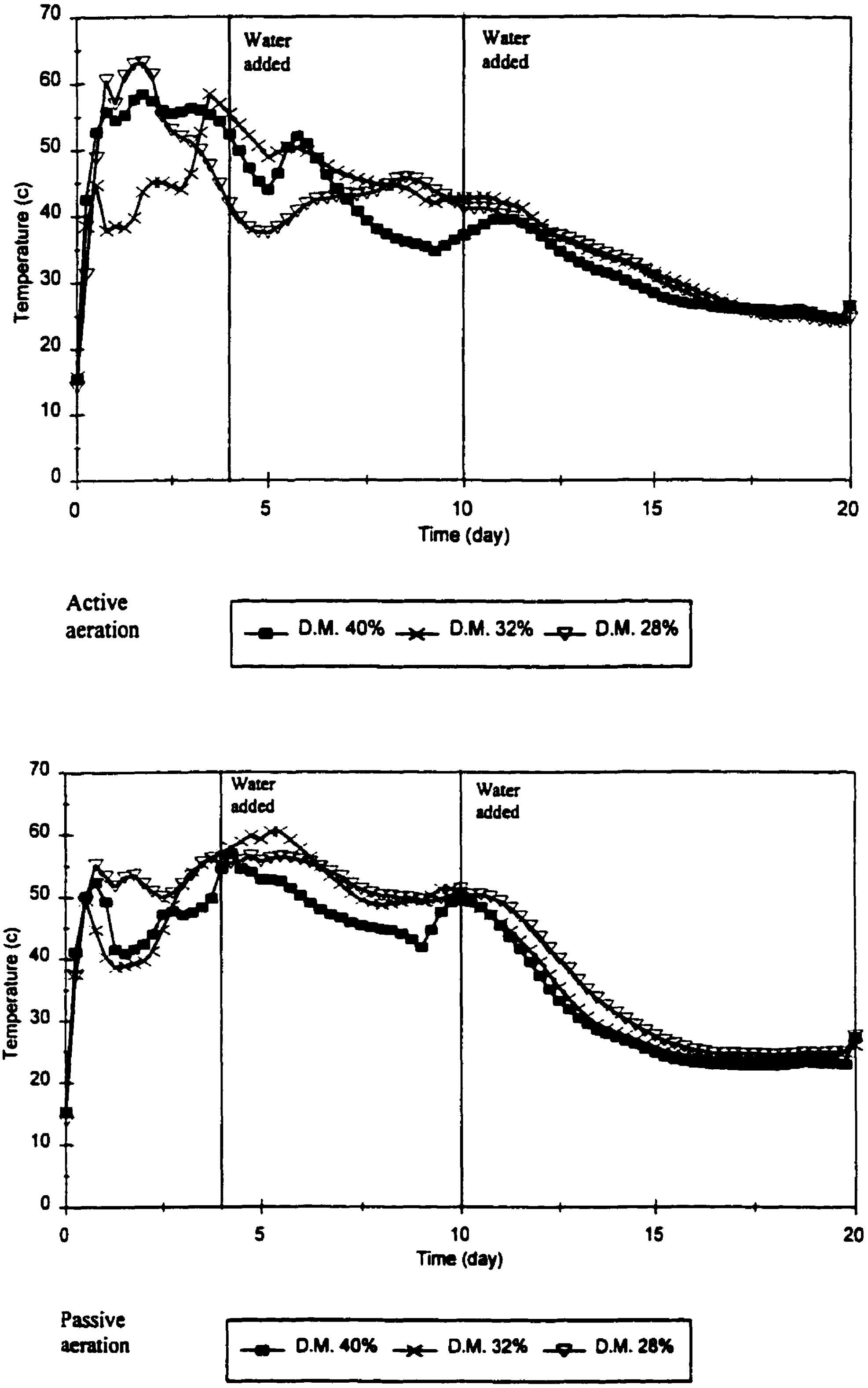
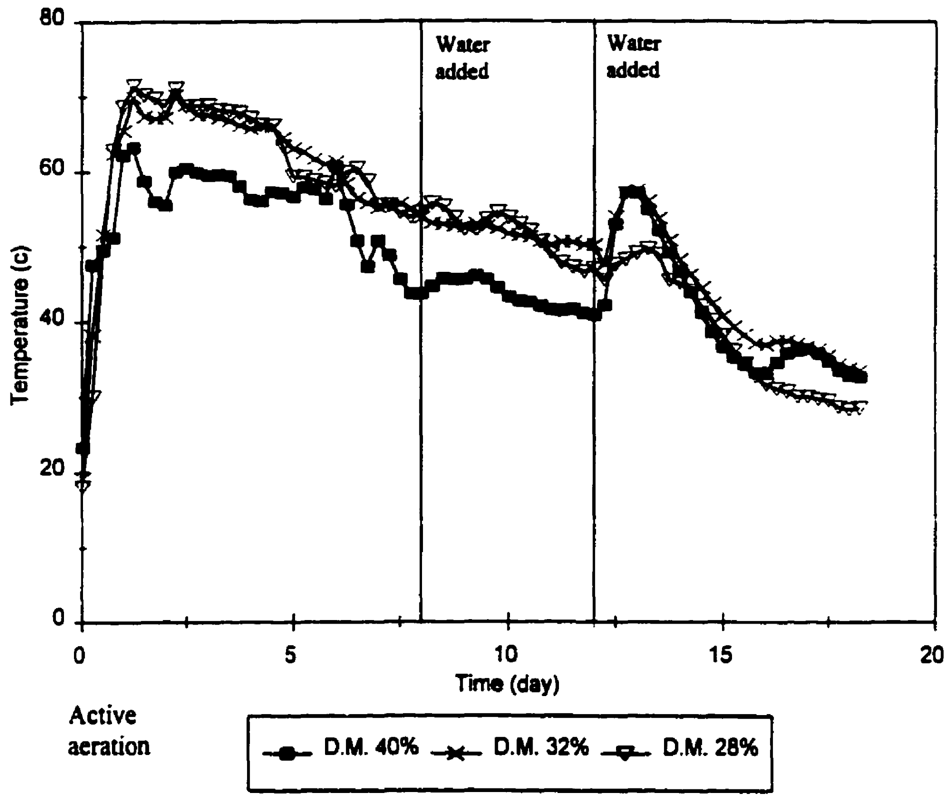


Figure A.5. Temperature regime for wheat straw.



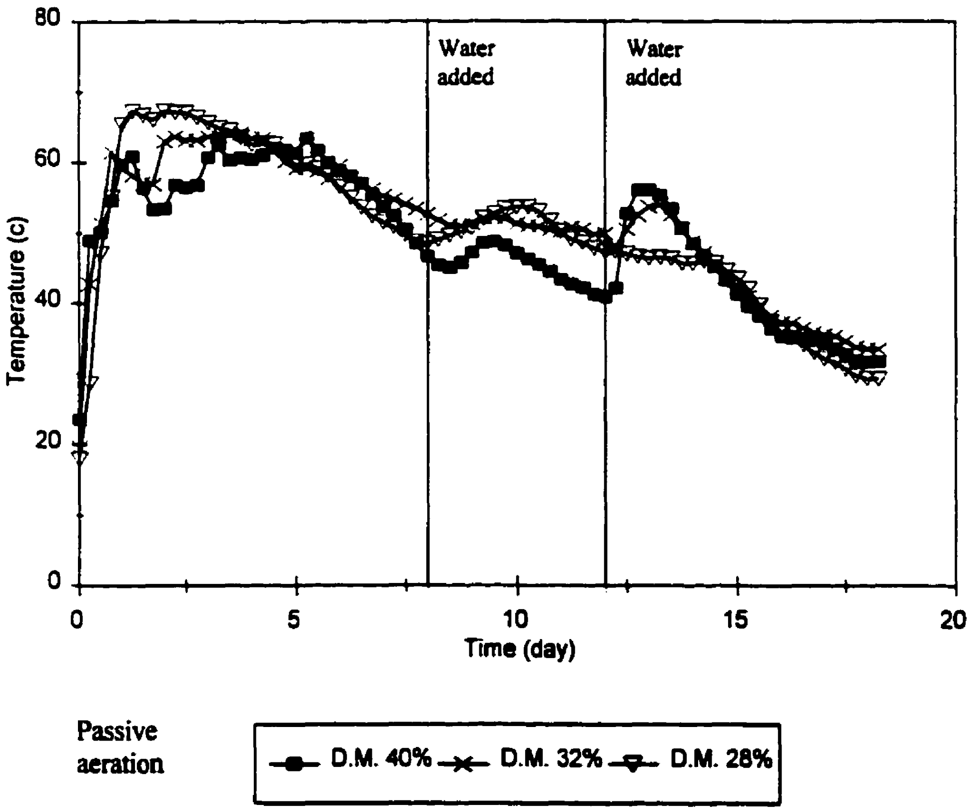


Figure A.6. Temperature regime for oat straw.

APPENDIX B

Convective air flow figures for all treatments.

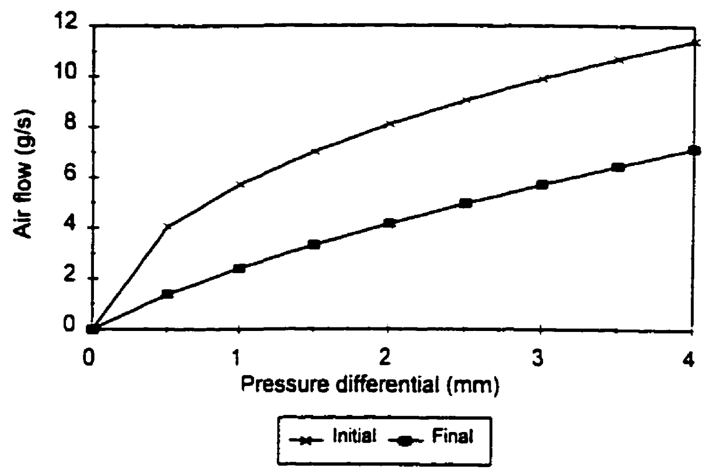


Figure B.1. Air flow properties for hay with pressure change.

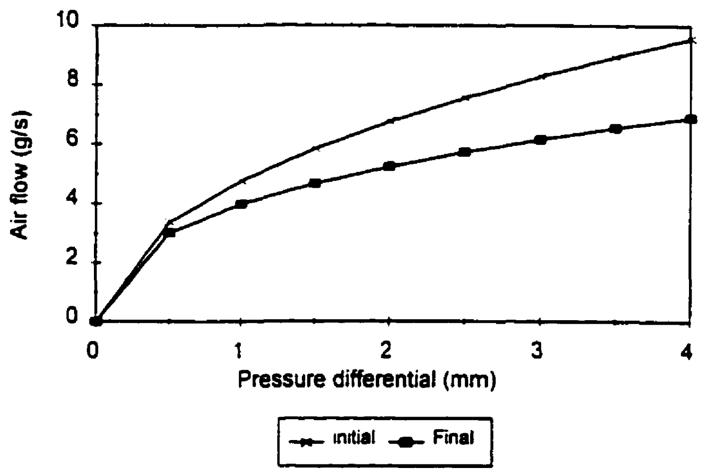


Figure B.2. Air flow properties for wood with pressure change.

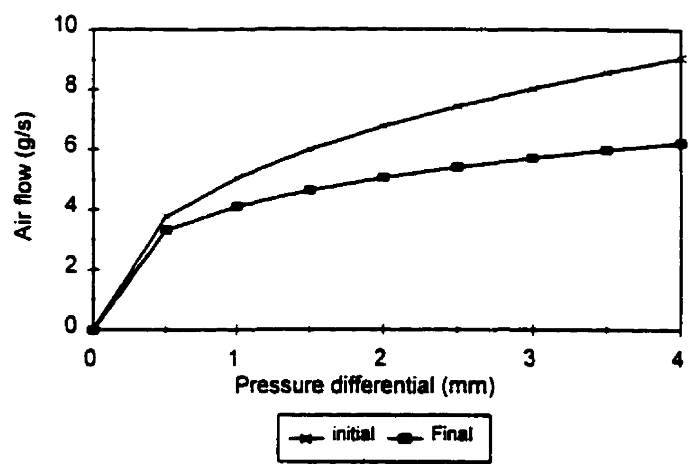


Figure B.3. Air flow properties for straw with pressure change.

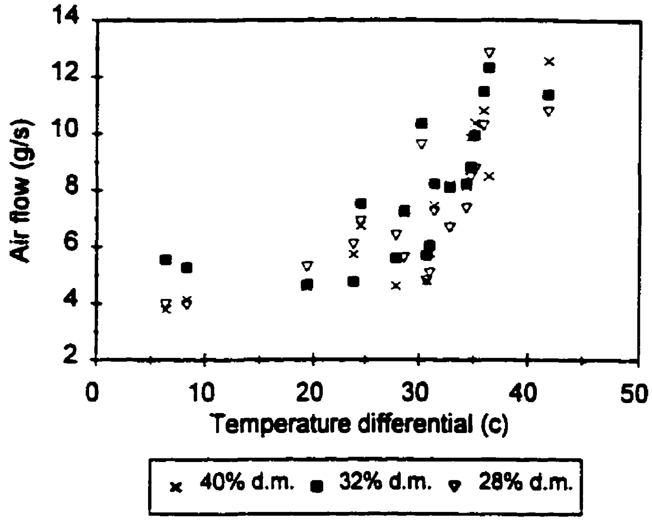


Figure B.4. Convective Air Flow for Hay Compost

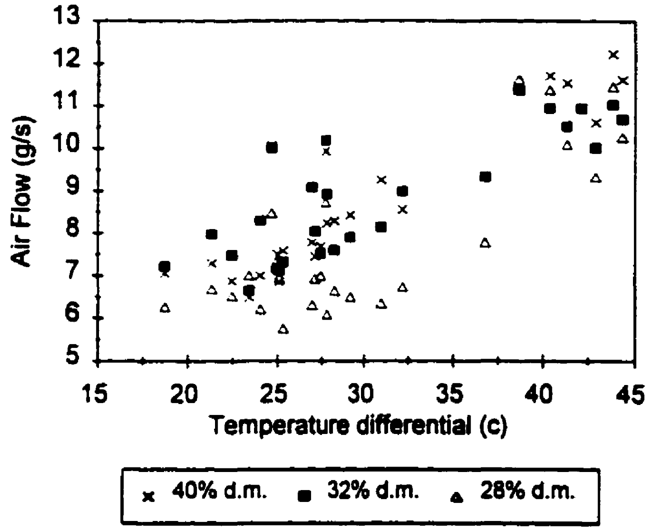


Figure B.5. Convective Air Flow for Wood Compost.

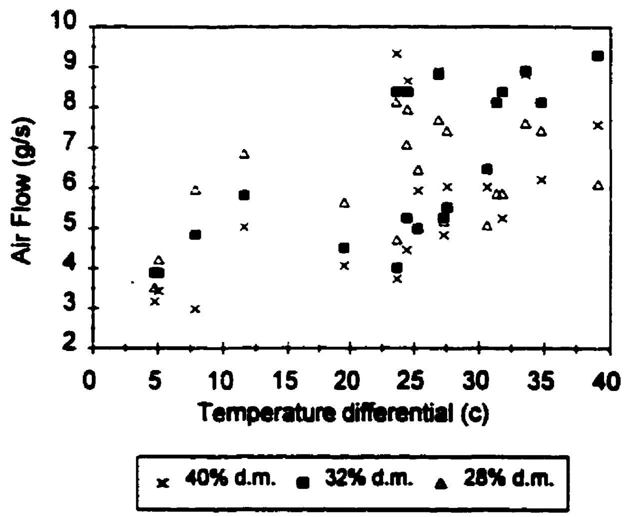


Figure B.6. Convective Air Flow for Straw Compost.

APPENDIX C

ANOVA output of N and C losses for all treatments.

Table C.1 SAS OUTPUT FOR N LOSSES

The SAS System
Analysis of Variance Procedure

Dependent Variable: NITRO

source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	35	20364.5367277	581.84390651	1.98	0.0224
Error	36	10578.4411800	293.84558833		
Corrected Total	71	30942.9779077			

R -Square	C.V	Root MSE	NITRO Mean
0.658131	34.9243	17.1419248	49.08305556

Source	DF	Anova SS	Mean Square	F Value	Pr > F
AIR	1	0.6612500	0.66125	0.00	0.9624
MOIST	2	517.80777	258.90388	0.88	0.4231
AGENT	5	14700.600	2940.12009	10.01	0.0001
AIR*MOIST	2	464.09693	232.048466	0.79	0.4617
AIR*AGENT	5	1511.4313	302.286276	1.03	0.9977
MOIST*AGENT	10	483.66215	48.3662155	0.16	0.9977
AIR*MOIST*AGENT	10	2686.2767	268.627673	0.91	0.5310

Table C.2 SAS OUTPUT FOR C LOSSES

Dependent Variable: CARBO

source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	35	16942.9253500	484.0835814	3.89	0.0001
Error	36	4474.41391000	124.2892752		
Corrected Total	71	21417.3392600			

R -Square	C.V	Root MSE	CARBO Mean
0.791085	38.04844	11.1485100	29.30083333

Source	DF	Anova SS	Mean Square	F Value	Pr>F
AIR	1	9.3744500	9.3744500	0.08	0.7852
MOIST	2	1200.6397	600.31985	4.83	0.0139
AGENT	5	13834.455	2766.8910	22.26	0.0001
AIR*MOIST	2	464.09693	232.048466	0.79	0.4617
AIR*AGENT	5	108.97278	21.7945566	0.18	0.9701
MOIST*AGENT	10	828.89650	82.8896500	0.67	0.7468
AIR*MOIST*AGENT	10	764.17023	76.4170233	0.61	0.7910