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Animal Solid Waste Management through Composting Techniques. Closed Semi-Continuous Composters as a New Approach for *in-Situ* Carcasses Disposal

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ABSTRACT

A major issue facing modern society is waste management, and the best method to manage agricultural and animal wastes for agricultural use (soil conditioning and agricultural production) is by recycling through composting. From a scientific point of view, the composting process is started and managed under controlled environmental conditions rather than accepting the results of natural, uncontrolled decomposition. The design of successful composting systems requires an understanding of biological, physical and chemical processes such as carbon and nitrogen uptake and heat production and transfer. When managed properly, composting improves the handling characteristics of any organic residue by reducing its moisture content, volume and weight. The process increases the value of raw wastes by destroying pathogens and weed seeds and creating a media for the production and proliferation of beneficial organisms. The study of waste production and management lends itself to interdisciplinary study and farm composting provides an opportunity for real-world problem solving with cooperative learning groups. This work is organised in three parts. In the first one, we review developments on the composting as an animal wastes management strategy through the analysis of objectives and conditions for composting, facilities and alternatives, composting ingredients and qualities of compost. The second part, devoted to show the composting as a suitable method for carcasses disposal, contains the formulation and general principles of the method and the specific procedures, with their advantages and disadvantages. At the end, a new closed semi-continuous composter designed for the *in-situ* composting of animal mortalities, developed at the University of Valladolid, is presented.

Keywords: animal mortalities, farm composting, recycling, soil conditioning, waste reuse

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COMPOSTING OF ANIMAL SOLID WASTE: A BRIEF REVIEW

Introduction

Animal wastes which are taken out from the farm are classified into three types: solid, slurry and waste water. Solid wastes are treated by drying or composting. Dried wastes are used not only as fertilizer but also as fuel for combustion to obtain energy. Slurry is treated by liquid composting or methane fermentation (Guimarâes 2002). Waste water is treated by the activated sludge process to obtain clean water or simplified aeration method to produce liquid fertilizer. The most appropriate techniques of animal waste manage-

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ment should involve proper treatment prior to the application to land.

Raw wastes with a high water content are dirty, offensive, putrescible and troublesome in handling. Reduction of water content is necessary for convenience in handling of animal wastes. Drying in a greenhouse with solar heating is superior to that with oil heating, because expenses can be reduced and energy saved. The area of greenhouse required for construction can be easily estimated based on the evaporation power and the amount and water content of animal wastes to be dried.

The objectives in composting are to stabilize the biodegradable organic matter in raw wastes, to reduce offensive odours, to kill weed seeds and pathogenic organisms, and finally, to produce a uniform organic fertilizer suitable for land application (Haug 1993).

Conditions for composting

Controlled conditions are important for composting, to distinguish it from other natural biological decomposition processes such as rotting and putrefaction. Composting is the aerobic (oxygen requiring) decomposition of manure organic materials in the thermophilic temperature range of 45–65°C. Nature provides an extensive, native population of microorganisms that are generally attached to all organic wastes. When conditions are right, these microbes grow and multiply by decomposing the material to which they are attached. The composted material is odourless, fine-textured, and low-moisture and can be used for non-agricultural and agricultural purposes with little odour or fly breeding potential. Animal wastes contain a sufficient amount of nutrients (biodegradable organic matter) for microorganisms and an adequate number of microorganisms to enhance the composting process. However, the water content of raw wastes is too high to supply oxygen to the microorganisms. Moisture control of the raw wastes should range between 45 to 60% (wet basis) by the addition of dry materials such as cereal straw, sawdust, rice hull and dried compost or by pre-drying in greenhouses, and it is necessary to achieve suitable composting (Inbar *et al.* 1988; Campbell *et al.* 1990; Hansen *et al.* 1993). The active degradation of organic matter by the microorganisms under controlled conditions leads to heat generation during composting. The high temperature (higher than 60°C) contributes to the killing of weed seeds and pathogenic organisms, to the evaporation of water and production of sanitary compost for convenience in handling. With occasional turning of the compost pile, the complete composting process requires several weeks.

The rate of composting, like the rate of plant or animal growth, can be affected by a number of factors. Four keys factors are: Nutrient balance, moisture content, temperature and aeration. Nutrient balance is determined primarily by the ratio of carbon to nitrogen in the compost mixture. The microorganisms require carbon and nitrogen for growth since these elements are the main components of carbohydrates and protein. Reduction of the C:N ratio during the composting process is a good indication of digestion of carbon sources by microorganisms and production of CO and heat. If nitrogen is in excess, large amounts of ammonia will be released to the atmosphere. If carbon is in excess, the composting rate will decrease. Addition of carbon source materials to animal solid wastes provides suitable conditions for successful composting. It facilitates proper aeration, speeds the escape of potentially toxic gases like ammonia, reduces the accessibility of composted material to insects and rodents and provides additional energy for microbial (specifically fungal) activities (Haug 1993). The moisture content should ideally be 55% after organic wastes have been mixed. Maintaining the correct moisture level during the thermophilic phase of composting can be difficult in an open-air windrow system due to dry or wet climatic conditions. When the moisture content exceeds 65%, the windrows subside and lose porosity (Kube 2002) thereby becoming anaerobic. Fermentation will set in and odours will be emitted from the material. If the moisture content decreases below 40%, the rate of decomposition decreases because nutrients must be in solution to be utilized by microorganisms. As the microorganisms decompose organic matter, heat is generated and the temperature of the compost rises (Collins 1996).

Decomposition is a dynamic process, accomplished by a succession of microorganisms, each group reaching its peak population when conditions are optimum to support that particular group. When one group of microorganisms dies, another group populates the composting material until the next incremental change in nutrition and temperature occurs. Since the release of heat is directly related to the microbial activity, temperature is a good process indicator. Many authors (Rynk 1992; Haug 1993; Keener *et al.* 2001; Reinikainen *et al.* 2001; Díaz *et al.* 2002) said that the composting con be divided on two different phases: The first one, the active or heating phase, with a great consume of oxygen (aeration needed), thermofilic temperatures, odour potential and rapid reductions in biodegradable solids. In this phase the temperatures of composting materials typically follow a pattern of a rapid increase to 45-60°C which is maintained for several weeks (Gonzalez *et al.* 2005). In the second phase, the maturation phase, a series of slower reactions occur and temperature decreases to 35°C as active temperature composting due to nutrient consumption, and a final levelling off at ambient air temperature. Aeration is no longer a limiting factor of the maturation phase. Additional aeration of the composting material is normally produced passing from the first to the second phase (Barton *et al.* 1990; Carter *et al.* 1996). In the second phase, the temperature pattern is described generally in **Fig. 1**.

During the initial days of composting, readily degrada-

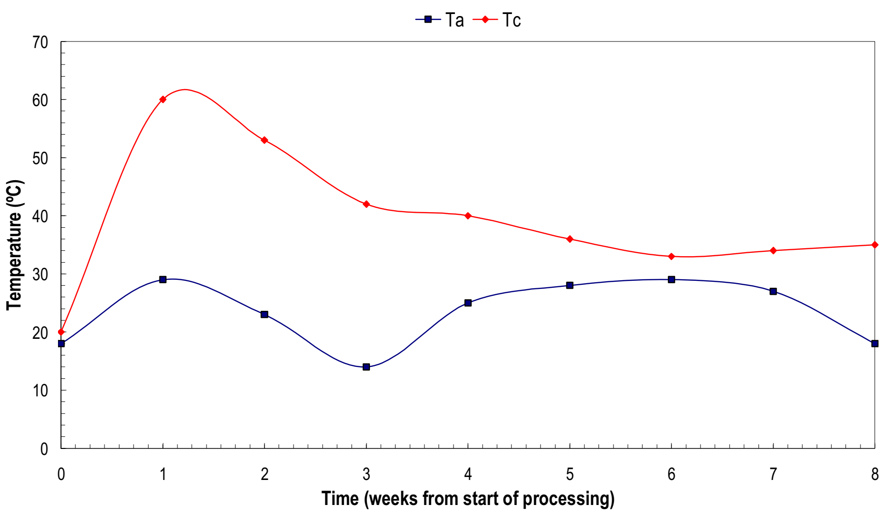

Fig. 1 General time-temperature pattern for composting. Ta, air temperature; Tc, compost temperature.

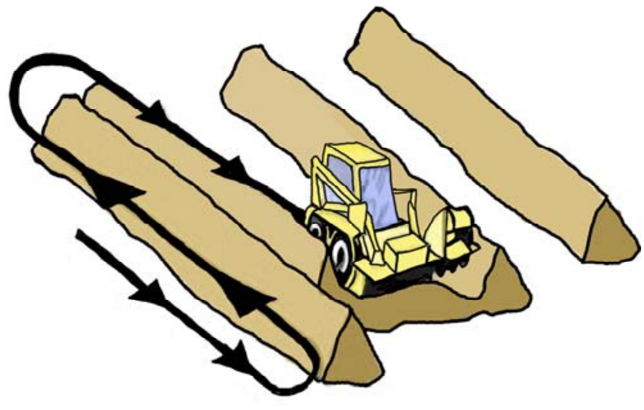

Fig. 2 Open windrows with mechanical turning. (Based on Rynk 1992).

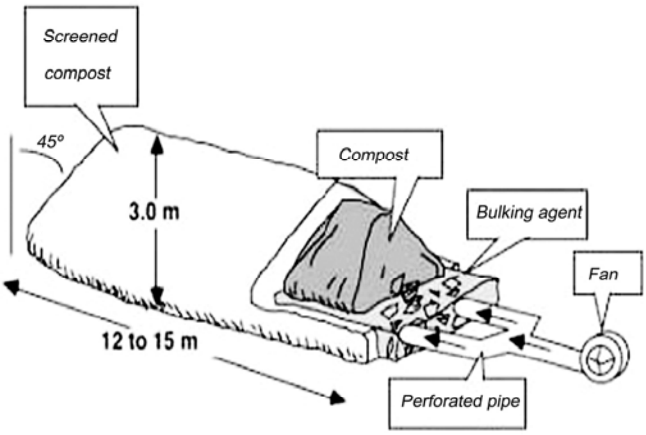

Fig. 3 Active aerated windrow. (Based on Rynk 1992).

ble components of the raw material are rapidly metabolized, therefore the need for oxygen is greatest at the early stages and decreases as the process continues. Without sufficient oxygen, the materials become anaerobic (Hoitink *et al.* 1993). Anaerobic processes are generally slower and less efficient than aerobic processes. Little heat is generated under anaerobic conditions and intermediate compounds such as methane, organic acids, hydrogen sulphide and other odorous compounds are generated. Aeration also removes heat, water vapour and other gases trapped within the composting materials. Livestock manures will compost rapidly under conditions specified in Rynk (2003).

Facilities of composting and composting alternatives

Open-window composting using some form of mechanized turner is used very frequently (**Fig. 2**). Methods commonly used for composting include: passive windrow (also referred to as static pile composting), passively aerated windrow (supplying air at ambient pressure through perforated pipes embedded in the windrow), active aerated windrow (forced air through perforated pipes, **Fig. 3**), composting bin, rotating vessel, stationary drums and vermi-composting (using worms to degrade organic material). Front end loaders, skid steers with buckets, conventional solid manure spreaders, tub grinders or mixing wagons are among the equipment used to mix the compost ingredients and deposit the material in the piles. The method selected depends on the type of livestock, size of the operation, climatic conditions and available capital. Fabric covers have been made commercially available to cover open-air windrows, protecting the material from changing climatic conditions, yet allowing free gas-exchange. Static pile composting is generally not recommended where a rapid composting strategy is required (e.g., where composting space is limited).

Turning the windrows restores porosity to the piles and reduces the particle size increasing the surface area of bulking material. Porosity refers to the spaces between particles in the compost material. These spaces are partially filled with air that can supply oxygen to the organisms and provide a path for air circulation. As the material becomes water saturated, the space available for air decreases, thus slowing the composting process. Compacting the composting material reduces the porosity. Excessive shredding can also impede air circulation by creating smaller particles and pores. Turning fluffs up the material and increases its porosity. Adding coarse materials such as straw or woodchips can increase the overall porosity, although some coarse materials will be slow to decompose. Porosity must be around 35% to facilitate the air penetration inside the pile and to maintain optimum microbial growth (Keener *et al.* 2001). During the turning process, oxygen is introduced into the windrow but it normally is rapidly consumed by microorganisms often within a matter of hours. However, restoring porosity enhances the passive movement of air into the windrow and accelerates decomposition. Excessive turning of the material can accelerate nitrogen loss, water loss and result in cooling of the compost. Generally turning the compost once a week for the first 4 weeks (with initial moisture levels of 70%), then once every 2 weeks for the next 8 weeks, has been found to yield an excellent composted product without the addition of water (Buckley 2001). It is critical to maintain the moisture level in the range of 60% in the initial 4 weeks of composting. If the moisture levels falls below 50% composting activity will slow and eventually cease as the material continues to dry.

Nutrient content of compost ingredients

Manure nutrient contents vary according to species, diet and handling systems for animal wastes. The bulking agent used as a source of carbon or amendment to increase porosity of the mixture varies according to preference and availability. Characteristics of livestock manure and common bulking agents are given in **Tables 1** and **2**.

Depending on the bulking agent used in the mixture, solid manure or separated liquid manures can be composted in 60–120 days using windrow composting and mechanical turning. Chicken manure, broiler litter and turkey manure mixtures frequently require the addition of water to achieve the desired moisture content. Temperatures in these composts have been known to exceed the maximum recommended temperature levels and require close monitoring to produce a quality product. High carbon amendments are known to reduce nitrogen loss from high nitrogen manures (Mahimairaja *et al.* 1994).

In spite of the variability in nutrient content of manures and cereal straw, as well as the variability in proportion of each of these ingredients in the mixture, in most cases the material composts extremely well and the addition of inoculum to speed the process is of questionable value.

Quality of compost

Chemical nutrients in compost vary with the type of animal manure and the type of additional materials used. Many methods have been proposed to estimate the degree of maturity of composts from animal wastes. Only a few methods, however, are easy to use and reliable.

The three factors that define compost quality are consistency, absence of pathogens and fine texture. The nitrogen, phosphorus and potassium in composted manures are not the components of highest value. The greatest benefit is probably in the microbiology and the organic matter of the material. Currently there is no value attached to these components and, until this value is established through research, the margin of return for composted manure products will remain low. Microbiological methods used to evaluate soil microbiology may be used in the future as standard analytical methods to determine compost quality. Compost quality could be determined, in part, by the concentration of six

Table 1 Characteristics of common composting materials (I).

Material	Nitrogen (%, dry weight)	C:N (dry weight)	Water content	Bulk density (kg·m^{-3})
Beef				
Feedlot with bedding	1.3	1.8	68	710
Dairy				
Solid manure handling	1.7	18	79	710
Liquid slurry	2.40-3.60	16	88-92	990
Solids separated from slurry	1.45	23	77	650
Pigs				
Liquid slurry	0.15-5.00	20	93-99	1000
Solids separated from slurry	0.35-5.00	1.9	75-80	270-860
Poultr				
Broiler breeder layer	3.6	10	46	470
Broiler litter	4.7	15	25	330
Turkey litter	4.2	14	33	380
Horse manure				
With bedding	1.40-2.30	22-50	59-79	725-960
With straw	1.5	27	67	-
With shavings	0.9	65	72	-
Sheep manure	1.30-3.09	13-20	60-75	-
Straw				
General straw	0.30-1.10	48-150	27	58-357
Oat straw	0.60-1.10	48-98	14	130-192
Wheat straw	0.30-0.50	100-150	10	135
Barley straw	0.75-0.78	-	18	-
Legume grass hay	1.80-3.60	15-19	10-30	-
Sawdust	0.06-0.80	200-750	19-65	207-267
Wood waste (chips)	0.04-0.23	212-1313	15-40	264-368

Adapted from: Rynk 1992; Eghball *et al.* 1998; Guimarães 2002.

Table 2 Characteristics of common composting materials (II).

Category	Source	Nutrient content (%)		
		N	P	K
Animal waste	Cow manure	0.7	0.5	2.31
	Cattle urine	0.8	<0.01	0.03
	Sheep and goat dung	2.0	0.51	2.32
	Night soil	1.2	0.35	0.21
	Leather waste	7.0	0.04	0.10
Farmyard manure	Farmyard manure	0.8	0.08	0.25
Compost and plant residues	Poultry manure	2.9	1.26	0.97
	Town compost	1.8	0.44	0.62
	Rural compost	0.8	0.09	0.21
	Rice straw	0.6	0.08	2.10
	Lawn clipping and leaves	3.0	0.30	3.50

functional groups of microorganisms: aerobic bacteria, anaerobic bacteria, fungi, actinomycetes, pseudomonads and nitrogen-fixing bacteria. There is evidence that specific organisms that inhibit the growth of plant pathogens can be isolated from compost and compost extracts. For that reason composts could be tailored to suppress specific plant diseases prevalent in horticultural and agricultural production and to clean-up environmental contamination (Martín-Gil *et al.* 2008). Another indicator of compost quality is compost maturity, which is determined by an assay for the presence of phytotoxic compounds, and measurement of pH, sodium content and electrical conductivity (Buckley 2001).

Main reasons for and against composting

Among the benefits, the most important are: *(i)* composting leads to the production of an excellent soil conditioner which adds organic matter, improves soil structure and water-holding capacity, and reduces fertilizer requirements and potential of soil erosion; *(ii)* the composting process entails a reduction in weight and mass, and an improvement in handling characteristics *(iii)* the composted product is also suitable for bedding for poultry; *(iv)* the resulting product can be stored and applied at convenient times of the year, since organic N is less susceptible to leaching and ammonia losses; *(v)* in comparison to raw manure mixed with straw, the compost C/N ratio is more suitable for land applications; *(vi)* weed seeds, soilborne pathogens, flies and odours are eliminated; and *(vii)* potential incomes from tipping fees for organic waste.

On the other hand, there are also several disadvantages with regard to composting: *(i)* it is necessary to develop a suitable site for composting activities in order to prevent runoff and leaching of nutrients; *(ii)* the composting site, storage of raw materials and finished compost require a considerable area of land; *(iii)* important investment in terms of cost of equipment, labour and management, which might be even higher due to climatic limitations; *(iv)* stockpiled materials collected for composting may produce odours; *(v)* it is essential to develop a marketing plan for excess compost; *(vi)* the composting process involves a diversion of nutrients from agricultural land to other uses; *(vii)* potential loss of nitrogen; and *(viii)* slow release of nutrients due to the higher concentrations of organic nitrogen in compost compared to manure (nonetheless, this could be considered a benefit on soils with poor nutrient retention capacity).

COMPOSTING: A SUITABLE METHOD FOR CARCASSES DISPOSAL

Introduction

Disposal of animal mortalities has traditionally been done through incineration or burial of carcasses, but other methods (called alternatives in many cases) can be considered, like anaerobic digestion, alkaline hydrolysis, lactic acid fermentation and composting. Decision-makers should come to understand each disposal technology available to them, thereby. Such awareness implies an understanding of an array of factors for each technology, including the principles of operation, personnel requirements, costs, logistical details, environmental considerations and disease agent considerations (Stanford *et al.* 2000, 2007)

On the other hand, the elimination of carcasses in intensive livestock farms of the developed countries is an increasing problem (Sánchez *et al.* 2008). So, in the European Union the European Regulation CE 1774/2002 enforces removal of carcasses from farms to authorized treatment plants, which poses a high risk of epizootic dispersion among farms, calling for the implementation of elimination systems within each farm. These systems, without ground or water contamination in farms, should not attract insect or scavenging animals and should not entail animal storage (Kellegher *et al.* 2002; Körner *et al.* 2003). Improper animal mortality disposal may generate various environmental and health hazards such as odor nuisance (resulting from the anaerobic breakdown of proteins) that can reduce the quality of life and decrease property values. Pathogens, which may still be present in the decomposed material, are capable of spreading diseases in soil, plants, animals and humans. The potential leaching of harmful nitrogen and sulfur compounds from animal mortalities to ground water is another concern. To control these side effects, compost facility operators need to know and understand the science and guidelines of carcass composting (Kalbasi *et al.* 2005, 2006).

Incineration of mortalities, mainly by open-air burning, raises concerns with airborne infectious agents. Nevertheless, fixed-facility and air-curtain incineration pose fewer pollution problems (Ford 2003). Burial is currently the main option as the preferred disposal method in catastrophic mortality events. However, buried dead bodies decompose in air-limited conditions without sealing, so contamination of groundwater can not be avoided (Morgan Morrox *et al.* 2006). Furthermore, the burying system is not an economical elimination method, since it needs skilled labour and specific equipment for the periodical excavation of ditches and for the daily coverage of the corpses (Wineland *et al.* 1987).

Composting of animal mortalities has increased in popularity in recent years due to decreased availability and increased costs associated with the traditional animal rendering industry. The primary goals of mortality composting are to prevent the transmission and dissemination of infection, minimize opportunities for infectious materials to contaminate important elements of the environment (air, water, soil or vegetation) and to convert carcasses to beneficial end products. With increasing foreign animal disease and transmission concerns, composting has received considerably more attention as a potential method for carcasses disposal.

General principles

Carcass composting is a natural decomposition process by aerobic (oxygen-dependent) bacteria y fungi. Under optimum conditions, during the first phase of composting the temperature of the compost increases, the organic materials of mortalities break down into relatively small compounds, soft tissue decomposes, and bones soften partially. During this first phase of composting process, the volume and weight of compost mass may be reduced by 40-60%. After the first phase the entire compost pile should be mixed, displaced, and reconstituted for the secondary phase. In the second phase, the remaining materials (mainly bones) break down fully and the compost turns to consistent “humus” with a musty odour containing primarily non-pathogenic bacteria and plant nutrients. In these phase, if needed, moisture should be added to the materials to reheat the composting materials until an acceptable product is achieved. The end of the second phase is marked by an internal temperature of 25-30°C, and a reduction in bulk density of approximately 25%.

Temperature and moisture are two of the most important composting factors. Monitoring temperature and anticipating problems such as odours or excessive moisture enables the operator to judge the progress of the composting process. Microorganisms responsible for effective composting require an optimum range of 55 to 65°C for maximum efficiency. During the first phase, the temperature at the core of the compost pile should rise to at least 50-60°C within 10 days and remain there for several days. The compost mass should be aerated when temperatures reach above 70°C, which can kill the composting microorganisms (Busto *et al.* 1997), primarily *Aspergillus niger* and *Trichoderma reesei*. These organisms convert cellulose, hemicellulose, and lignin of supplemental carbon from the co-composting material to smaller molecules, and finally, to CO to neutralize the free ammonia and maintain pH at or near neutral. Conversely, a pile below 40°C may indicate an inadequate oxygen level, and it should be aerated.

Moisture levels of the composting material should range between 45 to 60% (wet basis), because active composting slows when it falls below 40% or can totally cease (<15%). If the level is greater than 65%, pores for oxygen transfer may become blocked and odour emissions can increase (anaerobic conditions).

Proper aeration is important in maintaining uniform temperature and moisture contents throughout the composting mass during the two phases of the process. Uniform airflow and temperature are important to avoid clumping of solids and to minimize the survival of several microorganisms such as faecal coliforms and *Salmonella*. The most traditional aeration method is by windrow turning, tearing down a pile and reconstructing it (Diaz *et al.* 1993, 2002). The efficiency of this process arises from uniform decomposition that results from exposing, at one time or another, all of the composting material to the most active interior zone of a pile.

The composting time depends on several factors, like temperature profile, size and weight of carcasses, material formulation, aeration and management decisions. For animal mortalities, it is admitted that the approximate composting rate (ACR) of properly managed composting processes is of 1-2 $kg{\cdot}day^{-1}$ (Sander *et al.* 2002; Keener *et al.* 2006).

Carcass composting systems require a variety of ingredients or co-composting materials, including carbon sources, bulking agents and biofilter layers.

Various materials can be used as a carbon source, including sawdust, straw or ground corn stover, poultry litter, hay, wood shavings, paper, silage, leaves, rice and peanut hulls and a variety of waste materials like matured compost. These materials provide supplemental carbon to microorganisms and also absorb excess moisture from the carcasses, distribute moisture content throughout the compost bulk, maintain porosity (low bulk weight) and modify the C:N ratio of the pile (Keener *et al.* 2006). A 50:50 (w/w) mixture of separated solids from manure and a carbon source can be used as a base material for carcass composting. Finished compost retains nearly 50% of the original carbon sources. Use of finished compost in the compost process minimizes the needed amount of fresh raw materials, and reduces the amount of finished compost to be handled. A carbon-to-nitrogen (C:N) ratio in the range of 25:1 to 40:1 generates enough energy and produces little odour during the composting process. As a general rule, the weight ratio of carbon source materials to mortalities is approximately 1:1 for high C:N materials such as sawdust, 2:1 for medium C:N materials such as litter, and 4:1 for low C:N materials such as straw.

Bulking agents or amendments also provide some nutrients for composting. They usually have bigger particle sizes than carbon sources and thus maintain adequate air spaces (around 25-35% porosity) within the compost by preventing packing of materials. Bulking agents typically include materials such as sludge cake, spent horse bedding, wood chips, refused pellets, rotting hay bales, peanut hulls and tree trimmings. The ratio of bulking agent to carcasses should result in a porosity of 35% and a bulk density of final compost mixture that does not exceed 600 $kg{\cdot}m^{-3}$ (Haug 1993).

A biofilter is a layer of sorptive and reactive carbon, which deodorizes the unpleasant gases released (dimethyl disulfide, dimethyl sulfide, carbon disulfide, ammonia, trimethyl amine, acetone, and methyl ethyl ketone), treats potential air pollutants in gas streams from compost materials, and maintains proper conditions of moisture, pH, nutrients, and temperature to enhance the microbial activities (Hoitink *et al.* 1993). The biofilter also prevents access by insects and birds and thus minimizes transmission of disease agents from mortalities to livestock or humans.

Carcasses composting alternatives

Windrows and bin composting are the most usual composting systems for carcasses disposal. To increase the rate of carcass decomposition, different methods have been practiced. Most of the efforts have been focused on making consistent and uniform raw materials (carcasses and carbon sources) by grinding and mixing (Kube 2002), improving aeration rates (Farrell 2002) and using closed containers such as rotating vessel (Rynk 2003), stationary drum (Cekmecelioglu *et al.* 2003) and aerated synthetic tube (Haywood 2003), for the first phase and then windrow for the maturation phase of composting. With these methods, composting time can be decreased between 30-60% and controlling and adjusting composting parameters (temperature, moisture content and pH) is easier.

Windrow composting

The compost pile is constructed on a compacted soil with low liquid permeability, on crushed and compacted rock or on concrete pads, with a plastic liner as a moisture barrier. The liner should then be completely covered with a base of co-composting material (such as straw, sawdust or wood chips. The co-composting material layer should have a thickness of 30 cm for small carcasses (poultry and turkey), 45 cm for medium carcasses (sheep and young swine) and 30 cm for large (mature swine) and very large (cattle and horses) carcasses. A layer of highly porous bulking material should then be placed on top of the co-composing material to absorb moisture from the carcasses and to maintain adequate porosity. The thickness of the bulking material should be 15 cm for small carcasses and 30 cm for all others. An evenly spaced layer of mortalities should then be placed directly on the bulking material layer. In the case of small and medium carcasses, mortalities can be covered with a layer of co-composting materials (thickness of 30 cm), and a second layer of evenly spaced mortalities can be placed on top of the co-composting material. This layering process can be repeated until the windrow reaches a height of approximately 2 m. The entire windrow should be covered with a 30 cm thick layer of biofilter material (such as carbon sources and/or bulking agents).

Windrow systems for carcasses composting piles are generally located in open spaces and not protected from weather, rain or wind. This situation exposes the pile to adverse weather conditions, which may affect the composting operation and its maturation process. In these conditions, composting duration is not defined (Sims *et al.* 1992; Collins 1996; Lawson *et al.* 1999).

Bin composting

Bin composting can be used for small and medium sized mortalities (poultry and swine). Because bin composting of large and very large carcasses is sometimes impractical, these carcasses may best be accommodated by a windrow system.

In this system, carcasses and co-composting materials are confined within a container constructed by many materials (such as wood, hay bales or concrete), which usually have a roof. Roofed composters are more expensive but have the advantages of reduced weather effects, better moisture control, lower leaching potential and better working conditions for the operator during inclement weather. The structure in layers of a bin composting is very similar to the windrows composting. The wall height for bins should be 2 m and the bin width should be adequate for the equipment, but generally should not exceed 2.5 m. The minimum front dimension should be 60 cm greater than the loading bucket width. In bins, carcasses should not be placed within about 30 cm of the sides, front or rear of the compost bin to prevent heat loss.

Simple and economical bins are built by large round bales placed end-to-end to form three-sided enclosures. They can be used for large carcasses but they are usually unroofed and are therefore susceptible to precipitation and weather variations.

A mini-composter can be constructed by fastening panels with metal hooks to form a box. In cold climates, additional insulation may be needed to enable the mini-composter to reach the desired temperatures (> 55°C) for pathogen destruction and effective degradation (Keener *et al.* 2006).

Bin composting had some advantages over windrows composting. The structure of bin composting allows higher stacking of materials, better use of floor space than free standing piles, elimination of weather problems when a roof is used, containment of odours and better temperature control (Rynk 1992).

Equipment

Different equipment and devices are used by farmers for easy operation of composting process and to avoid any direct contact with raw materials. This equipment includes different types of agricultural machinery for moving, lifting, loading, unloading, dumping, displacement, formation and turning of composting piles (trucks, tractors, backhoes, front-end loaders or skid loaders outfitted with different bucket sizes).

Grinding or shredding equipment used for the composting process includes hammer mills, tub grinders, vertical grinders and continuous mix pug mills. Grinding of animal mortalities and carbon sources produces a relatively homogenous mixture of raw materials that can be composted in windrows, bins or other composters (Kube 2002). Small pieces of materials increase the ratio of surface area to volume in the carcass pile, and the composting process takes place much faster (with a much larger surface area exposed to oxygen, compost bacteria could attack and decompose the materials in a much shorter time than whole carcasses), particularly if the particle sizes of carcass and co-composting materials are similar.

Several types of batch mixers can be used in composting processes, including mixers with augers, rotating paddles and rotating drum mixers. In rotating drum mixers the rotating process accelerates the decomposition to the point that the material leaving the drum is unlikely to produce odours or attract pests. Rynk (2003) suggested using a rotating drum 3 m in diameter and 15 m long for complete mixing as well as to complete the first phase of the composting process. The residence times of rotating drum mixers can vary from a few hours to several days.

Windrow turners can be classified into three groups (Manser *et al.* 1996): Rotating-tiller turners, straddle turners and side-cutting turners. Bucket loaders and rotating-tiller turners (rototillers) are commonly used for turning windrow piles. If a bucket loader is used, it should be operated such that the bucket contents are discharged in a cascading manner rather than dropped as a single mass. For large windrows, self-propelled windrow turners should be used, because they require much less space for maneuvering and therefore the windrows can be closer to each other.

The most common screeners used for separation of big particles from the finished compost product include disc screens, flexible oscillating (shaker) screens, belt screens, trommel screens and vibrating screens (Dougherty 1999). Trommel screens with perforations of less than 2.5 cm can be used to remove any remaining bones from the finished compost product (Sherman-Huntoon 2000). The larger materials remaining on the screen can be recycled back into active composting pile.

Finally, other instruments are required for monitoring and controlling physical properties of a composting system. These instruments are thermometers, pH and electrical conductivity meters, moisture testers, oxygen measurement equipment and data acquisition devices.

OTHER CONSIDERATIONS

Mortalities should be quickly removed from corrals, pens or houses and transferred directly to the composting area. Storage time should be minimized, selecting dry areas downwind of other operations and away from property lines.

Selected sites need to be selected that are not public health risks to air, water, or from direct contact if the infectious agents that are being composted can pose a direct threat to humans and other animals. All activities with composting will require some human activity, which may have direct health concerns if the disease is highly contagious and proper handling procedures are not followed.

A compost site should be located in a well-drained area with an adequate slope (1-3%) to allow proper drainage and it should be separated from sensitive water resources (such as wells, streams or ponds). Fencing should be installed to prevent access by livestock and scavenging animals. Runoff from the composting facility should be collected and directed away from production facilities and treated through a filter strip or infiltration area. Composting facilities should be located downwind of nearby residences to minimize potential odours.

After composting is complete, the finished product has a pH of about 5.5 to 8.0, an organic matter content of approximately 35-70% and a bulk density of about 500 to 600 $kg \cdot m^{-3}$. It can be recycled, temporarily stored, or, if appropriate, added to the land as a soil amendment according to a farm nutrient management plan.

In reference to biosecurity considerations, during the first phase of a composting process, pathogenic bacteria are inactivated by high thermophilic temperatures, with inactivation a function of both temperature and length of exposure. In order to maximize pathogen destruction, it is important to have uniform airflow and temperature throughout the composting process. Also during composting, actinomycetes and fungi produce a variety of antibiotics which destroy some pathogens. This way, actinomycetes and fungi become more important near the end of the composting process. The fungi are more tolerant of low moisture and low pH conditions, but less tolerant of low-oxygen environments than bacteria, and are better decaying agents on woody substrates (Rynk 1992). Although the heat generated during carcass composting results in some microbial destruction, because it is not sufficient to completely sterilize the end product, some potential exists for survival and growth of pathogens (spore-formers, such as *Bacillus anthracis*, and other pathogens, such as *Mycobacterium tuberculosis* or prions like BSE – bovine spongiform encephalopathy – will survive).

In addition, since weed seeds are usually destroyed at 62°C, they can be killed by the heat generated during composting thermophilic phase. Weed seeds may be present if the animals ingested weeds or in the co-composting materials.

Numerous publications and information are available for evaluating the potential of composting to control pathogens. As an example, for the poultry diseases Senne *et al*. (1994) evaluated survival of highly pathogenic avian influenza virus and egg drop syndrome-76 virus during composting, and Glanville *et al*. (2006) analysed the potential of composting to control catastrophic viral disease outbreaks. They also evaluated pathogen inactivation vaccine strains of avian encephalomyelitis and Newcastle Disease virus during composting, and the possibility of viruses escaping the composting mixture and affecting surroundings.

Generally, the heat energy required for inactivation of microbes (obtained from a time/temperature relationship equation or Arrhenius Model) is between 50 and 100 $kcal \cdot (g\text{-}mol)^{-1}$ for many spores and vegetative cells (Haug 1993). Based on this theory, he calculated the heat inactivation of enteric pathogens by considering the conditions common to composting, and concluded that the average temperatures of 55 to 60°C for a day or two will provide this energy and should be sufficient to reduce essentially all pathogenic viruses, bacteria, protozoa (including cysts) and helminth ova to an acceptably low level. In the same way, Millner (2003) estimated that over 99% of pathogens and parasites are killed when heated to 65°C for three consecutive days, measured in the middle of the pile. The temperature requirements for pathogen destruction of composting materials in closed composting systems (such as rotating vessels), based on the Canadian Council of Ministers for the Environment (COME) regulations, should be about 55°C for three consecutive days (Chaw 2001). The levels of pathogenic bacteria remaining in the end product depend on the heating processes of the first and second phases, and also on cross contamination or recontamination of the end product.

Murray *et al*. (2007) have explored the application of the polymerase chain reaction (PCR) as a method for assessing the persistence of transgene and mitochondrial DNA markers during the composting of euthanized transgenic pig. There was at least a 10^7-fold reduction of genetic material to a level that not either transgene or mitochondrion markers were detectable. At the end of the composting period, only bone fragments that were completely demineralised and chalky were detected. Chemically the compost was similar to that from pig litter and poultry mortalities, except the copper content was lower. Based on these data, composting appears to be an appropriate method for the disposal of transgenic animals.

Xu *et al*. (2007a) investigated greenhouse gas emissions during co-composting of calf mortalities with manure. Turning technology had no effect on greenhouse gas emissions or the properties of the final compost. The CO_2 (75.2 $g\ d^{-1}\ m^{-2}$), CH_4 (2.503 $g\ d^{-1}\ m^{-2}$), and N_2O (0.370 $g\ d^{-1}\ m^{-2}$) emissions were higher ($p < 0.05$) in manure + straw + calf mortalities (CM) than in manure + straw (control compost [CK]) (25.7, 0.094, and 0.076 $g\ d^{-1}\ m^{-2}$ for CO_2, CH_4, and N_2O, respectively), which reflected differences in materials used to construct the compost windrows and therefore their total C and total N contents. The final CM compost had higher ($p < 0.05$) total N, total C, and mineral N content ($NO_3^- + NO_2^- + NH_4^+$) than did CK compost and therefore has greater agronomic value as a fertilizer.

To some extent, emissions from manure might be curtailed by altering feeding practices (Külling *et al*. 2003; Hindrichsen *et al*. 2006), or by composting the manure (Amon *et al*. 2001; Pattey *et al*. 2005), but if aeration is inadequate CH_4 emissions during composting can still be substantial (Xu *et al*. 2007b). All of these practices require further study from the perspective of their impact on whole life-cycle of total global anthropogenic of greenhouse gases emissions.

NEW CLOSED SEMI-CONTINUOUS COMPOSTER FOR CARCASSES DISPOSAL

Composter design

The new closed semi-continuous composter has been developed to small and medium carcasses disposal by the research group on composting of the University of Valladolid (Spain). This equipment is divided of two parts: The Box-Compost container and the Compostronic device. **Fig. 4** shows different views of the composter.

Dimensions of the Box-Compost container are 2370 × 1080 × 1420 mm (**Fig. 5**), and it is constructed with panel of polyester in both faces and polyurethane foam (thickness of 60 mm), with an external stainless steel structure of 2 mm of thickness. It has six orifices in the top side to take solids and gases samples (with tubes of PVC with 50 mm of diameter). The composter is loaded by the folding top side. The bottom of the composter is open and it is unloaded by lifting it.

Inside the Box-Compost container, temperature, moisture and oxygen contents of the compost mass are conditioned and automatically controlled by the Compostronic device. Air is distributed inside the composter by means of 11 tubes of PVC (in three rows of, respectively, 6, 2 and 3

Fig. 4 Different views of the composter.

tubes), 1100 mm in length and 25.4 mm of diameter, with perforations of 6 mm of diameter each 30 mm. Tubes are finalized in a curved coupler to the collector air pipe. They enter by one of the greater length side of the Box-Compost container. The collector air pipe is directly fed from the air conditioner equipment and is made of PVC of 90 mm of diameter, perforated for the incorporation of the air distribution tubes. The water pipe, of polyethylene of 12.7 mm of diameter, supplies water for the compost mass from the top side of the Box-Compost container by means of sprinklers of 100 L·h^{-1}. The air conditioner equipment is constituted by a high pressure centrifugal ventilator of 3 CV of power and an air heater of 7.5 KW. It is equipped with temperature sensors, for the measurement of temperature inside the composter and into the collector air pipe. Composter operation is automatically controlled by a programmable logic controller (**Fig. 6**).

Experimental procedure

Composting experiences have been developed to evaluate the availability of the composter to decompose animal mortalities. These experiences have been made during four years with hens, poultry, young swine and trouts, with different operation parameters (aeration cycles, composting recipes and temperatures).

In all the experiences the co-composting materials were straw and poultry litter. Composter loading begins with a layer of straw of 30 cm of thickness, and continues with evenly spaced layer of mortalities and poultry litter. Carcasses were placed within about 20 cm of the sides. All operations with the composter (loading, unloading, lifting, moving) were mechanized by farm agricultural machinery to avoid any direct contact with raw materials. Sometimes carcasses were frozen between experiences to maintain them.

The amount of carcasses and co-composting materials added was recorded during each loading of the composter. Additionally, pH, conductivity and redox potential were recorded during composting processes, on a weekly basis, and for the final product. Samples for physico-chemical analyses were also taken.

Physico-chemical analysis of the composting product was conducted following the Spanish Official Methods of Analysis (MAPA 1994). Preparation of the samples was done by homogenization and drying at 65°C in a forced air oven and further grinding in a mill. To measure the pH, conductivity and redox potential, it was used a residue/

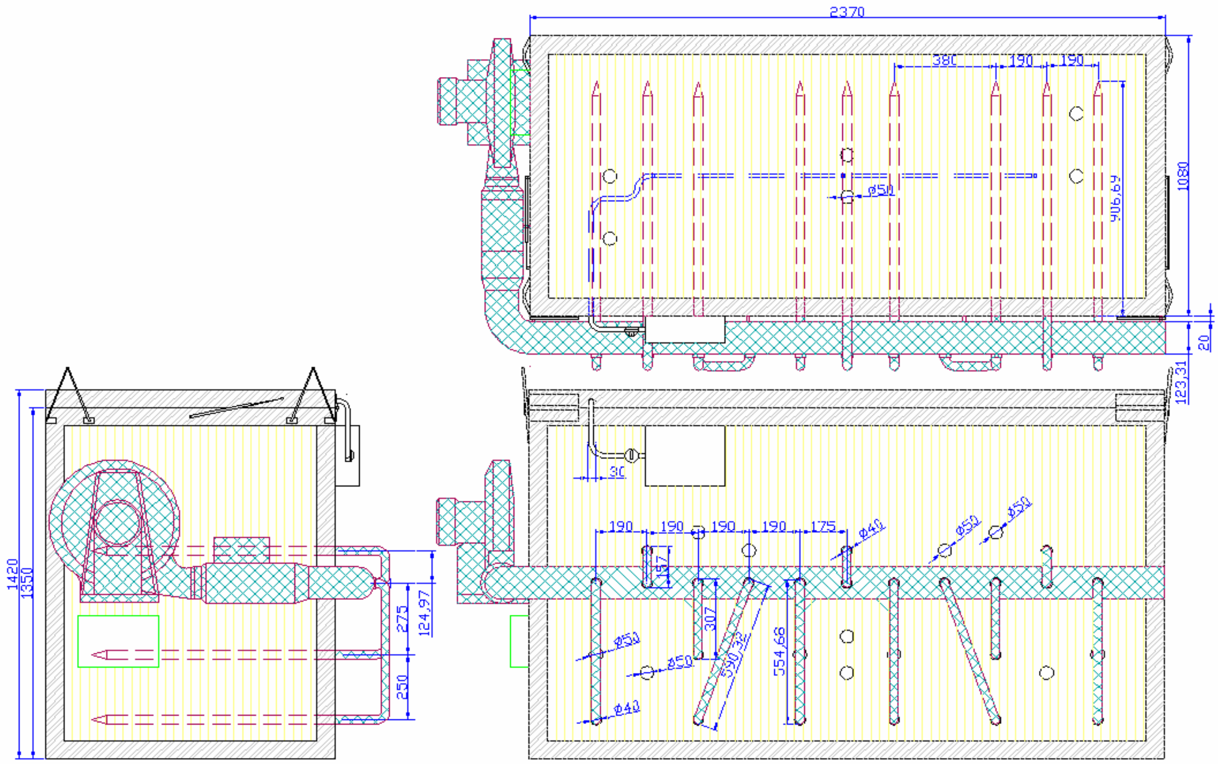

Fig. 5 General design of the composter.

Fig. 6 Control system for automatically controlling of temperature, moisture content and aeration.

Fig. 7 Gases measurement system inside the composter by an automatic analyser.

water ratio of 1:25, for which 4 g of residue were diluted in 100 mL of water and shaken during 30 min. Moisture was measured inside the compost mass during the experiences by an automatic moisture meter. Moisture was also calculated by drying samples in an oven at 105°C until constant weight. Organic matter was analyzed by ashing/calcination in a muffle furnace at 550°C for 8 h. Total nitrogen was determined with an automatic analyzer. COD (Chemical Oxygen Demand) was determined by the Spanish regulation UNE 77-004-89 and BOD (Biological Oxygen Demand) was analyzed by a constant-volume respirometer. C:N relation was determined by a automatic infrared detector. For *in-situ* weekly measures of pH, conductivity and redox potential it was used a portable measurer.

Gases released from the decomposing material (CO_2, CH_4, NO_2 and NH_3) were also measured on a weekly basis by an automatic analyser. Measurement of gases was undertaken by connecting the analyzer inside the composter, through one of the holes of the top side. Measurement of gases was also undertaken one half metre away from the composter (**Fig. 7**).

Temperatures of the material mass inside the composter and outside the composter were recorded continuously with Pt-100 sensors and a data logger device. Continuous logging of internal operating temperatures in three zones of the mass permitted to assess general composting performance and the ability to meet pathogen reduction criteria used in the biosolids composting industry. Agricultural evaluation of the final product was determined by the procedure described by Zucconi *et al.* (1985).

Over the past year, we have conducted several composting experiments both with hens and young swine, and these will be explained in detail in further papers.

CONCLUSIONS

Agricultural use of animal wastes as compost is recommended. Total amounts of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) contained in animal wastes nearly equal to those of chemical fertilizers applied to arable land. Insufficient treatment and/or illegal dumping of excess animal wastes cause serious pollution problems. Then, recycling of animal wastes without any environmental pollution will be closely related to the development of sustainable agriculture with organic fertilizer.

Composting can potentially serve as an acceptable disposal method for management of animal mortalities, obtaining a beneficial end product that can be utilized as fertilizer or co-composting material. Successful conversion of whole materials into good-quality compost requires daily and weekly control of odour, temperature and moisture during the first and second phases of composting. Operations need to be prepared with site locations, cover materials and equipment to effectively compost carcasses. This management and control will prevent the need for major corrective actions. Composting has been shown to be effective in destruction of pathogenic agents. In order to minimize the environmental impacts, composting of animal mortalities should begin within 24-48 hours of death. For a carcass compost pile, a C:N ratio of 30-35:1, moisture content of 40-60% (wet basis by mass) and proper air movement (particle size of 3-12 mm and 35% air-filled porosity) provide thermophilic temperatures of 55-60°C for more than two weeks, accelerating aerobic degradation and pathogens inactivation.

Experiences carried out with the closed semi-continuous composter developed at the University of Valladolid (Spain), have shown than this equipment is useful to small and medium carcasses disposal.

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