Carcass Disposal: A Comprehensive Review

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Chapter 3

Composting

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Abbreviations & Definitions

Though most of the terms related directly and indirectly to carcass composting have been defined to some extent in the text, for convenience the following glossary of technical terms is provided. Definitions were adopted from Rynk (1992), Franco and Swanson (1996), Pocket Information Manual (2003), Ellis (2001), Merriam-Webster's Dictionary (2003), and Oregon Department of Environmental Quality (2003).

Actinomycete: A group of microorganisms, intermediate between bacteria and true fungi that usually produce a characteristic branched mycelium. These organisms are responsible for the earthy smell of compost.

ADL: average daily loss, or rate of animal mortality in kg/day

Aeration: The process by which the oxygen-deficient air in compost is replaced by air from the atmosphere. Aeration can be enhanced by turning.

Aerobic: An adjective describing an organism or process that requires oxygen (for example, an aerobic organism).

Ambient temperature: The temperature of the air in the vicinity of the compost pile.

Ammonia (NH_3): A gaseous compound comprised of nitrogen and hydrogen. Ammonia, which has a pungent odor, is commonly formed from organic nitrogen compounds during composting.

Anaerobic: An adjective describing an organism or process that does not require air or free oxygen.

AUSVETPLAN: Australian Veterinary Emergency Plan, Agricultural and Resource Management Council of Australia and New Zealand

APHIS: USDA Animal & Plant Health Inspection Service

Bacillus anthracis: The causative organism for anthrax.

Bacteria: A group of microorganisms having single-celled or noncellular bodies. Bacteria usually appear as spheroid, rod like, or curved entities but occasionally appear as sheets, chains or branched filaments.

Batch mixer: A type of mixer, which blends materials together in distinct loads or batches. The materials are loaded, mixed, and then unloaded in sequence rather than moved through in a continuous flow. Batch mixers for composting are often modified livestock feed mixers using paddles or augers as the mixing mechanisms.

Bin composting: A composting technique in which mixtures of materials are composted in simple structures (bins) rather than freestanding piles. Bins are considered a form of in-vessel composting, but they are usually not enclosed. Many composting bins include a means of forced aeration.

Biofilter: A layer or blanket of carbon source and/or bulking agent materials that maintains proper conditions of moisture, pH, nutrients, and temperature to enhance the microbial activities and that deodorizes the gases released at ground level from the compost piles.

Biosecurity: All processes to contain a disease or disease agent.

Bucket loader: A vehicle which employs a hydraulically operated bucket to lift materials. Includes farm tractors with bucket attachments, skid loaders, and large front-end loaders.

Bulking agent: A nutrient materials for composting that has bigger particle sizes than carbon sources and thus prevent packing of materials and maintain adequate air spaces (around 25-35% porosity) within the compost pile. They should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contacts.

BVS: bio-degradable volatile solids

Carbon dioxide (CO_2): An inorganic gaseous compound comprised of carbon and oxygen.

Carbon dioxide is produced by the oxidation of organic carbon compounds during composting.

Carcass composting: A natural biological decomposition process that takes place in the presence of oxygen (air).

Carcass compost pile: An inconsistent mixture that consists of an animal mass with large amounts of water, high-nitrogen and low-carbon content, and low-porosity surrounded by a co-composting material of good-porosity, high-carbon, low-nitrogen, and moderate moisture levels.

C:N (carbon-to-nitrogen ratio): The ratio of the weight of organic carbon (C) to that of total nitrogen (N) in an organic material.

Cellulose: A long chain of tightly bound sugar molecules that constitutes the chief part of the cell walls of plants.

COMPO-Matic: The equipment designed for measuring, controlling and optimizing both oxygen and temperature during the composting process. This device has a special insertion probe which contains an oxygen-temperature sensor.

CGOEMC: Colorado Governor's Office of Energy Management and Conservation

Curing: Final stage of composting in which stabilization of the compost continues but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures.

Dry matter: The portion of a substance that is not comprised of water. The dry matter content (%) is equal to 100% minus the moisture content (%)

END: exotic Newcastle disease

Enteric: Pertaining to the intestinal tract.

Enzymes: Any of numerous complex proteins produced by living cells to catalyze specific biochemical reactions.

Fecal coliform: Enteric organisms that serve as an indicator of possible presence of pathogens.

Finished compost: Compost that has undergone active composting and curing stage and it is a stable and hygienic product.

FMD (foot and mouth disease): A highly infectious viral infection of cattle, pigs, sheep, goats, buffalo and artiodactyls wildlife spies characterized by fever, vesicles (blisters) in the mouth and on the muzzle, teats, and/or feet; and death in young animals. Affected animals may become completely incapacitated or be unable to eat/drink due to pain associated with the vesicles.

Fungus (plural fungi): A group of simple plants that lack a photosynthetic pigment. The individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called hyphae. The individual hyphae can grow together to form a visible body.

Grinding: An operation that cuts the raw materials and reduces their particle sizes. Grinding implies that particles are broken apart largely by smashing and crushing rather than tearing or slicing.

Groundwater: Water below the land surface in a zone of saturation.

Humus: The dark or black carbon-rich relatively stable residue resulting from the decomposition of organic matter.

Hydrogen sulfide (H_2S): A gas with the characteristic odor of rotten eggs, produced by anaerobic decomposition.

Inactive material: Carbon source substances with very low moisture and porosity, which have low heat conductivity.

Inoculum (plural inocula): Living organisms or material containing living organisms (such as bacteria or other microorganisms) which are added to initiate or accelerate a biological process (for example, biological seeding).

In-vessel composting: A diverse group of composting materials is contained in a reactor or vessel.

Land application: Application of manure, sewage sludge, municipal wastewater, and industrial wastes to land either for ultimate disposal or reuse of the nutrients and organic matter for their fertilizer value.

Leachate: The liquid that results when water comes in contact with a solid and extracts material, either dissolved or suspended, from the solid.

Lignin: A substance that together with cellulose forms the woody cell walls of plants, and the cementing material between them. Lignin is resistant to decomposition.

Litter, poultry: Dry absorbent bedding material such as straw, sawdust, and wood shavings that is spread on the floor of poultry barns to absorb and condition manure. Sometimes the manure-litter combination from the barn is also referred to as litter.

Manure: The fecal and urinary excretion of livestock and poultry, sometimes referred to as livestock waste. This material may also contain bedding, spilled feed, water or soil. It may also include wastes not associated livestock excreta, such as milking center wastewater, contaminated milk, hair, feathers, or other debris.

Mature (or maturation): A chemical condition of the compost. Immature compost will contain toxic chemical compounds that could affect plant growth.

Mesophilic: Operationally, the temperature range most conducive to the maintenance of optimum digestion by mesophilic bacteria, generally accepted as between 50 and 105°F (10 and 40°C).

Mesophilic temperatures: between 20°C (68°F) and 45°C (113°F), which mesophilic microorganisms grow well.

Mini composter: A smaller version of a bin composter.

Moisture content: The fraction or percentage of a substance comprised of water. Moisture content equals the weight of the water portion divided by the total weight (water plus dry matter portion). Moisture content is sometimes reported on a dry basis. Dry-basis moisture content equals the weight of the water divided by the weight of the dry matter.

MPN: most probable number

NAO: UK National Audit Office

NCSART: North Carolina State Animal Recovery Team

NRAES: Natural Resource, Agriculture, and Engineering Service

ODEQ: Oregon Department of Environmental Quality

Organic composting: As used in this document, refers to composting of biomass such as yard waste, food waste, manure, etc., (excludes composting of carcass material).

OSUE: Ohio State University Extension Service

OU: odor unit

Pathogen: Any organism capable of producing disease or infection. Often found in waste material, most pathogens are killed by high temperatures of composting processes.

pH: A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Thus, something that has a pH of 8 has ten times fewer hydrogen ions than something with a pH of 7. The lower the pH, the more hydrogen ions present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is considered neutral.

Phytotoxic: An adjective describing a substance that has a toxic effect on plants. Immature or anaerobic compost may contain acids or alcohols that can harm seedlings or sensitive plants.

Porosity: A measure of the pore space of a material or pile of materials. Porosity is equal to the volume of the pores divided by the total volume. In composting, the term porosity is sometimes used loosely, referring to the volume of the pores occupied by air only (without including the pore space occupied by water).

Poultry: Chickens or ducks being raised or kept on any premises in the state for profit.

Poultry carcass: The carcass or part of a carcass of poultry that died as a result of a cause other than intentional slaughter for use for human consumption.

Primary phase: The developing or heating phase that can take three weeks to three months is characterized by high oxygen-uptake rates, thermophilic temperatures, and high reductions in biodegradable volatile solids (BVS). This phase may last three weeks to three months, may harbor significant odor potential. The three sub-phases of primary phase are: initial, high rate, and stabilization.

PTO: Power take off. Drive shaft and coupling on a tractor which transmits power from the tractor engine.

Recipe: The ingredients and proportions used in blending together several raw materials for composting.

Runoff: Water that is generated on the site and runs off the site into ponds, swales, ditches, streams, and other water bodies.

Salmonella: Human pathogen that causes gastro-intestinal problems.

SCI: Sparks Companies Inc.

Secondary phase: Also called the maturation or curing phase, may require one month or longer. In this phase, aeration is not a determining factor for proper composting, and, therefore, it is possible to use a low-oxygen composting system. A series of retarding reactions, such as the breakdown of lignins, occurs during this maturation or curing stage and requires a relatively long time.

Shredding: An operation that reduces the particle size of materials. Shredding implies that the particles are broken apart by tearing and slicing.

SOER: surface odor emission rate

Stabilization: A stage in the composting process when the amount of available carbon that serves as a food source for microorganisms is very low. As a result, microbial activity is low and oxygen consumption by the microorganisms is low. Stable compost is a material that does not change rapidly, does not reheat, and has a very low respiration rate. Unstable compost will have great microbial activity because of carbon available as food for the microbes. Pathogenic microorganisms may regrow in unstable compost. As a result, the microbes will utilize soil nitrogen, and plants would not have enough nitrogen for their growth. Stable compost continues to decompose at a very slow rate and has a low oxygen demand.

Thermophilic: Heat-loving microorganisms that thrive in and generate temperatures above 105°F (40°C).

Thermophilic temperatures: Between 45°C (113°F) to 70°C to (158°F), which thermophilic microorganisms grow well.

TOC: threshold odor concentration

Ton: US ton, 2,000 lbs

Ton, metric: 1,000 kg (2,204.6 lb)

Turning: A composting operation, which mixes and agitates material in a windrow pile or vessel. Its main aeration effect is to increase the porosity of the windrow to enhance passive aeration. It can be accomplished with bucket loaders or specially designed turning machines.

US: United States

USDA: US Department of Agriculture

Windrow: A long, relatively narrow, low pile. Windrows have a large exposed surface area which encourages passive aeration and drying.

Windrow composting: This method involves placing the feedstock in long, relatively narrow, low piles called windrows. Windrows have a large exposed surface area which encourages passive aeration and drying. Aeration is achieved by convective airflow as well as turning. The windrow piles act like a chimney; the center gets hot, and air is drawn through the sides.

Section 1 – Key Content

This chapter provides a summary of various aspects of carcass composting, including processing options, effective parameters, co-composting materials, heat-energy, formulations, sizing, machinery, equipment, cost analysis, and environmental impacts. Guidelines and procedures for windrow and bin composting systems, especially for large numbers of animal mortalities, are discussed. This information was adapted from Murphy and Carr (1991), Diaz et al. (1993), Haug (1993), Adams et al. (1994), Crews et al. (1995), Fulhage (1997), Glanville and Trampel (1997), Mescher et al. (1997), Morris et al. (1997), Carr et al. (1998), Dougherty (1999), Monnin (2000), Henry et al. (2001), Keener et al. (2000), Lasaridi and Stentiford (2001), Morse (2001), Ritz (2001), Bagley (2002), Diaz et al. (2002), Hansen (2002), Harper et al. (2001), Langston et al. (2002), Looper (2002), McGahan (2002), Sander et al. (2002), Sparks Companies Inc. or SCI (2002), Tablante et al. (2002), Colorado Governor's Office of Energy Management and Conservation or CGOEMC (2003), Jiang et al. (2003), Mukhtar et al. (2003), Oregon Department of Environmental Quality or ODEQ (2003), and Rynk (2003).

1.1 – General Guidelines for Composting Carcasses in Windrow or Bin Systems

Definition, preparation, formulation, and general principles

Carcass composting is a natural biological decomposition process that takes place in the presence of oxygen (air). Under optimum conditions, during the first phase of composting the temperature of the compost pile increases, the organic materials of mortalities break down into relatively small compounds, soft tissue decomposes, and bones soften partially. In the second phase, the remaining materials (mainly bones) break down fully and the compost turns to a consistent dark brown to black soil or "humus" with a musty odor containing primarily non-pathogenic bacteria and plant nutrients. In this document the term "composting" is used when referring to composting of carcass material, and the term "organic composting" is used when referring to composting of other biomass such as yard waste, food waste, manure, etc.

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

Carbon sources

Various materials can be used as a carbon source, including materials such as sawdust, straw, corn stover (mature cured stalks of corn with the ears removed and used as feed for livestock), poultry litter, ground corn cobs, baled corn stalks, wheat straw, semi-dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, yard wastes, vermiculite, and a variety of waste materials like matured compost.

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 for recycling heat and bacteria 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 odor during the composting process. Depending on the availability of carbon sources, this ratio can sometimes be economically extended to 50:1. 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

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 pile by preventing packing of materials. They should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contact. Bulking agents typically include materials such as sludge cake, spent horse bedding (a mixture of horse manure and pinewood shavings), wood chips, refused pellets, rotting hay bales, peanut shells, and tree trimmings.

The ratio of bulking agent to carcasses should result in a bulk density of final compost mixture that does not exceed 600 kg/m^3 (37.5 lb/ft^3). As a general rule, the weight of compost mixture in a 19-L (5-gal) bucket should not be more than 11.4 kg (25 lb); otherwise, the compost mixture will be too compact and lack adequate airspace.

Biofilters

A biofilter is a layer of carbon source and/or bulking agent material that 1) enhances microbial activity by maintaining proper conditions of moisture, pH, nutrients, and temperature, 2) deodorizes the gases released at ground level from the compost piles, and 3) prevents access by insects and birds and thus minimizes transmission of disease agents from mortalities to livestock or humans.

Site selection

Although specific site selection criteria may vary from state to state, a variety of general site characteristics should be considered. A compost site should be located in a well-drained area that is at least 90 cm (3 ft) above the high water table level, at least 90 m (300 ft) from sensitive water resources (such as streams, ponds, wells, etc.), and that has adequate slope (1-3%) to allow proper drainage and prevent pooling of water. 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 odors or dust being carried to neighboring residences by prevailing winds. The location should have all-weather access to the compost site and to storage for co-composting materials, and should also have minimal interference with other operations and traffic. The site should also allow clearance from underground or overhead utilities.

Preparation and management of compost piles

Staging mortalities

Mortalities should be quickly removed from corrals, pens, or houses and transferred directly to the composting area. In the event of a catastrophic mortality loss or the unavailability of adequate composting amendments, carcasses should be held in an area of temporary storage located in a dry area downwind of other operations and away from property lines (ideally should not be visible from off-site). Storage time should be minimized.

Preparation and monitoring of compost piles

Co-composting materials should be ground to 2.5-5 cm (1-2 inches) and mixed. Compost materials should be lifted and dropped, rather than pushed into place (unless carcasses have been ground and mixed with the co-composting materials prior to the composting process). Compost piles should be covered by a biofilter layer during both phases of composting. If warranted, fencing should be installed to prevent access by livestock and scavenging animals.

The moisture content of the carcass compost pile should be 40-60% (wet basis), and can be tested accurately using analytical equipment or approximated using a hand-squeeze method. In the hand-squeeze method, a handful of compost material is squeezed firmly several times to form a ball. If the ball crumbles or breaks into fragments, the moisture content is much less than 50%. If it remains intact after being gently bounced 3-4 times, the moisture content is nearly 50%. If the ball texture is slimy with a musty soil-like odor, the moisture content is much higher than 50%.

A temperature probe should be inserted carefully and straight down into each quadrant of the pile to allow daily and weekly monitoring of internal temperatures at depths of 25, 50, 75, and 100 cm (10, 20, 30, and 40 in) after stabilization during the first and second phases of composting. During the first phase, the temperature at the core of the pile should rise to at least 55-60°C (130-140°F) within 10 days and remain there for several weeks. A temperature of 65°C (149°F) at the core of the pile maintained for 1-

2 days will reduce pathogenic bacterial activity and weed seed germination.

Proper aeration is important in maintaining uniform temperature and moisture contents throughout the pile during the first and second phases of the composting process. Uniform airflow and temperature throughout a composting pile are important to avoid clumping of solids and to minimize the survival of microorganisms such as coliforms, *Salmonella*, and fecal *Streptococcus*. During composting, actinomycetes and fungi produce a variety of antibiotics which destroy some pathogens; however, spore-formers, such as *Bacillus anthracis* (the causative agent of anthrax), and other pathogens, such as *Mycobacterium tuberculosis*, will survive.

After the first phase of composting, the volume and weight of piles may be reduced by 50-75%. After the first phase the entire compost pile should be mixed, displaced, and reconstituted for the secondary phase. In the second 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 (77-86°F), a reduction in bulk density of approximately 25%, a finished product color of dark brown to black, and the lack of an unpleasant odor upon turning of the pile.

Odor can be evaluated by placing two handfuls of compost material into a re-sealable plastic bag, closing the bag, and allowing it to remain undisturbed for approximately one hour (5-10 min is adequate if the sealed bag is placed in the sun). If, immediately after opening the bag, the compost has a musty soil odor (dirt cellar odor), the compost has matured. If the compost has a sweetish odor (such as slightly burned cookies), the process is almost complete but requires a couple more weeks for adequate maturation. If the compost odor is similar to rotting meat/flesh, is overpowering, is reminiscent of manure, or has a strong ammonia smell, the compost process is not complete and may require adjustments. After the primary and secondary phases of composting are complete, the finished product can be recycled, temporarily stored, or, if appropriate, added to the land as a soil amendment.

Compost equipment and accessories

Transport vehicles, such as trucks, front-end loaders, backhoes, tractors, or skid loaders outfitted with different bucket sizes (0.88-3.06 m^3 or 1-4 yd^3), can be used for a variety of purposes, including to construct and maintain composting piles for bin or windrow formation, to place mortalities on compost piles, to lift, mix, and place co-composting materials, to move compost from one place to another as needed for aeration, and to feed finished product into compost screeners or shredders.

Grinding or milling equipment used for the composting process includes tub grinders or tub mills, hammer mills, continuous mix pug mills (machines in which materials are mixed, blended, or kneaded into a desired consistency) and vertical grinders. A bale processor can be used to grind baled cornstalks, hay, straw, and grass. Several types of batch mixers (which may be truck- or wagon-mounted), including mixers with augers, rotating paddles, rotating drum mixers, and slats on a continuous chain can be used for mixing operations.

Tanker trucks with side-delivery, flail-type spreaders, honey wagons with pumps, or pump trucks can be used for hauling water to, or spreading water on, the composting piles.

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. Turning capacities range from about 727 to 2,727 metric tons/h (800 to 3,000 US tons/h).

Trommel screens with perforations of less than 2.5 cm (1 in) can be used to remove any remaining bones from the finished compost product, and the larger materials remaining on the screen can be recycled back into active windrows.

Instruments and supplies necessary for monitoring and recording physical and chemical properties of a composting system include thermometers (usually four-foot temperature probes), pH meters, bulk density testing devices (a weighing box made of 1.25 mm or 0.5 inch plywood, and volume of 0.028 m^3 or 1 ft^3 with a strap or wire, which can be suspended from a hanging scale), odor testing materials (re-sealable plastic bags), and log books to record compost activities and status along with test results.

Trouble shooting

In the event that liquids leach out of the pile, a well absorbing carbon source material should be spread around the pile to absorb the liquids and increase the base depth. If the pile appears damp or wet and is marked by a strong offensive odor and a brown gooey appearance, it should be transferred onto a fresh layer of bulking agent in a new location.

During the first phase, if the moisture content is low (less than 40%) and the internal pile temperature is high (more than 65°C [149°F]), the compost pile coverage or its cap should be raked back and water should be added at several locations. Conversely, if the internal pile temperature is very low (less than 55°C [130°F]), the compost pile may have been too moist (wet) and/or lacked oxygen, resulting in anaerobic rather than aerobic conditions. Samples should be collected and the moisture content determined by a hand squeeze moisture test.

If the compost temperature does not rise to expected levels within 1-2 weeks of the pile being covered and capped, the initial pile formulation should be evaluated for proper C:N ratio and mixture of co-composting materials and mortalities. Alternatively, cattle, chicken, or horse manure can be added to the compost pile.

In cold climates or winter, compost piles should be protected from the elements prior to loading. Carcasses should be stored in a barn, shed, or other covered space to protect them from freezing temperatures if they cannot be immediately loaded into the pile. Frozen mortalities may not compost until thawed. Bulking agents and other compost ingredients should also be kept dry to prevent freezing into unusable clumps.

Land application

The finished product resulting from composting of mortalities has an organic matter content of approximately 35-70%, a pH of about 5.5 to 8.0, and a bulk density of about 474 to 592 kg/m^3 (29.6- 40 lb/ft^3). Therefore, the material is a good soil amendment. Finished compost may be land spread according to a farm nutrient management plan. State regulations should be consulted prior to land application of finished compost.

Cost analysis

According to Sparks Companies, Inc. (SCI, 2002), the total annual costs of carcass composting are $30.34/head for cattle and calves, $8.54/head for weaned hogs, $0.38/head for pre-weaned hogs, and $4.88/head for other carcasses. The cost of machinery (the major fixed cost) represents almost 50% of the total cost per head. Other researchers have estimated carcass composting costs to range from $50-104 per US ton (Kube, 2002). Due to the value of the finished compost product, some estimates suggest the total cost of composting per unit weight of poultry carcasses is similar to that of burial. Reports indicate that only 30% of the total livestock operations in the US are large enough to justify the costs of installing and operating composting facilities. Of those production operations that do compost mortalities, at least 75% are composting poultry mortalities.

1.2 – Specific Procedures for Composting Carcasses in Windrow or Bin Systems

Although windrow and bin composting systems share some common guidelines, differences exist in the operation and management of the two systems. Specific guidelines and procedures for primary and secondary phases of windrow and bin composting are outlined below.

Windrow composting

While the procedure for constructing a windrow pile is similar for carcasses of various animal species, carcass size dictates the layering configuration within the pile. Regardless of mortality size, the length of a windrow can be increased to accommodate more carcasses. Carcasses can be generally categorized as small (e.g., poultry and turkey), medium (e.g., sheep and young swine), large (e.g., mature swine), or very large (e.g., cattle and horses).

Constructing a windrow pile

The most appropriate location for a windrow is the highest point on the identified site. A plastic liner (0.24 in [0.6 cm] thick) of length and width adequate to cover the base dimensions of the windrow (see following dimensions) should be placed on crushed and compacted rock as a moisture barrier, particularly if the water table is high or the site drains poorly. The liner should then be completely covered with a base of co-composting material (such as wood chips, sawdust, dry loose litter, straw, etc). The co-composting material layer should have a thickness of 1 ft for small carcasses, 1.5 ft for medium carcasses, and 2 ft for large and very large carcasses. A layer of highly porous, pack-resistant bulking material (such as litter) 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 0.5 ft for small carcasses, and 1 ft 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 1 ft [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 6 ft (1.8 m). Mortalities should not be stacked on top of one another without an appropriate layer of co-composting materials in between. For large and very large carcasses, only a single layer of mortality should be placed in the windrow. After placing mortalities (or the final layer of mortalities in the case of small and medium carcasses) on the pile, the entire windrow should be covered with a 1-ft (30-cm) thick layer of biofilter material (such as carbon sources and/or bulking agents).

Using this construction procedure, the dimensions of completed windrows will be as follows for the various categories of mortality (note that windrow length would be that which is adequate to accommodate the number of carcasses to be composted):

- Small carcasses: bottom width, 12 ft (3.6 m); top width, 5 ft (1.5 m); and height 6 ft (1.8 m)
- Medium carcasses: bottom width, 13 ft (3.9 m); top width, 1 ft (0.3 m); and height 6 ft (1.8 m)
- Large and very large carcasses: bottom width, 15 ft (4.5 m); top width, 1 ft (0.3 m); and height, 7 ft (2.1 m)

Bin composting

For a bin composting system, the required bin capacity depends on the kind of co-composting materials used. As a general rule, approximately 10 m^3 of bin capacity is required for every 1,000 kg of mortality (160 ft^3 per 1,000 lb of mortality). Because bin composting of large and very large carcasses is sometimes impractical, these carcasses may best be accommodated by a windrow system. This section provides specific guidelines for two-phase, bin composting of both small- and medium-sized mortalities.

Constructing a bin

Bins can be constructed of any material (such as concrete, wood, hay bales, etc.) structurally adequate to confine the compost pile. Simple and economical bin structures can be created using large round bales placed end-to-end to form three-sided enclosures or bins (sometimes called bale composters). A mini-composter can be constructed by fastening panels with metal hooks to form a box open at the top and at the bottom. Structures should be located and situated so as to protect the pile from predators, pests, and runoff. Bins may or may not be covered by a roof. A roof is advantageous, especially in high rainfall areas (more than 1,000 mm or 40 in annual average), as it results in reduced potential for leaching from the pile and better working conditions for the operator during inclement weather.

An impervious concrete floor (5 in [12.5 cm] thick) with a weight-bearing foundation is recommended to accommodate heavy machinery, allow for all-weather use, and prevent contamination of soil and surrounding areas. If an entire bin is constructed of concrete, bin walls of 6-in (15-cm) thickness are recommended. Walls and panels can also be constructed with pressure-treated lumber (e.g., 1-in treated plywood backed with 2 x 6 studs). To improve wet weather operation, access to primary and secondary bins can be paved with concrete or compacted crushed rock.

The wall height for primary and secondary bins should be 5-6 ft (1.5-1.8 m), and the bin width should be adequate for the material-handling equipment, but generally should not exceed 8 ft (2.4 m). The minimum front dimension should be 2 ft (61 cm) greater than the loading bucket width. The front of the bin should be designed such that carcasses need not be lifted over a 5-ft (1.5-m) high door. This can be accomplished with removable drop-boards that slide into a vertical channel at each end of the bin, or with hinged doors that split horizontally.

Bin composting process

Primary phase. A base of litter (or litter-sawdust, litter-shavings mixture) with a thickness of 1.5-2 ft (45-60 cm) should be placed in a fresh bin about two days before adding carcasses to allow for preheating of the litter. Immediately prior to introducing carcasses, the surface of the pre-heated litter (about 6 in [15 cm] in depth) should be raked back and the carcasses should be placed in the hot litter. A minimum of 1 ft (30 cm) of litter should remain in the base of the compost pile for absorbing fluids and preventing leakage. Carcasses should not be placed within about 8-12 in (20-30 cm) of the sides, front, or rear of the compost bin to prevent heat loss. Carcasses should be completely covered and surrounded with the preheated litter.

Carcasses can be placed in the bin in layers, although a 1-ft (30-cm) thick layer of carbon source material is necessary between layers of carcasses to insulate and maintain compost temperature. As a final cover material, carcasses should be completely covered with approximately 2 ft (60 cm) of sawdust, or a minimum of 2.5 lb (1.1 kg) of moist litter per pound of carcass, to avoid exposed parts or odors that attract flies, vermin, or predators to the pile and to minimize fluids leaching out of the pile.

Secondary phase. After moving the pile to the secondary bin, it should be covered with a minimum of 4 in (10 cm) of co-composting materials (such as straw and woodchips) to ensure that exposed carcass pieces are covered. This additional cover helps insulate the pile, reduce odor potential, and ensure decomposition of remaining carcass parts. Moisture should be added to the materials to allow the pile to reheat and achieve an acceptable end product. An adequately composted finished product can be identified by a brown color (similar to humus) and an absence of unpleasant odor upon pile turning. Note that some identifiable carcass parts, such as pieces of skull, leg or pelvic bones, hoofs, or teeth, may remain. However, these should be relatively small and brittle (or rubbery) and will rapidly disappear when exposed to nature.

1.3 – Disease Agent Considerations

During active composting (first phase), pathogenic bacteria are inactivated by high thermophilic temperatures, with inactivation a function of both temperature and length of exposure. 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. 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.

In order to maximize pathogen destruction, it is important to have uniform airflow and temperature throughout the composting process. Because carcass compost is an inconsistent, non-uniform mixture, pathogen survival may vary within different areas of the compost. Temperature uniformity is facilitated by proper aeration, and reduces the probability of microbes escaping the high-temperature zone. In spite of non-uniform temperatures, pathogenic bacterial activity is reduced when the temperature in the middle of the pile reaches 65°C (149°F) within one to two days. That is, a high core temperature provides more confidence for the carcass composting pasteurization process. Achieving an average temperature of 55 to 60°C (131 to 140°F) for a day or two is generally sufficient to reduce pathogenic viruses, bacteria, protozoa (including cysts), and helminth ova to an acceptably low level. However, the endospores produced by spore-forming bacteria would not be inactivated under these conditions.

1.4 – Conclusions

Composting can potentially serve as an acceptable disposal method for management of catastrophic mortality losses. Furthermore, the principles for composting catastrophic mortality losses are the same as for normal daily mortalities. Successful conversion of whole materials into dark, humic-rich, good-quality compost that has a soil- or dirt cellar-like odor requires daily and weekly control of odor, temperature, and moisture during the first and second phases of composting. This stringent management and control will prevent the need for major corrective actions.

Bin composting may not be economically suitable or logistically feasible for large volumes of small and medium carcasses. In such instances, windrow composting may be preferable in terms of ease of operation.

Section 2 – General Information

The livestock and poultry industry has historically been one of the largest agricultural businesses in the United States (US). According to Sparks Companies, Inc. (SCI) (2002), the market for US meat and meat-based products results in the annual slaughter of roughly 139 million head of cattle, calves, sheep, hogs and other livestock, as well as 36 billion pounds of poultry (broiler chickens, layer chickens and turkeys). Every year, millions of animals, representing billions of pounds of mortality, perish due to typical production death losses.

2.1 – History of Animal Mortality from Disease and Disasters

According to USDA Economics and Statistics Systems (2002), more than 439 million poultry (excluding commercial broilers) were raised for commercial sale in the US in 2002. Out of this production, about 52 million birds (almost 12% of the total production) died of various causes before they were marketable. SCI (2002) reported that ruminants (cattle, sheep, lamb, and goats) combine to account for about 22%, and swine 78%, of all mammalian livestock that die prior to slaughter each year. However, because they are considerably larger and heavier, cattle account for about 67% by weight of the total death loss each year.

Infectious and non-infectious diseases worldwide cause heavy losses of animal populations every year. Some of the worst catastrophic mortality losses resulting from various diseases in different countries during the last 10 years are summarized below.

In 1993, an outbreak of Newcastle disease occurred on a Venezuela farm having nearly 100,000 chickens (Pakissan.com, 2001).

- In 1997 and in 2001, foot and mouth disease (FMD) outbreaks in Taiwan generated millions of dead swine, sheep, and cattle carcasses to be disposed of in a biosecure and time-sensitive manner (Wilson & Tsuzynski, 1997).
- In 1998, animal diseases took a heavy toll. Newcastle disease damaged three poultry farms in New South Wales (Province of Australia), and FMD damaged pig farms in Central Asia, Africa, South America, China, and Middle Eastern countries like Israel. In another case, Rift Valley fever led to the loss of 70% of the sheep and goat populations, and 20-30% of the cattle and camel populations in East and West Africa. During the same year, African swine fever broke out in Madagascar leading to the death of more than 107,000 pigs (Pakissan.com, 2001).
- In 2001, an outbreak of FMD in the United Kingdom resulted in the slaughter and disposal of over 6 million animals, including cattle, sheep, pigs, and goats (NAO, 2002). Approximately 4 million of these animals were culled for welfare reasons rather than for disease control purposes.
- An exotic Newcastle disease (END) outbreak in 2003 in Southern California resulted in the depopulation of nearly 4.5 million birds and is another example of a disease outbreak in poultry operations (Florida Department of Agriculture and Consumer Services, 2003).

Natural disasters have the potential to cause catastrophic animal mortalities that are just as devastating as infectious diseases. Mortality due to natural disasters can be attributed to a wide variety of events, such as floods, storms, lightning, heat extremes, fires, droughts, and earthquakes. Heat extremes, especially in unusually hot summers, have significant impact on increasing animal mortality. The following natural disasters caused massive animal mortalities.

- Floods that occurred in Texas in 1998 resulted in livestock losses estimated to be approximately $11 million over 20 counties (Ellis, 2001).
- In 1999 Hurricane Floyd in North Carolina resulted in estimated losses of livestock and poultry valued at approximately $13 million (North Carolina State Animal Recovery Team, NCSART, 2001). Losses included over 2 million chickens, 750,000 turkeys, 28,000 hogs, and over 1,100 cattle.
- During a period of intense heat in July 1995, the mortality of feedlot cattle in Iowa and Nebraska increased tremendously. A total of 10,000 feedlot cattle perished, 3,750 within a single day. The estimated losses to livestock and poultry producers in central Iowa, respectively, were $28 million and $25 million (USDA, 2002).

In each catastrophe, animal mortalities caused a considerable economic loss to producers. In addition to economic consequences, catastrophic mortality losses may potentially impact public health or the environment.

2.2 – Historical Use of Composting

"Carcass composting" can be described as burying dead animals above ground in a mound of carbon source with decomposition of carcass tissues resulting from the aerobic action of various microorganisms. Composting produces water vapor, carbon dioxide, heat, and stabilized organic residue. Composting carcasses is relatively new in comparison with "organic composting," or composting of crop and horticultural residues. According to Murphy and Handwerker (1988), "carcass composting" began in the poultry industry after research conducted in the 1980s at the University of Maryland demonstrated that poultry carcasses could be fully biodegraded in only 30 days. This research used a relatively simple bin composting process that was less labor intensive than burial. Glanville and Trampel (1997) indicated this process was quickly adopted by the poultry industry in the southern and eastern seaboard states, but concern regarding its year round applicability, particularly in colder climates, slowed its acceptance in northern states. Kashmanian and Rynk (1996) reported that cold weather does not seriously affect the process as long as bins are adequately sized and properly loaded. Some researchers believe that the end products of carcass composting and conventional organic (plant residue) composting are comparable in terms of agricultural land application.

The main disadvantages of carcass composting have been summarized by many sources, including AUSVETPLAN (1996) and Ellis (2001). It was reported that composting of dead animals is a slow process (taking months), which requires longer management throughout the decomposition process.

2.3 – Objectives

The purpose of this work is to discuss various aspects of carcass composting as a mortality disposal option. This work is intended to provide information to those with planning and decision making responsibility to determine whether composting is suitable to the circumstances at hand, and if so, to choose the most appropriate carcass composting method.

Section 3 – Principles of Operation

3.1 – General Carcass Composting Process

Composting is becoming an increasingly preferred alternative for disposing of mortalities at animal feeding operations. Carcass composting offers several benefits, including reduced environmental pollution, generation of a valuable by-product (soil amendment), and destruction of many pathogens. Because finished compost is different than the original materials from which it was derived, it is free of unpleasant odor, easy to handle, and can be stored for long periods. This section provides a thorough review and discussion of the principles of the composting process, including the definition of composting, the natural degradation process, factors critical to the conversion process, physical changes that occur in a compost pile, as well as the microorganisms involved in the composting process.

Compost definition

Based on the work of many researchers (Murphy & Carr, 1991; Haug, 1993; Diaz et al., 1993; Manser & Keeling, 1996; Reinikainen & Herranen, 1999; Keener, Elwell, & Monnin, 2000; and Harper et al., 2001), composting of plant and animal residues or mortalities can be defined as a natural biological decomposition process with the following properties:

- Stabilization of biomass components using predominantly aerobic reactions.
- Development of populations of thermophilic, gram-positive, spore-forming bacilli (for example, *Bacillus* spp.), fungi, and actinomycetes.
- Conversion of complex organic material into relatively short molecules of proteins, lignins, celluloses, hemicelluloses, and some inorganic materials (water, carbon dioxide, and ammonia).
- Generation of an end product or "humus" which is a consistent, dark brown, soil-like material containing largely mesophilic bacteria.

Keener et al. (2000) and Bagley (2002) explained that in the early stage of the first phase of carcass composting, the decomposition process is anaerobic in and around the carcasses, but later, liquids and gases move away from the carcass into the co-compost material, which is an aerobic zone. Subsequently these gases are trapped in the surrounding supplement material and degraded by microorganisms to carbon dioxide and water. The surrounding material supports bacteria and forms a biological filter (biofilter). According to this concept, naturally occurring organisms change and convert the body of a dead animal (a good source of organic nitrogen) and carbon material into a stable and relatively homogenous mixture of bacterial biomass and humic acids used for soil amendment.

What happens during composting

Due to the considerable physical, chemical, and biological changes that occur during the composting process, the natural degradation of biomass components does not occur in a steady state, but rather in unsteady conditions. Though there is no obvious or distinct delineation between the two phases or stages of the composting process, some researchers, including Haug (1993), Diaz et al. (1993), Manser and Keeling (1996), Glanville and Trampel (1997), Keener et al. (2000) and Kube (2002), have divided the entire composting process into two major phases. Haug (1993) indicated that the first phase (also called the developing or heating phase) is characterized by high oxygen-uptake rates, thermophilic temperatures, and high reductions in bio-degradable volatile solids (BVS). This phase, which may last three weeks to three months, is also characterized by a higher potential for significant odor than that of the second phase.

The second phase (also called the maturation or curing phase), may require one month or longer for completion. In this phase, aeration is not a determining factor for proper composting, and, therefore, it is possible to use a low-oxygen composting system. A series of retarding reactions, such as the breakdown of lignins, occurs during this maturation or curing stage and requires a relatively long time. According to Bollen et al. (1989), the maturation phase could be as long as five months at temperatures below 40°C (105°F).

Bollen et al. (1989) and Keener et al. (2000) categorized the first phase of the carcass composting process into three sub-phases: initial, high rate, and stabilization. In the initial sub-phase which lasts one to three days, the temperature increases from ambient to as high as 43°C (110°F), and mesophilic microorganisms degrade sugars, starches, and proteins. In the second sub-phase (high rate), which lasts 10-100 days, the temperature increases from 43°C (110°F) to nearly 71°C (160°F), and thermophilic microorganisms degrade fats, hemicelluloses, cellulose, and some lignins. Finally, in the third sub-phase (stabilization) which lasts 10-100 days, the temperature declines and remains above 40°C (105°F). During this final sub-phase, further degradation of specific celluloses (probably shorter chains), hemicelluloses, and lignins occurs, and mesophilic microorganisms recolonize. The high temperatures in the first two sub-phases (initial and high rate) of composting are a function of the amount and degree of uniformity in aeration, moisture content, and composition of required materials. During equivalent phases in the composting cycle, the temperature of a pile in which carcasses are composted will be in lower than that of a pile in which organic plant residues are composted, unless physical and chemical conditions are optimized to provide microbiological uniformity and adequate aeration. Additionally, the compost pile must be large or have insulating material to maintain high temperatures, as described by Keener et al. (2000).

Factors affecting the composting process

This section provides a summary of factors key to a successful composting process, including temperature, time, porosity, and aeration.

Temperature

One of the most critical factors in carcass composting (especially in the developing phase) is temperature. Studies by Harper et al. (2001), Keener and Elwell (2000), and Langston et al. (2002) demonstrated that the rate of the decomposition process at thermophilic temperatures (40 to 71°C [105 to 160°F]) is much faster than that at mesophilic temperatures (10 to 40°C [50 to 105°F]). They reported that the thermophilic process generates its own heat, and a properly constructed compost pile is self-insulating to maintain higher temperatures and encourage rapid decomposition. One of the advantages of thermophilic temperatures is inactivation of weed seeds which may be present if the animals ingested weeds. Looper (2002) reported that weed seeds are usually destroyed at 62°C (145°F). The temperature rise is affected not only by the type of microorganisms present and the co-composting materials used, but also by moisture content, as well as the size and depth of carcasses in the co-composting materials. Mukhtar et al. (2003), studying the compost process of large cow and horse carcasses with and without placement on pallets, measured the rise in pile temperature along with the corresponding ambient temperature and precipitation amount. Figures 1, 2, and 3 in Appendix B show that the following results were obtained from this study:

- Because the composting process for the horse and cow carcasses was initiated in different seasons with quite different rainfall amounts (1 in [2.5 cm] for the horse versus approximately 8 in [20 cm] for the cow), the rise in compost pile temperature lasted one month for the horse carcass and five months for the cow carcass (Figures 1 & 2, Appendix B).
- Within a few days of pile construction, the temperature both below (bottom) and above (top) the composted cow and horse carcasses on pallets exceeded 55°C (131°F), and the temperature below the carcasses remained 5-10°C (41-50°F) higher than that above the carcasses. This is explained by drying of the pile (Figure 2, Appendix B).
- Compost piles containing cow and horse carcasses without pallets were turned (aerated) after three months. This aeration, coupled with a series of rainfall events preceding aeration, caused a significant increase in microbial activity and resulted in the cow compost pile reaching the highest temperature of 74°C (165°F) within five days of aeration (Figure 3, Appendix B).
- Due to differences in moisture and nutrient contents of cow and horse carcasses, the

temperature within the cow compost pile remained above or near 55°C (131°F) for the three months after aeration, whereas the temperature within the horse compost pile continued to decrease, with occasional upward swings due to rainfall events (Figure 3, Appendix B).

Most researchers believe that when the overall compost temperature reaches 55-60°C (131-140°F), it should remain at this temperature for one to two weeks. For more confidence on pathogenic bacterial inactivation, the core temperature of carcass composting should reach 65°C (149°F) and remain at this level for one to two days. That is, the compost pile could be turned or displaced with minimal risk of spreading pathogenic bacteria when these time and temperature criteria have been achieved. Furthermore, if the compost pile temperature exceeds 65°C (149°F) for more than two days, it should be turned and aerated to prevent thermal inactivation of beneficial microorganisms.

That is, although higher compost temperatures are beneficial in terms of more rapid decomposition and more effective pathogen elimination, excessively high temperatures may inactivate desirable enzymes produced by beneficial microorganisms. Microorganisms, such as *Aspergillus niger* and *Trichoderma reesei*, that convert cellulose, hemicellulose, and lignin to smaller molecules are destroyed when exposed to high temperatures (60 to 70°C [140 to 158°F]) for more than two to three hours (Busto et al., 1997; Jimenez et al. 1995). Miller (1993) confirmed the fact that fungi effectively assimilate complex carbon sources such as lignin or cellulose that are not available to most bacteria; however, fungal activity is greatly restricted above 55°C (131°F). They observed that at high compost temperatures (60 to 70°C [140 to 158°F]), many carbon-digesting enzymes will be inactive, nitrogen compounds will be lost, and more unpleasant nitrogen gas odors will be produced. Kube (2002) mentioned that microbial activities declined at compost temperatures above 65°C (150°F), and retarded at temperatures of more than 71°C (160°F).

Time

The time required to complete the composting process depends on a variety of factors, including the temperature profile achieved, the species being composted, the compost formulation, as well as preparation, mixing, aeration, and monitoring conditions. Generally, composting time is shorter in warmer climates than in colder climates. The size and weight of carcasses has a direct effect on the time required for completion of the composting process. A longer time is required to decompose heavier and intact carcasses. In order to facilitate the use of mathematical models to predict the required space and time for carcass composting, Keener et al. (2000) classified carcasses into four different weight groups, as follows:

- Small – less than 50 lb (23 kg), such as poultry
- Medium – 50-250 lb (23 to 114 kg), such as swine
- Large – 250-500 lb (114 to 227 kg)
- Very large – those exceeding 500 lb (227 kg)

The time at which piles are moved from primary to secondary stages (turning time) for small carcasses (such as poultry) is about seven to ten days, for medium sized carcasses (such as pigs) is about 90 days, and for large carcasses is about six months. Table 1 in Appendix C, adapted from Monnin (2000), shows the time needed for primary, secondary, and storage stages.

Harper et al. (2001) reported that effective composting of 405 lb (184 kg) of porcine mortality tissue was successfully done in 171 days (about six months). Murphy and Carr (1991) reported that composting of broiler carcasses required two consecutive seven-day periods to reduce carcasses to bony residues, and the materials continued to react and stabilize for extended periods when stored for 6 or more months. Fulhage (1997) indicted that a composting time for medium weight carcasses (such as swine) of three months in the first phase and three months in the second phase usually provides an acceptable finished product. Keener and Elwell (2000) explained that the composting time for moderate size animals (pigs, sheep, etc.) is generally less than three months after the last carcass has been placed into the pile.

Sander et al. (2002) reported that composting of intact pig and cattle carcasses takes nine to ten months, but they may biodegrade more quickly if partitioned or cut open prior to composting. To decrease composting time and to allow the carcass to be laid flat, Bagley (2002) and Looper (2002) recommended opening the body cavity of the animal before composting.

Looper (2002) stated that decomposition of a mature dairy cow carcass generally takes six to eight months, with a few small bones remaining. It was noted that after eight weeks, 90% of the flesh was decomposed and the bones were cleaned. After four months, it was somewhat difficult to find carcasses in the pile with only several small bones present (seven to ten bones per carcass).

Porosity

The oxygen available for the composting process depends highly on the voids and porosity of the pile. These important factors are related to bulk, packed, and true densities of the compost mixture. According to Keener et al. (2000) and Looper (2002), particle size controls the porosity (air space) of the pile and allows air to penetrate and maintain oxygen concentrations to optimize microbial growth. They recommended the porosity, or small open spaces, should be around 35-40% of the pile volume. In a composting process, decomposition occurs on particle surfaces, and degradability can be improved by reducing the particle size (which increases the surface area) as long as porosity is not a problem (Rynk, 1992).

Optimum porosity is achieved by balancing particle size and water content of the materials in the compost pile. Porosity not only affects temperature, resistance of organic material to the decomposition process, and availability of oxygen, but also impacts the aeration process, microbial growth, kinetic reaction rates, and the time required for complete composting. Harper et al. (2001) indicated that the porosity of the bulking agent allows entry of oxygen and promotes the composting process. The decomposition process will not proceed fully in the absence of adequate air penetration, which can be due to "packing" of the pile or to excessive moisture content. Instead of homogenizing the compost content (for the purpose of increasing porosity), Harper et al. (2001) increased the porosity of the compost pile by mechanically disturbing or "turning" the pile thereby introducing oxygen into the material.

Aeration

The "aeration process" is important in maintaining uniform temperature and moisture content throughout the pile during the first and second phases. When the temperature appears to decline, the pile should be aerated (moved, turned, mixed, or stirred) to reactivate the process and increase the temperature. Lasaridi and Stentiford (2001) studied the effects of aeration by turning at weekly intervals a windrow pile in which organics were composted and found high core temperatures (up to 74°C [165°F]) due to high aerobic fermentation. Tiquia et al. (2002) also studied the temperature profiles and dynamics of yard trimmings composting in a windrow system and showed a rapid self-heating of the compost mass from an ambient temperature of 20°C (68°F) to 71°C (160°F) in the first 24 hours of the decomposition process. This thermophilic temperature generated by the aeration process was sustained until day 14, then decreased to ambient towards the end of the process (day 63).

To ensure adequate aeration, the particle size of composting materials should range from 1/8 to 1/2 inch (3.1 to 12.7 mm) in diameter (Looper, 2002). Moving and turning the compost pile helps to increase air penetration. Keener et al. (2000) suggested that moving a carcass compost pile from a primary to a secondary bin introduces air back into the pile and mixes the contents, leading to more uniformity in the finished compost.

Aeration has a considerable effect on the quality of the finished compost product. Umwelt Elektronic GmbH and Co. (2003) studied the odor units (OU) of an organic compost pile equipped with an Oxygen Regulated Aeration System, which worked on regular intervals and measured the odor units at its open rectangular heap. The OU of fresh material (0 days), and those observed after 3, 10, and 75 days, respectively, were 9,500, 1,805, 336, and 90 OU/m^3 (269, 51, 10, and 3 OU/ft^3). That is, within 3 days the odor level was reduced by more than 80% compared to the original fresh materials.

Measuring the oxygen content in windrow composting materials is very important. The oxygen content of the composting mass is mainly affected by the amount of aeration. According to Umwelt Elektronic GmbH and Co. (2003), air quantity above that which is necessary for the composting process unnecessarily withdraws water from the decomposition material. Furthermore, depending on the water content of the additional air and the temperature of the windrow, aeration can withdraw water in quantities up to 0.25 kg/m^3 (0.016 lb/ft^3) of injected air. In this case, degradation will be slowed and the windrow must be watered and re-stacked.

Changes in pile properties during composting

The most important changes that occur in a carcass compost pile are weight and volume loss, pH changes, and production of gases and odors.

Weight and volume loss

The biochemical reactions of the composting process transform large organic molecules into smaller ones, and produce different gases and odors. As a result, the weight of the end product becomes much less than that of the parent materials. Due to their different natures, carcasses and co-composting materials have different rates of shrinkage during the compost process. According to Langston et al. (2002) and Kube (2002), after three months of composting swine and cow carcasses, the final volume of the piles was 20% and 25% less, respectively, than that of their originals. Thus the average shrinkage rate of the whole compost pile was about 0.2-0.3% per day. Looper (2002) reported that in a properly managed compost pile in which a core temperature of around 63°C (145°F) was obtained in three to four days, the volume of cattle carcasses was reduced to one-half of the original after approximately two weeks. Harper et al. (2001) reported that the final weight of 26.1 kg (58 lb) of afterbirth and dead piglets after composting for two weeks was only 3.1 kg (6.9 lb), and the remaining tissue was easily crumbled in the sawdust medium. In this experiment, the average daily weight loss was more than 6% of the original animal mass. Due to significant changes in mass and volume of composted carcasses, the bulk density of finished product decreases considerably, and, if added to agricultural soils, may potentially increase the overall porosity and aeration.

pH

A high-alkali or low-acid environment is not well-suited to the composting process. Since the bio-degradation process releases carbon dioxide (CO_2, a weak acid) and ammonia (NH_3, a weak base), the compost process has the ability to buffer both high and low pH back to the neutral range as composting proceeds (Haug, 1993). Based on this fact, the right amount of carbon and nitrogen sources (for production of these two essential gases) is very important. Carr et al. (1998) remarked that a proper carbon-to-nitrogen (C:N) ratio keeps pH in the range of 6.5 to 7.2, which is optimum for composting. If the pH approaches 8, ammonia and other odors may become a problem. They suggested that the pH could be reduced by adding an inorganic compound, such as granular ferrous sulfate. Langston et al. (2002) indicated that a pH of 6.5-8.0 is one of the requirements for optimum conditions composting swine carcasses.

Gases and odors

Fermentation and oxidation of carcasses during composting produces unpleasant gases (CO_2, NH_3, hydrogen sulfide or H_2S, etc.) and odors associated with the liquid or solid biomass. Different methods have been suggested to neutralize the unpleasant effects of these gases. Some researchers used wood ash as an absorption medium. Rosenfeld and Henry (2001) studied the use of activated carbon and wood ash to neutralize odors produced from wastewater, compost, and biosolids including dimethyl-disulfide, dimethyl-sulfide, carbon disulfide, ammonia, trimethyl-amine, acetone, and methyl-ethyl-ketone. While the activated carbon had 87% carbon, they demonstrated that increasing carbon concentrations and surface areas of wood ash (as a co-composting material) increased the odor absorbing capacity. Wood ash with about 30% carbon possessed characteristics similar to activated carbon and was able to absorb compost odors effectively. A properly covered compost pile that is biodegrading carcasses under aerobic conditions should generate little or no odor.

Carcass composting microorganisms

The microorganisms necessary for carcass composting are often present naturally in the raw materials. According to Rynk (1992), Morris et al. (1997), and Langston et al. (2002), composting is a biochemical conversion of materials and is mainly carried out by sufficient catalytic bacteria, enzymes, etc. within the mortalities to degrade them over time. Rynk (1992) observed that larger organisms such as worms and insects also play a minor role in composting at lower temperatures (near room temperature).

Due to the heterogeneity of microorganisms in similar compost piles, and even within different sections of a single pile, and due to continuously changing microbial activities, no one species or organism dominates. Due to this diversity and mixture of microorganisms, the composting process continues even when conditions vary from pile to pile, or time to time.

The mesophilic and thermophilic species of three types of microorganisms (bacteria, fungi, and actinomycetes) are active in carcass composting. Rynk (1992) indicated that bacteria are the most numerous of the three, and generally are faster decomposers than other microbes. Conversely, fungi are larger than bacteria and form a network of individual cells in strands or filaments. While they are more tolerant of low-moisture and low-pH conditions than bacteria, they are less tolerant of low-oxygen environments. Fungi are also better at decomposing woody substrates and other decay-resistant materials (Rynk, 1992). Rynk also stated that the actinomycetes are smaller and form filaments like fungi, but have a low tolerance for acidic conditions. They tend to become more pronounced after compounds are easily degraded and when moisture levels are low.

Different types of microorganisms are more active at different stages of composting. According to Rynk (1992), bacteria tend to flourish especially in the early stages of composting before the easily degraded materials are consumed. The fungi and actinomycetes become more important near the end of the composting process, feeding on the resistant materials that remain.

As a compost pile heats up, thermophilic organisms play a major role and the activity of mesophilic organisms is retarded, though they may continue to survive. If the temperature rises to about 70°C (160°F), nearly all active microorganisms die, leaving only the heat-resistant spores formed by certain species of bacteria and actinomycetes. As the pile cools again, spore-formers, thermophilic populations, and then mesophilic populations recover. Eventually the pile cools enough to be inhabited by common soil microorganisms, protozoa, worms, mites, insects, and other large organisms that feed upon microorganisms and organic matter.

In a commercial composting operation where speed and uniformity of end product are important, trained staff can carefully control the composting process. Langston et al. (2002) indicated that specific organisms and enzymes or inocula cultured for specific environmental conditions can enhance and speed up the composting process. The inocula are arbitrarily added to the materials to improve the efficiency of composting. Although most studies have shown that inocula are neither necessary nor advantageous to composting, Rynk (1992) suggested that they might be beneficial for materials lacking in large colonies of microorganisms (such as sterilized food wastes). In general, it is best to inoculate fresh material with active compost made from that same material.

Like other aerobically-respiring organisms, bacteria involved in carcass composting have certain needs. Murphy and Carr (1991) remarked that providing good supplement materials, along with suitable physical and chemical conditions, leads to high biological activities. Providing oxygen (in 25 to 30% free airspace), nutrients in necessary proportions and adequate amounts (for example, 15 to 35 parts carbon to 1 part nitrogen), water (about 45 to 55%), bulky materials (mass retains heat and maintains optimal thermal environments for respiration), and time (enough for the degradation process) are essential for the efficient activities of mesophilic and thermophilic bacteria. Compost microorganisms continue to react with the materials and stabilize the compost for extended periods when stored for six months or more. As previously noted, a compost pile will fail to heat up, or may become malodorous, if the moisture content exceeds a certain level. This is because saturated piles quickly exclude the needed oxygen, retarding the growth and activities of some aerobic microorganisms and forcing them to survive by adapting to anaerobic conditions.

3.2 – Carcass Composting Options

Important factors in converting carcasses to high-quality end products are selecting an appropriate composting system and employing appropriate management techniques for the system selected. Composting can be carried out in a variety of configurations, namely windrow, bin, or in-vessel systems. Mescher et al. (1997) explained that both windrow and bin composting systems work well in spite of differences in initial cost and management requirements. This section provides a discussion of various composting system options.

Regardless of composting configuration, the carcass compost pile represents an inconsistent mixture that consists of an animal mass with large amounts of water, high-nitrogen and low-carbon content, and low-porosity surrounded by a co-composting material of good-porosity, high-carbon, low-nitrogen, and moderate moisture levels. Mortality composting has two different stages, primary and secondary. Monnin (2000) indicated that the primary stage reduces the mortality so that only large bones remain, and the secondary stage allows complete decomposition of the mortality and stabilizes the compost.

Windrow composting

A windrow design allows the composting process to take place in a static pile. No walls or roofs are employed in this system, thus loading, unloading, and turning from all sides of the pile is possible. Usually windrows are built in open spaces and not protected from weather, rain, or wind, thereby exposing the pile to more adverse weather conditions which can affect the operation of the pile. Figures 1, 2, and 3 in Appendix C illustrate the general windrow cross section and layout, layers of poultry carcasses in cross sections of a windrow, an actual photo of a poultry compost pile, completed poultry mortality composting, and finally the layout of a carcass compost site with large round bales.

Keener et al. (2000) recommended that static piles be established on a concrete pad, or on a geotextile-lined gravel base with low-permeability soil to control water infiltration. In windrow systems, the length of the pile can be extended to accommodate the quantity of mortality to be composted. Windrow piles are mounded to shed rainfall for better control of moisture, temperature, gases, and odors, and to maintain adequate biofilter cover. The recommended height for a static system is 5-7 ft (1.5-2.1 m).

This technique is most popular for composting large carcasses or significant quantities of mortality. Carcasses, nutrients, and bulking agents are placed in specific orders and turned periodically, usually by mechanical equipment. Haug (1993) stated that the required oxygen is supplied primarily by natural ventilation resulting from the buoyancy of hot gasses in the windrow, and, to a lesser extent, by gas exchange during turning. Aeration is also achieved by moving and turning the pile. Mescher et al. (1997) reported that after the windrow pile is allowed to compost for a minimum of 90 days (first phase period) it is aerated by moving to a secondary area where it completes another 90-day period (second phase of composting). At that time, a new primary compost pile can be constructed in the area previously occupied by the turned pile. In this management system, piles are continually being built and moved onto the composting pad. The initial cost for a windrow-composting facility is reportedly less than that of a bin-composting facility; however, more intense management is required for a windrow system.

Bin composting

Bin composting refers to the simplest form of a contained composting method. In this system, carcasses and co-composting materials are confined within a structure built from any materials that is structurally adequate to confine the compost pile material (Fulhage, 1997; Mukhtar et al., 2003). Bin structures may or may not be covered by a roof. A simple and cheap bin system can be constructed of large round bales placed end-to-end to form three-sided enclosures or bins, allowing the pile to be protected from predators, pests, and runoff. These types of bins, which sometimes are called bale composters, are located in free space without any roof. They are more susceptible to precipitation and weather variation. Figures 4, 5, and 6 in Appendix C show the schematic layouts and actual views for such structures. Conversely, roofed composters have the advantages of reduced weather effects, less moisture and potential leaching from the pile, and better working conditions for the operator during inclement weather (Fulhage, 1997).

A smaller version of a bin composter is called a mini-composter. As Keener and Elwell (2000) specified, the size of carcasses that can be placed in these bins is usually limited to less than 40 lb (18 kg). In cold climates additional insulation may be needed to enable the mini-composter to reach the desired temperatures (> 55°C or 131°F) for pathogen destruction and effective degradation.

While the costs of establishing some types of bin composting systems are higher than those of windrow systems, bin composting has some advantages. According to Rynk (1992), the structure of bin composting allows higher stacking of materials, better use of floor space than free-standing piles, elimination of weather problems, containment of odors, and better temperature control.

A summary of processing practices and management procedures used in the first and second phases of bin composting is discussed below.

Primary phase

A base of litter (or litter-sawdust, litter-shavings mixture) with a thickness of 1.5-2 ft (45-60 cm) should be placed in a fresh bin about two days before adding carcasses to allow for preheating of the litter. Immediately prior to introducing carcasses, the surface of the pre-heated litter (about 6 in [15 cm]in depth) should be raked back and the carcasses should be placed in the hot litter. A minimum of 1 ft (30 cm) of litter should remain in the base of the compost pile for absorbing fluids and preventing leakage. Carcasses should not be placed within about 8-12 in (20-30 cm) of the sides, front, or rear of the compost bin to prevent heat loss. Carcasses should be completely covered and surrounded with the preheated litter.

Carcasses can be placed in the bin in layers, although a 1-ft (30-cm) thick layer of carbon source material is necessary between layers of carcasses to insulate and maintain compost temperature. As a final cover material, carcasses should be completely covered with approximately 2 ft (60 cm) of sawdust, or a minimum of 2.5 lb (1.1 kg) of moist litter per pound of carcass, to avoid exposed parts or odors that attract flies, vermin, or predators to the pile and to minimize fluids leaching out of the pile.

Secondary phase

After moving the pile to the secondary bin, it is covered with a minimum of 4 in (10 cm) of co-composting materials (such as straw and woodchips) to ensure that exposed carcass pieces are covered. This additional cover helps insulate the pile, reduce odor potential, and ensure decomposition of remaining carcass parts. Moisture is added to the materials (40-60% wet basis) to allow the pile to reheat and achieve an acceptable end product. An adequately composted finished product can be identified by a brown color (similar to humus) and an absence of unpleasant odor upon pile turning. Note that some identifiable carcass parts, such as pieces of skull, leg or pelvic bones, hoofs, or teeth may remain. However, these should be relatively small and brittle (or rubbery) and will rapidly disappear when exposed to nature.

Table 2 in Appendix C provides a typical schedule that can be used for bin composting various small and medium size carcasses.

In-vessel carcass composting

Although bin composting of small numbers or volumes of carcasses has proven to be a practical method with advantages that include simplicity, low maintenance, and relatively low capital costs, composting of large numbers or volumes of carcasses in this way is more difficult. Various means of composting in fully contained systems (vessels) have been evaluated and are briefly reviewed here.

Aerated synthetic tube

An in-vessel system of composting organics using aerated synthetic tubes called EcoPOD (Preferred Organic Digester) or Ag-Bags has been available commercially for the past 10 years (Ag-Bag Environmental, 2003). As shown in Appendix C, Figure 7, the system consists of a plastic tube about 5-10 ft (1.5-3 m) in diameter and up to 200 ft (60 m) long. These tubes are equipped with an air distribution system connected to a blower. Raw materials are loaded into the tube with a feed hopper. Tubes used for medium or large intact carcasses are opened at the seam prior to loading raw materials and then sealed for forced air distribution during composting.

Farrell (2002) used the Ag-Bag system and successfully composted bio-solids with grass clippings and chipped brush and wood. The woody materials were ground to a 3-in (7.5-cm) size before composting, and reground to 1.5 in (3.8 cm) after composting. The materials were composted in the bags for eight to ten weeks at temperatures reaching 70°C (160°F). Finished product can remain in the bags long after composting is complete. In 2002, Ag-Bag Environmental (2003) in cooperation with the USDA Animal and Plant Health Inspection Service (APHIS) composted over 100,000 birds infected with avian flu virus depopulated from poultry houses in West Virginia. According to their reports, the composting process was completely aerobic and acceptable to USDA-APHIS.

Cawthon (1998) used this forced-air, in-vessel system for composting poultry mortalities. A mixture of hay and poultry carcasses at moisture contents of 30-35% was combined with poultry litter as a co-composting material. Temperatures inside the tube ranged from 70 to 82°C (160 to 180°F) after 5 to 7 days of composting. The high temperature of 82°C (180°F) was attributed to litter dust in the co-composting materials. This system was also used by Cawthon and Beran (1998) to compost dairy manure. Temperatures in the tube at different locations ranged from 60 to 70°C (140 to 160°F) after one week of composting. In both cases, some spoilage of ingredients and rotting parts of the carcasses were observed in the finished products. Figure 7 in Appendix C shows the poultry carcasses and carcass parts being added to the aerated synthetic tube (Ag-Bag). Experiments by Haywood (2003) demonstrated difficulties in composting medium to large size carcasses in the aerated synthetic tube system; end products were observed to have disintegrated into solid and liquid portions with visibly rotten carcasses remaining. These results were attributed to anaerobic conditions within the tube arising from non-uniform air distribution caused by inconsistent (non-homogeneous) mixing of materials prior to loading into the tube.

The aerated synthetic tube system offers several advantages, including a reduction in composting time, a reduction in the land area required, elimination of odors and leachate production, and a reduced potential for negative impacts by inclement weather. However, the system is not practical for composting larger carcasses (e.g., swine and cattle) unless they are ground and thoroughly mixed with an appropriate quantity of bulking agent to provide more than 30% porosity (Cawthon, 1998). While this aerated synthetic tube system currently has potential for composting small or ground carcasses, further research is needed to address issues of air distribution, porosity, uniform packing, and exhausting of accumulated gases to prevent incomplete and anaerobic digestion.

Other vessel systems

Using a vessel for the first phase of carcass composting is another approach to minimizing the time and management requirements. Although the application of vessel and rotary vessel composting for carcasses has not been practiced extensively, using this system for composting other similar products provides an indication of its practicality. Cekmecelioglu et al. (2003) evaluated a system for composting a mixture containing food waste, manure, and bulking agent in a stationary polypropylene vessel for 12 days with aeration based on a 1/40 minute (1.5 sec) on/off operation cycle and compared its performance and final product with a conventional windrow composting system. They obtained the highest temperature rise of 50°C (122°F) for vessel composting and reported that the best recipe for mixing food waste, manure, and bulking agent respectively was 50%, 40%, and 10% w/w. They observed similar inactivation trends for fecal coliforms and pathogenic microorganisms in both in-vessel and windrow composting systems. While further research is needed to determine the applicability of this system, these results indicate that in-vessel composting may be a good option for carcass composting.

Pre-processing (grinding) of carcasses

One factor being evaluated is preprocessing (e.g., grinding) of carcasses; this pre-processing step can be used in combination with almost any composting configuration. Any process that minimizes composting time will result in a more efficient operation that is easier to manage. In this respect, grinding of cow carcasses and mixing with carbon source materials prior to composting has been practiced by some. Kube (2002) mixed ground Holstein steers (approximately 450 kg or 1000 lb) with sawdust and composted in a windrow system. At the same time, he composted intact Holstein carcasses in a windrow system. The grinding process decreased the time required to compost cow carcasses from twelve months to six months, in spite of the fact that only one turning process was employed rather than the standard three. In fact, combining grinding and turning processes condensed the composting time considerably.

Recently Rynk (2003) evaluated ground carcasses mixed with co-composting material in a system in which the primary composting phase was carried out in a rotating vessel or drum followed by windrow composting. Results indicated that turning the mixture every 15 days reduced the composting time to 75 days. Although this system may require more capital investment, overall it is less expensive than conventional bin or windrow composting. When adequate grinding capacity is available, this system has the potential to speed up carcass composting and facilitate high capacity. According to Rynk (2003), this method has the following advantages:

- Diminishes the composting time and thus management cost.
- Reduces the co-composting materials up to one-fourth of the conventional system.
- Decreases the risk of odor production and risk of scavengers
- Allows better control over key composting parameters such as temperature pattern, pH, particle size, and color.
- Produces a more uniform product.

The Colorado Governor's Office of Energy Management and Conservation (CGOEMC, 2003) used a vertical dairy-type grinder-mixer (up to 500 revolutions per minute) for preparation and mixing of mortalities and bulking agent prior to composting. Because the grinder produced material with a much larger surface area exposed to oxygen, compost bacteria could attack and decompose the materials much easier. By using this grinding step, the weight ratio of bulking agent to carcasses was reduced from 4:1 (for typical bin composting) to 1:4. Compared to bin composting, the composting time was also decreased by 30 to 60%, resulting in reduced management, labor, and overall cost.

A key advantage of grinding is the possibility of directly cutting and mixing carcass material with proper amounts of various bulking agents such as straw, grass, weeds, non-woody yard waste, sawdust, wood shavings, old alfalfa, and woody materials (tree branches, processed wood, etc). Additionally, homogenizing and adjusting the moisture content to 60 to 70% is much easier than conventional bin or windrow carcass composting.

3.3 – Compost Design and Layout

The concept of design in carcass composting is to have suitable capacity and even flow of input and output materials while maintaining quality. Fulhage (1997) indicated that a composting system must be designed so that it can be filled and emptied on a schedule as needed to "keep up" with the flow of carcasses. However, undersized or oversized capacities (due to improper design) may cause anaerobic fermentation, insufficient thermophilic activities, inadequate temperature rise, incomplete destruction of pathogenic bacteria, production of unpleasant gases and odors, and may introduce some environmental contamination. In this section the issues of design parameters, layout, and construction features of bin and windrow composting systems are discussed.

Design parameters

Choosing the right design parameters for an effective composting facility is important for a successful operation. Researchers such as Dougherty (1999), Keener and Elwell (2000), Morse (2001), Langston et al. (2002), McGahan (2002), and Tablante et al. (2002) considered the following design principles for bin and windrow carcass composting systems:

- Two composting phases, namely primary and secondary.
- Storage of end products for recycling and flexibility in land application. The storage volume must be greater than or equal to the secondary bin size since it must hold all material emptied from a secondary bin.
- Daily mortality rate and composting time, which determines total loading for the primary phase.

Based on the original weight of carcasses, the weight of co-composting materials, and the daily weight loss of the compost, mathematical models have been developed for predicting the time, volume, and/or capacity of primary, secondary, and storage phases of composting systems. According to the CGOEMC (2003) manual, under standard conditions, for every 10 lbs (4.5 kg) of mortality, there is a need for about 4.25 L (1.5 ft^3) of combined bin capacity for the primary phase of composting (Rynk, 2003).

Murphy and Carr (1991) stated that the capacity of bin systems for composting poultry depends on theoretical farm live weight. They presented the following formula as a model for estimating the peak capacity of dead poultry for the first phase of composting, which was based on the market age and weight of birds (Example 1 in Appendix D shows how these formulae can be applied in different poultry and broilers operations):

Daily composting capacity = Theoretical farm live weight /400 (1)

Theoretical farm live weight = Farm capacity x market weight (2)

Morris et al. (1997) used the bulk density of composting materials to estimate the needed primary and secondary bin areas for mortality composting using the following equations (Example 2 in Appendix D shows how equations (3) and (4) can be applied):

$$A_1 = n.\ W / h.\ d_1 \quad (3)$$

$$A_2 = n.\ W / h.\ d_2 \quad (4)$$

Where: A_1 and A_2 are, respectively, the needed areas for the primary and secondary bins, W is the average weight in kg of each carcass to be disposed, n is the number of carcasses per year, h is the height of the bins, d_1 and d_2 are, respectively, the bulk densities of composting material at the beginning of first and second phase of composting (respectively, about 600 and 900 kg/m^3).

Keener and Elwell (2000) developed models based on the results of experiments for a bin system for poultry (broilers), a windrow system for swine (finishing), and a windrow system for cattle (mature). They assigned a specific volume coefficient of 0.0125 m^3/kg mortality/growth cycle (0.20 ft^3/lb mortality/growth cycle) for calculating primary, secondary, and storage volumes (V1, V2, and V3, respectively). As discussed earlier, the composting times of primary, secondary, and storage phases (T1, T2, and T3, respectively) are affected by various factors in the composting pile and are not equal to each other. Based on the above-mentioned information, they suggested the following models for calculating composting time and volume needed for primary, secondary and storage phases:

$$T_1 = (7.42)\ (W_1)^{0.5} \geq 10, \text{ days} \quad (5)$$

$$V_1 \geq (0.0125)\ (ADL)\ (T_1),\ m^3 \quad (6)$$

$$T2 = (1/3)\ (T1) \geq 10, \text{ days} \quad (7)$$

$$V2 \geq (0.0125)\ (ADL)\ (T2),\ m3 \quad (8)$$

$$T3 \geq 30, \text{ days} \quad (9)$$

$$V3 \geq V2 \quad \text{or}$$

$$V3 \geq (0.0125)\ (ADL).\ T3),\ m3 \quad (10)$$

Where: W_1 is the average weight of mortality in kg, and ADL is an average daily loss or rate of mortality in kg/day. The Ohio State University Extension service (OSUE) in 2000 prepared data in regard to poultry, swine, cattle/horses and sheep/goats mortality rates and design weights, which are shown in Tables 1a and 1b of Appendix D. This will determine the mortality produced from operations in kg (lbs)/year, and the average daily-loss for composting in kg (lbs)/day. For using equations (5) to (10), Keener and Elwell (2000) considered the following items:

- The first parameter required for calculation of compost volume and capacity is annual livestock death loss. The worksheet of Table 2 in Appendix D shows how to calculate this important parameter.
- In estimating composting time, the primary and secondary composting times for heavy animals (exceeding 500 lb [227 kg]) were assumed as a ceiling time.
- Equations (6), (8), and (10) provide reasonable values of V1, V2, and V3 for composting small weight carcasses (less than 50 lb [23 kg], such as poultry) and medium weight animals (50 to 250 lbs [23 to 114 kg], such as swine) in bin and windrow systems.
- Table 3 in Appendix D represents the worksheet for calculating primary, secondary, and storage bin volumes, as well as the relation between bin volume, width, and length.
- For composting a large mass of carcasses (more than 250 lb [114 kg]) or very large carcasses (those exceeding 500 lb [227 kg]), a windrow system is recommended because individual primary bins would be large and the placement of animals would be difficult. For mature cattle or horses, a separate pile for individual mortalities is recommended. In these cases it is necessary to use the modified equations described in Table 4 of Appendix D.
- A value of 10 days was used as a minimum for poultry composting work. Since a secondary bin must hold all material emptied from a primary bin, it should be greater than or equal to the primary bin size. The secondary bin sometimes handles volumes up to three times that of the primary bin.
- Storage of the finished compost product is a key factor for having a uniform carcass composting process, and the storage volume should provide enough capacity for a minimum of 30 days. The main reasons were (1) land application of the finished compost may not be feasible at the time of removal from the secondary stage and (2) the finished compost could often be used in the primary stage if limited to less than one-half of the amendment.
- Sometimes an additional bin with dimensions equal to that of the primary bin is used to hold raw materials without initiation of the composting process and is called a waiting or preparation bin. Usually after a preparation process that may take a few days (because of insufficient raw materials), the bin becomes a primary bin of composting.

Based on these data and the prescribed equations, Keener and Elwell (2000) analyzed systems for a 10,000-bird broiler operation, a 2,940-head swine finishing operation, and a 154-cow herd. Results are shown in Tables 5-a, 5-b, and 5-c of Appendix D. Example 3 of Appendix D demonstrates the use of these data for calculating the time and volume for different stages of carcass composting.

Layout and construction features

As discussed earlier, layout and construction features are the two key points in successful carcass composting. Additional information about this matter for both windrow and bin composting systems is provided here.

Windrow composting

Although different cross-section designs for windrow systems have been used in organic composting, they have had limited applications in carcass composting. Recently, some researchers used ground carcasses as a uniform and consistent raw material for windrow composting and observed that, because of the higher rate of decomposition, the turning and mixing processes could be carried out in a manner very similar to that of an organic composting pile. Haug (1993) reported that in a modern windrow process, composted organic materials are turned at regular intervals by specialized mobile equipment that produce cross sections of various shapes (haystack, rectangular, trapezoidal, triangular, etc.) depending largely on characteristics of the composting material and the equipment used for turning. Figure 1 in Appendix D shows the typical cross section (high parabolic, low parabolic, trapezoidal, and triangular) and layout of different forms of windrow composting. Cross sections that push the water are useful in humid climates, and those that keep the water in the top of the piles are useful in dry climates. Mescher et al. (1997) proposed a trapezoidal windrow for primary and secondary carcass composting, and indicated that the side slopes of a windrow in most cases were 1:1 (α=45°). Figure 2 in Appendix D shows the trapezoidal cross-section used for windrow composting of swine mortality along with its pad layout.

The most appropriate location for a windrow is the highest point on the identified site. A plastic liner (0.24 in [0.6 cm] thick) of length and width adequate to cover the base dimensions of the windrow (see below) should be placed on crushed and compacted rock as a moisture barrier, particularly if the water table is high or the site drains poorly. The liner should then be completely covered with a base of co-composting material (such as wood chips, sawdust, dry loose litter, straw, etc). The co-composting material layer should have a thickness of 1 ft for small carcasses, 1.5 ft for medium carcasses, and 2 ft for large and very large carcasses. A layer of highly porous, pack-resistant bulking material (such as litter) 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 0.5 ft for small carcasses, and 1 ft 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 1 ft [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 6 ft (1.8 m). Mortalities should not be stacked on top of one another without an appropriate layer of co-composting materials in between. For large and very large carcasses, only a single layer of mortality should be placed in the windrow. After placing mortalities (or the final layer of mortalities in the case of small and medium carcasses) on the pile, the entire windrow should be covered with a 1-ft (30-cm) thick layer of biofilter material (such as carbon sources and/or bulking agents). See Figures 1, 2, and 3 in Appendix A.

Using this construction procedure, the dimensions of completed windrows will be as follows for the various categories of mortality (note that windrow length would be that which is adequate to accommodate the number of carcasses to be composted):

- Small carcasses: bottom width, 12 ft (3.6 m); top width, 5 ft (1.5 m); and height 6 ft (1.8 m)
- Medium carcasses: bottom width, 13 ft (3.9 m); top width, 1 ft (0.3 m); and height 6 ft (1.8 m)
- Large and very large carcasses: bottom width, 15 ft (4.5 m); top width, 1 ft (0.3 m); and height, 7 ft (2.1 m)

Bin composting

For bin composting, a wide range of structures is possible, including new or existing facilities. Morse (2001) suggested new facilities, such as poured concrete, pole construction, and hoop houses, and for low cost options existing facilities such as machine sheds, corn cribs, or cattle sheds (as long as their ceiling is high enough to allow the front-end or skid loader to lift and turn the compost) have all been used for bin composting in Minnesota.

Fulhage (1997) recommended using bins enclosed on three sides with an opening wide enough for a front-end loader. One of the methods to increase the efficiency of bin composting is modularity, or making compartments in the construction of needed bins. In this respect, Murphy and Carr (1991) suggested the basic unit of carcass composting which includes a dead-bird composter and two multi-compartmentalized features of the bin system. Schematic diagrams of these bin composters are provided as Figures 3, 4, and 5 in Appendix D. Figure 6 in Appendix D shows the overall top and isometric views of a bin layout. According to Glanville (2001), a research unit was built in Iowa that consisted of six composting bins (three primary and three secondary bins) and two storage bins for the woodchip cover material. They were 10 ft (3 m) wide by 12 ft (3.6 m) deep, and designed to be loaded to a depth of 5 ft (1.5 m). These bins were 24 ft x 40 ft post-frame, metal-clad structures with 2-ft overhangs.

Murphy and Carr (1991), Mescher et al. (1997), Glanville (1999), and Langston et al. (2002) provided important guidelines for construction of bins. Bin composters can be constructed of any material structurally adequate to confine the compost pile material (such as concrete, wood, hay, bales etc). Simple and economical bin structures can be created using large round bales placed end-to-end to form three-sided enclosures or bins (sometimes called bale composters). A mini-composter can be constructed by fastening panels with metal hooks to form a box open at the top and at the bottom. Structures should be located and situated so as to protect the pile from predators, pests, and runoff. Bins may or may not be covered by a roof. A roof is advantageous, especially in high rainfall areas (more than 1,000 mm or 40 in annual average), as it results in reduced potential for leaching from the pile and better working conditions for the operator during inclement weather.

An impervious concrete floor (5 in [12.5 cm] thick) with a weight-bearing foundation is recommended to accommodate heavy machinery, allow for all-weather use, and prevent contamination of soil and surrounding areas. If an entire bin is constructed of concrete, bin walls of 6-in (15-cm) thickness are recommended. Walls and panels can also be constructed with pressure-treated lumber (e.g., 1-in treated plywood backed with 2 x 6 studs). To improve wet weather operation, access to primary and secondary bins can be paved with concrete or compacted crushed rock.

The wall height for primary and secondary bins should be 5-6 ft (1.5-1.8 m), and the bin width should be adequate for the material-handling equipment, but generally should not exceed 8 ft (2.4 m). The minimum front dimension should be 2 ft (61 cm) greater than the loading bucket width. The front of the bin should be designed such that carcasses need not be lifted over a 5-ft (1.5-m) high door. This can be accomplished with removable drop-boards that slide into a vertical channel at each end of the bin, or with hinged doors that split horizontally. Hinged doors should be designed to swing back flat against adjoining bins, and removable hinge-pins at both ends should permit the door to swing open from either end. As an alternative to building individual secondary bins, a large area to accommodate materials from more than one primary bin can be used.

3.4 – Raw Material, Energy, and Equipment Requirements

Since carcasses by themselves are not suitable substrates for making a good compost product, it is necessary to combine carcasses with supplementary co-composting materials and provide suitable environmental conditions to initiate the necessary biological, chemical, and physical changes. Additionally, in the event of significant quantities of mortality, equipment for moving, lifting, loading, unloading, dumping, displacement, and pile formation is critical. This section summarizes essential inputs and requirements for an efficient carcass composting process.

Co-composting materials and recipes

Co-composting materials, which serve as a source of moisture and carbon, included at an appropriate ratio are needed for a successful compost process. This section outlines the specifications of co-composting materials and typical “recipes” for use.

Moisture

Water in the compost process has an important role in providing nutrients to the beneficial microorganisms thereby facilitating production of required enzymes. The enzymes produced by the bacteria are responsible for most of the biochemical transformations and, in fact, break down large organic molecules. According to Murphy and Carr (1991), Keener et al. (2000), and Franco (2002), the required moisture content for carcass compost piles depends on the character of the material, but should generally be between 50 and 60% (wet basis). This means that in dry regions and in covered facilities, water must be added to maintain the biochemical reactions. Excess water should be avoided as it has the potential to generate odor and leaching conditions. Murphy and Carr (1991) reported that excessively wet carcass compost piles fail to heat up and become malodorous. Furthermore, saturated piles quickly become anaerobic and exclude needed oxygen. Looper (2002) reported that moisture content of greater than 60% will generate odors and increase the chance of runoff (leachate) from the compost pile. However, turning the compost and adding more dry materials will solve the problem.

Looper (2002) and other researchers suggested a general rule: if the compost mixture feels moist, without water dripping from a handful when squeezed, the moisture is adequate. Water consumption for carcass composting is based on the dryness of co-composting materials. For example, if sawdust is dry, water should be added to obtain a damp feel and appearance. Up to 1–1.5 gal/ft^3 (135–200 L/m^3) of water can be added to each unit volume of sawdust (Fulhage, 1997).

Carbon sources

Achieving a proper ratio of carbon to nitrogen is key to the necessary bacterial processes. A carbon source (co-composting material) is used to cover carcasses and provides a suitable physical, chemical, and biological environment for composting. According to Rynk (1992), Haug (1993), and Sander et al. (2002), carbon sources have properties that enhance the composting process by absorbing excess moisture from carcasses, equilibrating moisture content throughout the whole mass, reducing bulk-density, maintaining higher porosity, increasing air-voids thereby aiding diffusion of oxygen into the pile, allowing proper aeration, speeding the escape of potentially toxic gases like ammonia, reducing the accessibility of composted material to insects and rodents, and increasing the quantity of biodegradable organics in the mixture (and thereby the energy content of the mixture).

Organic materials provide adequate carbon for microbial—specifically fungal—activities, resulting in some scientists like Haug (1993) referring to these materials as "energy or fuel providers." In addition to providing adequate carbon, their physical and chemical composition effectively traps odors and gases released by the carcass composting process. For example, sawdust is an ideal carbon source because of its small particle size, high carbon-content, and ability to absorb moisture or potential leachate generated during composting (Fulhage, 1997). It is also easy to handle. Some researchers like Keener and Elwell (2000) have shown that mixtures of sawdust and straw could be used outside or in covered piles. In roofed piles, straight straw or corn stover can be used alone, but requires periodic water addition during composting to prevent inhibition of the process. Although corn stover does not have all the properties of sawdust, it does have a high C:N ratio, is a good absorbent, and helps facilitate uniform aeration in a compost pile. Looper (2002) indicated that a base material for carcass composting can be created from separated manure solids mixed in a 50:50 ratio with a carbon source. Table 1 in Appendix E shows the C:N ratio of different supplemental materials.

Haug (1993) and Sander et al. (2002) emphasized use of an amendment that is dry, has a low bulk weight, and is relatively degradable. In addition to sawdust and corn stover, many other carbon sources could be used, including poultry litter, ground corncobs, baled corn stalks, and semi dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, refuse fractions, yard wastes, vermiculite, and a variety of waste materials like matured compost. Recently, Mukhtar et al. (2003) used spent horse bedding (a mixture of horse manure and pinewood shavings) for composting cow and horse carcasses and obtained successful results.

Bulking agents. Bulking agents or amendments also provide some nutrients for composting. They usually have bigger particle sizes and thus maintain adequate air spaces (around 25-35% porosity) within the compost pile by preventing packing of materials. Haug (1993) suggested that bulking agents should have a three-dimensional matrix of solid particles capable of self-support by particle-to-particle contact. That is, in order to achieve high porosity and void volumes in the co-composting materials, the particles should have three visible dimensions rather than being flat (having only two noticeable dimensions). Haug (1993) reported that sludge cake could be viewed as occupying part of the void volume between particles and, because of having organic content, it increases the energy of the compost mixture as a secondary benefit. Although wood chips (2.5–5 cm [1–2 inch]), refused pellets, shredded tires, peanut shells, and tree trimmings have been used commonly as bulking agents for organic composting, they have not been used in carcass composting. Hay and straw will also work well as bulking agents. Morse (2001) reported that drier hay or hay with more grass will have more carbon (higher C:N ratio) than greener hay or hay with more legumes (lower C:N ratio). Crop residues such as wheat straw or corn stalks can be used as co-composting materials for carcass composting but may require shredding or some other form of particle size reduction. In choosing a bulking agent, two important factors include availability and cost.

The ratio of bulking agent to carcasses should result in a bulk density of final compost mixture that does not exceed 600 kg/m^3 (37.5 lb/ft^3). As a general rule, the weight of compost mixture in a 19 L (5 gal) bucket should not be more than 11.4 kg (25 lb); otherwise, the compost mixture will be too compact and lack adequate airspace.

Biofilters. A biofilter is a layer of carbon source and/or bulking agent material that 1) enhances microbial activity by maintaining proper conditions of moisture, pH, nutrients, and temperature, and 2) deodorizes the gases released at ground level from the compost piles, and 3) prevents access by insects and birds and thus minimizes transmission of disease agents from mortalities to livestock or humans.

Composting recipes

Producing a good end product without any offensive environmental aspects depends heavily on achieving an adequate balance of composting materials; a proper C:N ratio is key. Murphy and Carr (1991), Glanville and Trampel (1997), Keener and Elwell (2000), Franco (2002), and Bagley (2002) explained that a proper C:N ratio generates adequate energy and produces little odor during the composting process. Acceptable C:N ratios generally range from 25:1 to 40:1, and may even reach as high as 50:1. 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_2 along with heat energy. Mukhtar et al. (2003) composted cow (2,000 lb [909 kg]) and horse (1,100 lb [500 kg]) carcasses using spent horse bedding as a co-composting material. They reported that the initial C:N ratio of 42:1-46:1 was reduced to nearly one-half of the original after nine months of composting in both small and large piles. This was mainly due to the reduced carbon and increased nitrogen contents for both piles. Fulhage (1997) obtained good results by adding 100 ft^3 (2.8 m^3) of sawdust per 1,000 lb (454 kg) of carcasses in a compost bin, and reported that good results could be achieved by amending the mixture with ammonium nitrate to increase the available nitrogen for the process. Werry (1999) observed sawdust to be one of the best mediums to mix with mortalities, and recommended 1 kg (2.2 lb) of sawdust per 1 kg (2.2 lb) of mortalities in a static-pile or windrow. Sussman (1982) suggested an appropriate recipe for converting nitrogenous materials (for example, manure and birds) and carboniferous materials (for example, cellulose paper, straw-stover, and sawdust). The detail of his experiment using poultry and straw as a carbon source has been provided in Table 2, Appendix E.

Dougherty (1999) outlined optimum values of various effective parameters, such as C:N ratio, moisture content, oxygen concentration, particle size, porosity, bulk density, pH, and temperature, of an active compost pile. More information about carbon and nitrogen sources is provided in Tables 3 and 4 in Appendix E, which show typical formulae for a suitable and successful compost process.

Since finished compost retains nearly one-half of the original carbon source content, Fulhage (1997) suggested using finished compost as a carbon source for initial composting. Recycling heat and bacteria in the compost process, minimizing the needed amount of fresh raw materials, and reducing the amount of finished compost to be handled are the main advantages of this procedure. Langston et al. (2002) reported that blending broiler litter and swine carcasses with high-carbon, low-nitrogen materials such as wheat straw and sawdust increased the low C:N ratios from 15:1 to 25 or 30:1 and improved porosity and aeration of the composting process. They reported that wheat straw has been the favored carbon amendment for poultry carcass composting because it has a C:N ratio that may be as high as 150 and is a good absorbent. They suggested that although wood shavings have C:N ratios around 500:1, they are not as absorbent as straw. Additionally, adding sawdust to poultry litter increases the carbon content without substantially increasing the nitrogen content of the compost. They recommended blending sawdust uniformly with the litter and using 2-2.5 lb (0.90-1.13 kg) of this mixture to 1 lb (0.45 kg) of swine carcasses (weight ratio of 2-2.5:1 for co-composting materials to mortality). Carr et al. (1998) suggested ratios of 20:1 to 35:1 for C:N, and 100:1 to 150:1 for carbon-to-phosphorus ratios, for desirable carcass composting.

Heat-energy

The activity of microorganisms inside the compost pile generates heat and causes a controlled or limited combustion. The heat-energy used for chemical reactions has a strong relation with the thermodynamics of the composting process. Since all chemical reactions have a standard free-energy change, Haug (1993) indicated that the free energy is extremely useful because most enzymatic processes occur under such conditions, and the spontaneous chemical reactions proceed in the direction of decreasing free energy. In other words, the available useful free energy is related directly to the feed substrate used by a microbial population. If the free energy change is zero, the reaction is at equilibrium and no substrate is utilized by microorganisms. Haug (1993) reported that if a substrate or mixture of substrates does not contain sufficient energy to drive the composting process, further conditioning for controlling the water at certain levels (either by limiting the drying process, reducing the substrate water content by improved dewatering, or adding supplemental energy amendments) is required to control the energy balance. According to Dougherty (1999), the ability to heat the compost pile and sustain high temperature is affected by the six following factors:

- Chemical, physical, and biological composition of the compost materials,
- Accessibility of nutrients, including carbon, to the composting microorganisms,
- Moisture contents in the source ingredients,
- Aeration rate in the compost pile,
- Structure of the compost pile (particle size, bulk density, and texture),
- Total size and surrounding environment (temperature, humidity, wind, etc.) of compost pile.

Maintaining necessary free-heat energy is critical in terms of the time-and-temperature relationship, which is in turn important in the inactivation of microbes. Proper sizing of composting facilities has considerable influence on heat retention during composting and becomes an important consideration in cold climates in which substantial heat loss can take place at the perimeter of the composting bin (Glanville & Trampel, 1997). Within the temperature range desirable for composting (45 to 65°C), bacterial activity roughly doubles with each 10°C-increase (18°F-increase) in temperature. Glanville and Trampel (1997) indicated that a small composting operation with a low volume (corresponding to a low heat-generating capacity) and high surface area (corresponding to a high potential for heat loss) could be significantly impaired by low temperatures. They studied a poultry carcass process conducted in outdoor bins during the winter with external temperatures ranging from −15 to 0°C (5 to 32°F). They observed that temperatures measured at locations less than 15 cm (0.5 ft) from bin walls were often 25 to 30°C (45 to 54°F) cooler than the temperature near the center of the bin. As the composting bins used in this work were relatively large (2.4 m long x 1.8 m wide x 1.5 m high), composting was not seriously hampered because the cool zone near the walls did not comprise a large portion of the total volume. Looper (2002) suggested that any compost pile requires a layer of inactive material approximately 30 cm (1 ft) thick to insulate and maintain its high temperature.

Equipment and devices

Carcass composting is becoming more widely used and animal producers are expanding their composting management strategies to use the best available and most economically feasible machinery for ease of operation and for avoiding any direct contact with raw materials. According to Dougherty (1999), over 8,000 farms are now composting animal mortalities, manure, crop residues, and selected organic materials from communities and industries. At least 75% of farm composting operations are composting poultry mortalities. Operations use various types of agricultural machinery and equipment for windrow and bin composting. The types of equipment, instruments, and machinery needed for different size carcass composting operations are discussed in this section.

Grinders and crushers

The composting process may be facilitated by the use of various pre- and post-composting practices. As discussed previously, composting time can be reduced by grinding carcasses and mixing with co-composting materials; this practice requires equipment such as crushers, mixers, mills, screeners, manure or compost spreaders, and sprinklers.

The initial experiments of grinding animal mortalities carried out by Kube (2002) and Rynk (2003) demonstrated several advantages. This process produces a relatively homogenous and uniform mixture of raw materials that can be composted in bins, vessels, or windrows. According to Rynk (2003), the basic design of the grinder-mixer has been modified and presently includes more knives on the auger, stationary knives mounted on the tub, and a different auger to adjust to the conditions of grinding and mixing large carcasses. In this system, the grinder-mixer is loaded with the appropriate amount (about 20% of the weight of the mortalities) of bulking agent such as wheat straw and corn stalks. Grinding and initial mixing of carcasses with co-composting materials should proceed for about 15-45 min (depending on the nature of materials and particle sizes), to achieve an optimum particle size for proper aeration of 1/8 to 1/2 inch (3.1 to 12.7 mm) (Looper, 2002).

The most common crushing machinery, which can be used for reducing the particle sizes of supplement materials, specifically carbon sources, includes shear shredders, handfed chippers (disc type), rotary augers with counter knives, and woodchoppers.

Dougherty (1999) recommended considering the following items (in order of importance) while selecting a size-reducing device:

- Capital and operating costs (including power consumption),
- Appropriateness in relation to feedstock characteristics and desired product,
- Capacity and speed,
- Safety,
- Compatibility with existing equipment, and
- Maintenance requirement.

Mixers

It may be necessary to mix and homogenize the supplement or co-composting materials, especially if they have different size and shape characteristics. In a bin composting method, batch mixers (similar to mixers used by livestock feed producers) may be used for preparation of co-composting materials. According to Rynk (1992), several types of batch mixers have been used and tested for composting operations, including mixers with augers, rotating paddles, and slats on a continuous chain. He indicated that most batch mixers could be truck or wagon-mounted and, if equipped with sizable loading hoppers, could eliminate the need for dump trucks or wagons. For a windrow operation, fertilizer or manure spreaders (especially side-delivery, flail-type spreaders) can be used for mixing and formation.

The mixing operation should not be too long (perhaps only a few minutes); otherwise, the size of particles may become very small, and free airspace created by the bulking agent may become filled with the wetter feedstock (like manure or water) which decreases porosity. Rynk (1992) recommended using a crusher for big pieces and placing drier bulking agents or amendments into the batch mixer first, and then adding denser and wetter materials on top. The most common mixers used in composting processes are auger-type batch mixers, reel-type batch mixers, and rotating drum mixers.

Mixing of ground carcasses with granules of carbon source can take place in a rotating drum. Rynk (2003) suggested using a rotating drum 3 m (10 ft) in diameter and 15 m (50 ft) long for complete mixing as well as to complete the first phase of the composting process. The rotating process keeps odors of mixed materials inside while it accelerates the decomposition process to the point where the material leaving the drum is unlikely to produce odors or attract pests.

Mills

In addition to the batch mixer, some of the most common milling equipment used for the composting process includes tub grinders, hammer mills, continuous mix pug mills, and vertical grinders. Rynk (1992) recommended using stationary pug mills (a machine in which materials are mixed, blended, or kneaded into a desired consistency) and rotating drum mixers for organic composting. Although this equipment has not been recommended for mixing co-composting materials, it may be necessary to use it for high-capacity mixing in carcass composting. Included below are properties of this mixing equipment.

Stationary pug mills. These devices work slowly using counter-rotating paddles or hammers to blend materials and provide a good mix on a continuous basis. The feedstock should be fed continuously in proper proportions. Although they are faster than batch-operated mixers, they lack the mobility provided by batch mixers.

Rotating drum mixers. Some of the larger rotating drums hold feedstock up to 90 cm (36 in). Residence times can vary from a few hours to several days, depending on the drum length, diameter, material depth, heat transfer coefficient of drum wall thickness, and rotation speed.

Compost spreader and screeners

A conventional, beater-type manure spreader, is recommended for hauling and spreading finished compost on fields. Presently, finished product is used directly for agricultural farm activities but not for horticultural activities. If the qualities of the carcass composting end product are to meet the USDA regulations similar to plant residue composted materials, the finished product may require refinement post-composting to meet regulatory and/or market requirements. In addition to size reduction or mixing, screening and removing foreign materials may also be required, and can be accomplished by either vibration and gravity forces, or vibration and suction forces (air-classification system).

The most common screeners, which may be used for separation of big particles from the finished compost product, include disc screens, flexible oscillating (shaker) screens, belt screens, trammel screens, and vibrating screens (Dougherty, 1999). Table 5 and Figure 1 in Appendix E show the capacity and horsepower ranges as well as schematic views of selected screening equipment. According to Rynk (2003), a trommel screen with perforations of less than 2.5 cm (1 in) is recommended for removing any remaining bones from the finished compost product. Larger material remaining on the screen (primarily bones) is recycled back into active piles.

Loaders

Different types of moving machinery, including bucket loaders, skid loaders, and dump trucks have been used for loading and unloading processes. According to Fulhage (1997), skid-steer or front-end loaders can be used for conveying carcasses to the composter; placing carcasses on the compost pile; lifting, mixing and pile/windrow formation; covering carcasses with fresh sawdust or finished compost; moving compost from one bin to another as needed for aeration and mixing; receiving, storing, and piling sawdust prepared by sawmills; and loading finished compost for field spreading.

Loaders, especially front-end loaders, require less labor and cost less than mixing equipment. Although loaders are not mixing equipment, they can be used to repeatedly bucket the co-compost materials to achieve mixing prior to the composting process. Additionally, loaders can also be used for handling materials needed for construction of walls and pads in bin composting. Dump trucks, wagons, and sometimes bucket loaders can be used to transport mixed ingredients to the site and to build the initial pile or windrow if the composting site is far from the mixing area.

Windrow turners

After carcass pile formation, under proper conditions there is no need for mechanical disturbance processes until the pile is ready for the second composting stage. In the bin system, an adjustable loader can be used to move materials from primary to secondary bins and can achieve optimum aeration. In static pile and windrow composting systems, windrow turning machinery will be used for the required mixing and aeration.

Windrow turning is traditionally and conventionally associated with composting. Haug (1993) and Diaz et al. (1993) defined the term “turned” or “turning” as a method used for aeration, tearing down a pile, and reconstructing it. They indicate the first automatic turner used was in the mushroom industry in the 1950s. In succeeding years, other mechanical turners began to appear in increasing numbers and design variations. 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 particularly active interior zone of a pile. While windrow turning has many advantages, it may also reduce the particle size of the material. Diaz et al. (1993) explained that the turning process would accelerate the loss of water from the compost materials, if the moisture content were overly high.

Windrow dimensions should not be so large as to inhibit proper aeration and must conform to the capabilities of the turning equipment. If a specialized turner is to be used, a specific pile configuration may be required. According to Rynk (1992), materials are often unloaded directly into windrows by backing up to the end of the existing windrow and tilting the bed of the truck or wagon while slowly moving the vehicle forward. The speed and vehicle bed dimensions will determine the pile/windrow height. If necessary, a front-end loader can be used to reshape or enlarge the pile/windrow formed. He observed that high-speed turning machines such as windrow turners, if overused, could physically destroy the porosity and texture of a compost mix. Excessive turning, grinding, or shredding may pulverize materials and should be avoided. If particle sizes are too small, piled materials will pack together and impede air movement.

Some operations use bulldozers and bucket loaders for turning windrows. Diaz et al. (2002) stated the simplest equipment for tearing down and reforming a windrow are bulldozers and bucket loaders, which provide minimal aeration and the materials are compacted instead of being mixed and fluffed. He preferred using a bucket loader instead of a bulldozer due to less compaction and more flexibility. Due to cost considerations, the use of a bulldozer or bucket loader for turning continues to be a fairly widespread practice. 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.

Manser and Keeling (1996) classified windrow turners into three groups: rotating-tiller turners, straddle turners, and side-cutting turners. The rotating-tiller turner is more common in carcass composting systems. Other specialists classified windrow turners on the basis of required motivation forces (whether they are self-propelled or must be towed). Other types of turners include the auger turner, the elevating face conveyor, and the rotary drum with flails.

Diaz et al. (2002) reported that self-propelled types are more expensive than towed types. However, the tow vehicle (tractor) can be used for other purposes between turnings. In addition to convenience, the self-propelled type requires much less space for maneuvering and, therefore, the windrows can be closer to each other. Turning capacity of the machines ranges from about 727 to as much as 2,727 metric tons/h (800 to 3,000 US tons/h) with the larger, self-propelled versions. Similarly, the dimensions and configuration of the windrows vary with type of machine (e.g., 9-12 ft in width and 4-10 ft in height [2.7-4 m in width and 1.2-3.0 m in height]).

The rotating-tiller (rototiller) has a small capacity and, because of its maneuverability, is one of the most suitable types for small operations. According to Diaz et al. (1993), it has the ability to tear down the pile and spread the composting material to form a 30-60 cm (12-24 in) layer and accomplish the turning process. The rototiller is then passed back through the layer.

A partial listing and costs of self-powered and PTO (power take off) driven windrow turning equipment are presented in Tables 6 and 7 in Appendix E. The aerator-composter (PTO-driven) can process from 180-1080 metric tons of compost material per hour (200-1200 US tons/hr). Brown Bear Corp. (2003) has introduced a revised model of its farm tractor composter. The PTO PA35C-10.5 unit is designed to be attached to the front of 100-160 HP farm tractors. Figure 2 in Appendix E shows its general view during the windrow turning operation. Table 8 and Figure 3 in Appendix E show the specifications of turning and screening equipment with approximate capacity and horsepower ranges.

Instruments and supplies

The instruments required for monitoring and controlling physical properties of a composting system include thermometers, oxygen measurement equipment, data acquisition devices or composting logs, pH meters, and moisture testers.

Thermometers. Experience has shown that monitoring temperature during carcass composting is a key management factor of the operation. Many scientists have recommended using a probe-type dial thermometer with a 90 cm (3 ft) stainless steel stem. It will enable the operator to monitor internal pile temperature and judge the progress of the composting process.

Oxygen measurement and controlling devices. As mentioned earlier, measurement and control of oxygen content is critical. Umwelt Elektronic GmbH and Co. (2003) designed a system called COMPO-Matic for measuring, controlling, and optimizing both oxygen and temperature during the composting process. This device has a special insertion probe which contains an oxygen-temperature sensor. In this system, oxygen content is automatically regulated via an integrated aeration control mechanism, and a database-system enables the parallel measurement and control of up to 16 oxygen and temperature measuring points.

Data acquisition device or composting log. A logbook is needed where data such as dates, weights of carcasses placed in the composter, temperature, amounts of bulking agent used, dates when compost is turned, and amounts of finished compost can be recorded.

3.5 – Quality and Use of Composting End Product

The overall goal of carcass composting is not only to dispose of fallen carcasses properly, but also to produce a pathogen-free end product to serve as a soil amender for agricultural activities. The quality and applicability of the compost end product are significantly influenced by the characteristics of the feed substrates, the design parameters of the primary and secondary phases, the amount of pre- and post-processing, and the operating conditions maintained within the system. In the process of carcass composting, quality indicators are focused more on the co-composting materials, its balance with the carcasses, covering uniformity, temperature, composting procedures, water content, porosity, aeration, composting system, and design.

Compost quality

The compost facility must be designed and operated appropriately to produce the desired product. A number of different criteria have been established to define the end product of composting. According to Haug (1993), these include physical and chemical criteria such as particle size distribution, texture, color, odor, moisture content, general appearance, specific oxygen consumption rate (mg O_2/kg volatile solids per hour), absence of phytotoxic compounds, reduction of BVS across the system, nutrient content, nitrate/ammonia ratio, absence of readily degradable compounds (such as starch), and absence of anaerobic intermediates (such as acetic acid). Besides these parameters, the temperature of the compost at the end of the curing stage and before land application, along with a seed germination test, can be used to measure compost quality.

Analysis of compost at the final stage, or at the time of application to agricultural land, is a good tool for judging and evaluating the materials. The beneficial components of finished carcass compost, like finished compost from plant residues, include water, total nitrogen (N), available nitrogen (NH_4-N), phosphorus as P_2O_5, potash (K_2O), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), and copper (Cu). Analysis has shown nutrients found in manure and composted carcasses to be very similar. Murphy and Carr (1991) observed that the mineral content (phosphorus [P], potassium [K], Ca, Mg, S, Mn, Zn, and Cu) of dead bird compost and manure (built-up litter) was comparable. They observed that composted poultry mortalities provided a slower and more sustained release of nitrogen than did the built-up litter on which the birds were raised. This was caused by the conversion of mineral nitrogen to an organic form during composting. Manure had twice the water content and half the nitrogen content of poultry carcass compost. Furthermore, essential element content (including P_2O_5, K_2O, Mg, Mn, Zn, and Cu) of poultry carcass compost was similar to poultry manure. Nutrient analysis of other composted carcasses has shown similar results; Harper et al. (2001) reported the nutrient content of composted piglet mortality composted using mini-bins. Tables 1 and 2 in Appendix F show clearly the results of these two experiments. McGahan (2002) and Kube (2002) reported that the analysis or composition of finished compost depends upon the raw materials used, as well as the ratio of carcasses to other ingredients in the composting process. Details are shown in Tables 3 and 4 in Appendix F.

Total organic matter is also a good indicator of compost quality. According to Dougherty (1999), characteristics of composted carcasses include organic matter ranging from 35-70% (50-60% is optimum), pH ranging from 5.5 to 8.0, and bulk density ranging from 474 to 592 kg/m^3 (800 to 1,000 lb/yd^3). Comparison of the average bulk density of the original raw material (about 592 kg/m^3 [1,000lb/yd^3]) with the average bulk density of finished compost product (about 533 kg/m^3 [900 lb/yd^3]) showed a considerable reduction in bulk density. Soluble salt content (reported in units of decisiemens per meter [dS/m]) of finished compost ranges from 1 to 30 dS/m, but it is usually close to 10 dS/m. According to Dougherty (1999), the preferred soluble salt content is 5 dS/m or less.

Compost land application

Although the bacterial biomass and humus comprising the end product of animal carcass composting provide a beneficial fertilizer and soil amendment, biosecurity may be of concern. According to Dougherty (1999), it is recommended that composted mortality should be used solely for soil amendment on the land where the animals are produced. Based on their recommendation, mortality compost can be land spread as is manure, and can be included in the farm nutrient management plant. The nutrients, humus, and soil amending properties in mortality compost make it a valuable by-product to a livestock enterprise. Hansen (2002) land-applied the finished product of sheep, swine, and cattle carcasses composted with solid barn bedding as the co-composting material and reported that the soil moisture of compost-amended plots was higher than that of non-amended plots throughout the summer. He recommended that the finished product of composting should be applied in fall prior to spring planting.

At the end of curing or maturation, composted carcasses can be stored or land applied. Morris et al. (1997) indicated that this end product is still not completely stable, but the remaining small segments and bones are demineralized so that further degradation can be completed once spread on the land. Mukhtar et al. (2003) studied the end product of a combined pile of two cow carcasses and one horse carcass after nine months of composting. It was observed that most of the carcass material was completely biodegraded over this time period, and very few large bones remained. As Figure 1 in Appendix F shows, bones were easily disintegrated reducing the need for screening or mechanical crushing of bones prior to land application. However, if a separation process will be used to remove large particles from the compost end product, moisture content should not be high; otherwise, the efficiency of the screening process will be decreased. Diaz et al. (1993) recommended the moisture content of the final compost product be less than or equal to 30% to achieve adequate separation.

Finished compost should be applied to land in a manner similar to that used for spreading animal manure. Compost should be spread at agronomic rates so that applied nutrients do not exceed the uptake capabilities of the crop which will be planted in later years. Conventional agricultural manure spreaders are ideal for handling and spreading compost. Care should be taken not to spread compost in or near sensitive areas such as watercourses, gullies, public roads, etc.

In spite of the soil-amending quality, Dougherty (1999) emphasized that mortality compost should not be used as animal bedding, a feed supplement, or given to others for use off the farm.

3.6 – Cost of Carcass Composting

The feasibility of carcass composting, like any other agricultural processing activity, is closely related to its cost. For any specific carcass composting system to be a reasonable disposal method, the cost should be analyzed and compared with other composting methods. The most important factors involved in cost analysis of carcass composting processes have been described by Mescher (2000) and are listed below in order of importance:

- Volume and weight of mortality produced per established time period.

- Frequency of mortality occurrence.
- Labor requirements.
- Accessibility and timeliness.
- Impact on the environment.
- Required facilities and equipment (new and existing) and their useful life expectancy.

Cost factors can be divided into categories of variable and fixed; the first five above-mentioned factors relate to variable costs of operation, and the last one represents fixed costs. Variable and fixed costs of carcass composting process are discussed further below.

Variable costs

Variable costs include the value of carcasses (usually assumed to be zero), labor costs, and the cost of co-composting materials (oxygen and carbon sources) for a one-year period. According to SCI (2002), labor costs are influenced by the availability of laborers at the time of composting, type of labor (family size operation or company style situation), and level of composting mechanization. According to SCI (2002), labor costs for large animal carcasses are estimated as $10/carcass. The cost of carbon source materials depends on their accessibility in each livestock-producing district. For example, in Alabama the values of straw and litter, respectively, were about $60 and $20 per ton (Crews et al., 1995).

The cost of aeration depends on the system chosen for aeration. Continuous aeration processes have a considerable effect on the cost of the composting system. Furthermore, continuous aeration decreases the time required to complete the first and second phases of composting, and also eliminates the turning processes required in conventional carcass composting (bin and windrow). Umwelt Elektronic GmbH and Co. (2003) evaluated the effects of aeration time on the cost of finished product in windrow composting. They showed that continuous aeration of windrow composting piles for 8 weeks not only decreased the operational cost considerably, but also reduced the time and land required for composting. As demonstrated by Table 1 in Appendix G, when continuous aeration was applied to windrow composting of 10,000 lbs of raw material for 8 months, land requirements were reduced by 50% (from 6,426 to 3,136 m^2), time required was reduced by 60% (from 25 to 10 months), and operational costs were reduced by 70% (from €17.59 to €4.88 per metric ton, or from about $19.70 to $5.30 per US ton) as compared to composting a similar mass conventionally (non-aerated system).

The scale of operation also affects variable costs. Carcass composting operations that process a significant volume of mortalities are likely to experience relatively lower variable costs and, therefore, lower costs/head than smaller operations. Obviously, initial investment will vary greatly across alternative composting systems. According to SCI (2002), only 30% of the total livestock operations in the US are large enough to justify the costs of installing and operating composting facilities (see Table 2 in Appendix G). The SCI report indicated that most livestock production operations are quite small by industry standards, consisting of, for instance, fewer than 50 beef cattle, 30 dairy cows, or 100 hogs. For operations of this size, which incur relatively little mortality loss on an annual basis and receive modest revenues from their operation, it is better to use the facilities of one of their larger neighbors (perhaps paying a disposal fee for use of the proposed facility).

Crews et al. (1995) studied the annual net costs of six disposal methods for a flock size of 100,000 broilers per cycle. The disposal methods evaluated included disposal pit, large-bin composting, incineration, small-bin composting (mini-composter), fermentation, and refrigeration techniques. Results are summarized in Table 3 of Appendix G. According to their report, broiler farms have two options for composting. Large broiler operations (those who grow more than 40,000 birds per 45-day cycle) usually have tractor-loaders in their operations and prefer to use bin composting. Smaller operations, which may not have a tractor-loader, choose small-bin composting (mini-composters) and do not need major construction, machinery, or equipment. While the initial investment cost of large bin composting is more than three times that of small bin composting (mini-composter), the variable cost is about 15% less than that of mini-composters.

Fixed costs

For individual livestock producers, decisions regarding an appropriate carcass composting system will depend not only on the recurring expenses associated with the method, but also on the initial investment required for construction of the system (bin or windrow) and required agricultural machinery and equipment. For fixed cost evaluation, it is necessary to consider the initial investment in equipment and facilities, including facility construction (bin, pile or windrow system), number of bins (or pile area) required for the facility, as well as material and animal handling equipment. Additionally, the expected life of the carcass composting facility should be considered. According to SCI (2002), equipment and labor costs are likely to vary across operations based on availability and size of necessary equipment, machinery operating costs, assumptions used in depreciation, opportunity costs of time, and the extent to which family labor is employed and not counted as an expense. Estimating important cost items for constructing composting facilities for use on-farm is extremely difficult, and using different building materials, machinery, and equipment results in substantial variations. Mescher (2000) predicted the cost required for construction of bin and windrow composting systems (building raw materials + construction labor) with the following specifications:

Bin composting

- 4-5 ft (1.2-1.5 m) concrete base with 5-10 ft (1.5-3 m) front apron.
- 5 ft (1.5 m) treated sidewalk construction (min 3 sides).
- Steel roof.
- 6 in (15 cm) square posts.
- 2 ft x 4 ft (0.6 m x 1.2 m) purlin and 2 ft x 6 ft (0.6 m x 1.8 m) rafter supports.
- Construction labor.
- Estimated cost: $1,250-$1,700 per bin

Static pile or windrow systems

- Concrete pad of 4-5 in (10-12.5 cm) thickness.
- Site development, gravel access.
- Cost of geo-textile cloth and gravel base.
- Site development, accessibility.
- Estimated cost: one-third to two-thirds less than bin systems.

SCI (2002) indicated that the fixed cost of constructing a composting facility can be prohibitive, especially for smaller producers, and operating costs will vary based on the size and sophistication of the structure. As noted before, small-bin poultry composting systems do not require large capital investment, and therefore their fixed costs are less than large-bin systems (see Table 4 in Appendix G for more details). For example, cost estimates for the sheltering structure of a mini-composter (a 4 x 4 x 4 ft bin) for small broilers can be decreased to 25% of the cost of a full-scale bin composter for large broilers and will not exceed $1,500 (Crews et al., 1995).

Total costs

SCI (2002) evaluated the overall cost of composting carcasses of different species using the following assumptions:

- Equipment costs (rental or depreciation of a skid-steer loader) were assumed to be $35/hour.
- Cost of bulking agent (sawdust) at the rate of 11.3 L/kg (0.0067 yd^3/lb) of carcasses, was assumed to be about $22/metric ton ($20/US ton).
- For a typical on-farm facility, 95 hours of farm labor per year, plus 35 hours of machinery use would be needed to manage the process, turn the pile, move material between primary and secondary bins, and remove composted materials. Mature cattle would first need to be cut into smaller pieces, an activity estimated to take an additional 10 minutes per mortality. Labor costs were assumed to be $10/hour.

Using these assumptions, the report indicated the total annual costs of composting incurred by the livestock sector to be $30.34/head for cattle and calves, $8.54/head for weaned hogs, $0.38/head for pre-weaned hogs, and $4.88/head for other carcasses. Refer to Table 4 in Appendix G for additional details. This table also demonstrates that, regardless of carcass weight, the cost of machinery (the major fixed cost) per head was almost 50% of the total cost per head.

Furthermore, the minimum feasible capacity is very critical for investment in carcass composting facilities. According to SCI (2002), only about 28% of livestock operations would be considered large enough to justify investment in composting structures.

Henry et al. (2001) estimated the required investment for two types of facilities designed to compost about 40,000 pounds of mortalities per year, approximately the amount of death loss generated from a 300 sow farrow-to-finish_hog operation. They calculated costs for "high investment" and "low investment" composting constructions. The "high investment" option, which included seven concrete bins, had an estimated cost of $15,200. The "low investment" option, which included six smaller bins and no roof, had an estimated cost of $7,850. For both cases, the concrete work and the wooden portion were done with farm labor. Based on these results, and the fact that the majority of livestock operations are relatively small, SCI (2002) assumed a $7,000 investment per carcass composting operation (Table 5 of Appendix G). With these assumptions and the fact that composting facilities have a useful life of about 15 years, the maximum investment cost per carcass will be less than $5 per year.

Henry et al. (2001) estimated the costs of disposal by incineration, composting, and rendering for a swine production system needing to dispose of 18,000 kg/year (40,000 lb/year) or 49.5 kg/day (110 lb/day), as would be the case in a 300-sow farrow-to-finish operation with average death losses. Their results (which are presented in Table 6 of Appendix G) indicated the cost of composting sow farrow mortality was about $0.22/kg ($0.10/lb), which is similar to the cost presented in the SCI report (2002).

Kube (2002) composted cattle carcasses (1,000 lb [450 kg] each) using various adaptations of a windrow system, including conventional composting (no grinding), grinding carcasses before composting, and grinding of the finished compost. The cost analysis of this experiment (shown in Table 7 of Appendix G) indicated that, depending on the option selected for carcass composting, the total estimated cost ranged from $55 to $115/metric ton of carcasses ($50 to $104/US ton of carcasses [$0.044 to $0.11/kg, or $0.025 to $0.05/lb]). Although grinding carcasses before composting increased the operation cost by about $6/head, the time, area, and management costs were all reduced by about 50% compared to the conventional windrow system. Furthermore, the value of finished compost was estimated to be $10-$30 per carcass or $5.56-$16.67 per metric ton ($5-$15 per US ton), and the net cost per carcass was estimated to be approximately $5 to $42. Table 8 in Appendix G provides some of the specifications of this experiment.

The average unit cost of composting is comparable to other mortality disposal techniques. Mescher (2000) reported that composting has some economic advantages, such as long-life of the facility or pad, minimal cost of depreciation after start-up, similar labor requirements, inexpensive and readily-accessible carbon sources in most livestock production areas, and, finally, no need for new equipment. The total costs of bin composting were more than the burial method. However, when other economic parameters such as end product value were accounted for, the mini-composter had the lowest net cost per pound of carcass disposed at 3.50¢, followed by the burial method at 3.68¢, and bin composting at 4.88¢ (Crews et al., 1995).

Section 4 – Disease Agent and Environmental Considerations

The by-products of carcass composting (such as wastewater, odors, and gases) as well as the finished compost product should be safe and have little or no negative impact on public safety or the environment. This section provides a discussion of these considerations.

4.1 – Disease Agent Considerations

During active composting (first phase), pathogenic bacteria are inactivated by high thermophilic temperatures, with inactivation a function of both temperature and length of exposure. 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. This justifies the emphasis researchers tend to place on extending the duration of thermophilic temperatures during the composting process. 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. Haug (1993) observed that the following conditions can reduce actual pathogen inactivation during the composting process:

- Clumping of solids, which can isolate material from the temperature effects.
- Non-uniform temperature distribution, which can allow pathogens to survive in colder regions.
- Re-introduction of pathogens after the high temperature phase.

In order to avoid these conditions, it is important to have uniform airflow and temperature throughout the composting process. Keener and Elwell (2000) reported that because carcass compost is an inconsistent mixture, pathogen survival may be sporadic within the non-uniform composition of material in different areas of the compost. Keener indicated that preparation process (e.g., grinding and mixing of carcasses with co-composting materials) as well as modifications to the composting system (e.g., aeration) will provide more chemical and physical consistency and better conditions for controlling temperature and inactivation of pathogenic bacteria. For example, periodic turning aerates the compost pile and reduces the probability of microbes escaping the high temperature zone. In spite of non-uniform temperatures, Glanville and Trampel (1997) reported that pathogenic bacterial activity is reduced when the temperature in the middle of the pile reaches 65°C (149°F) within one to two days. That is, a high core temperature provides more confidence for the carcass composting pasteurization process.

As a result of its potential to harbor human or animal pathogens, much concern and attention has been focused on the use of municipal wastewater sludge (bio-solids) as a composting input. Sander et al. (2002) maintained that, regardless of the difference between the physical and chemical characteristics of sludge and animal wastes, the microbiological standards applied to composted sludge provide practical insight to procedures that could prove equally useful in carcass composting.

Haug (1993) pointed out that the inactivation energy (obtained from time/temperature relationship equation or Arrhenius Model) is between 50 and 100 kcal/mol for many spores and vegetative cells. Based on this theory, he calculated the heat inactivation of enteric (related alimentary tract or intestine) pathogens by considering the conditions common to composting, and concluded that the average temperatures of 55 to 60°C (131 to 140°F) for a day or two will provide this energy and should be sufficient to reduce pathogenic viruses, bacteria, protozoa (including cysts), and helminth ova to an acceptably low level. *Salmonella* and total coliform populations can normally be reduced to levels below 1 and 10 MPN/g dry solid (most probable number/g dry solid), respectively. However, the endospores produced by spore-forming bacteria would not be inactivated under these conditions.

Murphy and Carr (1991) showed the number of pathogenic viruses diminished significantly during composting of poultry carcasses (Table 1, Appendix H). Mukhtar et al. (2003) measured the pathogenic activities of carcass-compost piles after nine months of composting and observed very low levels of *salmonellae* and fecal coliform bacteria, which were used as indicators of pathogen populations in the compost end product. Harper et al. (2001) suggested that maintaining the internal stack temperature of a swine compost pile in a thermophilic range for an extended period of one or more weeks would be adequate to kill potential disease organisms such as *Pseudorabies* virus, *Salmonella* species, and *Actinobacillus pneumonia* species.

Salter and Cuyler (2003) composted food residuals in windrows and evaluated fecal coliform and *Salmonella* populations during the first and second phases (14 weeks for each phase). They documented temperatures of >55°C (>131°F) throughout the first phase, and observed that fecal coliform levels were below 1,000 MPN/g dry solids within the first five weeks of composting, and *Salmonella* levels remained above 3 MPN/4 g dry solids until seven weeks.

Bollen et al. (1989) used static compost heaps (2.5-4.6 m^3) with samples of crop residues heavily infested with soil-borne fungal plant pathogens. The temperature within the piles reached 50-70°C within 6 days. Of the 17 plant pathogens, only *Olpidium brassicae* and *Fusarium oxysporum* survived the composting process. They reported that the following three processes impact microbial activities during composting:

- Heat generated during the first phase.
- Toxicity of conversion products formed mainly during the first phase (fungitoxic volatiles have been detected in leachates and extracts from composted hardwood bark).
- Microbial antagonism during the first phase and maturation process (second phase).

The general presence of actinomycetes and fungi (like species of *Streptomyces* and *Aspergillus*) during composting and curing phases ensures the production of a variety of antibiotics that destroy some pathogenic bacteria (Diaz et al., 1993). However, microorganisms such as *Mycobacterium tuberculosis* and spore-formers like *Bacillus anthracis* will survive the typical composting process.

Biosecurity

In terms of biosecurity, composting facilities should not be located directly adjacent to livestock production units, and the vehicles associated with operation should be sanitized with appropriate cleaning and disinfecting agents for each trip. The site should be downwind from residential areas, provide a limited or appealing view for neighbors or passing motorists, and possibly have a pleasing appearance and landscape (Morse, 2001).

In addition to conserving energy and moisture content and minimizing odors, a biofilter also excludes insects and birds (as the most important carriers of disease microorganisms) from the compost pile, thus minimizing or preventing transmission of microorganisms from mortalities to livestock or humans. According to Schwartz (1997), ill or apparently healthy birds can carry the bacteria of infectious coryza, a respiratory disease affecting several avian species. Mosquitoes are also carriers of many diseases. According to the Harvard School of Public Health (2002), mosquitoes and ticks transfer viruses to people by their nature as blood-sucking arthropods, thereby serving as vectors for transmitting viruses (such as West Nile) from host to host.

4.2 – Site Selection in Relation to Environmental Factors

Disposal of animal carcasses may generate different environmental and health hazards. Various agricultural agencies (Alberta Agriculture, Food and Rural Development, 2002; AUSVETPLAN, 1996) indicated that improper carcass disposal processes might cause serious environmental and public health problems, including:

- Odor nuisance, resulting from the anaerobic breakdown of proteins by bacteria, reduces the quality of life and decreases property values.

- Pathogens which may be present in decomposed material are capable of spreading diseases in soil, plants, and in animals and humans.
- Leaching of harmful nitrogen and sulfur compounds from carcasses to groundwater.
- Attraction of insects and pests as potential vectors of harmful diseases for public health.

Location of a compost facility has an important role in meeting environmental interests. Choosing an appropriate site will help to protect water and soil quality, increase biosecurity, prevent complaints and negative reactions of neighbors, decrease nuisance problems, and minimize the challenges in operating and managing the composting operation. Based on The Ohio Livestock Mortality Composting Development Team (Keener & Elwell, 2000), a composting operation should:

- Protect surface and groundwaters from pollution.
- Reduce the risk of the spread of disease.
- Prevent nuisances such as flies, vermin, and scavenging animals.
- Maintain air quality.

Water

The location of the composting pile should be easily accessible, require minimal travel, be convenient for material handling, and maintain an adequate distance from live production animals. Sites near neighbors and water sources or streams should be avoided. Additionally, surface runoff and other pollution controls should be employed at the site. According to Mescher et al. (1997), leachate and runoff concerns are largely eliminated when using a bin system with a roof. A properly managed bin composter will not generate leachate from the pile, eliminating the need for a runoff storage or filter area. To control runoff, Looper (2002) suggested that a slope of approximately 1-3% should be incorporated to prevent pooling of water and allow proper drainage. McGahan (2002) stated that in higher rainfall areas (more than 1,000 mm or 40 in annual average.), a roof over the composting facility may be necessary. Fulhage (1997) indicated that composting facilities should be well-drained; away from sensitive water resources such as streams, ponds, and wells; accessible in all kinds of weather; and possibly located at or near the crest of a hill. Such a location will minimize the amount of surface water in the composting area.

Site preparation and runoff control structures are essential for static pile composting systems. Mescher et al. (1997), Morse (2001), and McGahan (2002) indicated that runoff from a carcass compost pile may contain organic compounds that could degrade the quality of nearby ground or surface water. To avoid this, all runoff from the composting facility should be collected and treated through a filter strip or infiltration area. The compost facility should be located at least 3 ft (1 m) above the high water table level and at least 300 ft (90 m) from streams, ponds, or lakes in the same drainage area. In addition, all clean surface water must be diverted away from the composting area to minimize the volume of water that must be treated or stored and keep the composting area dry. Excess water tends to exclude oxygen from the compost pile, slows the process, and makes the pile anaerobic which attracts flies and produces odors. Excessive drainage from such piles can potentially pollute not only surface waters but also soil.

Soil

Compost piles should be underlain with a water barrier in order to prevent compost leachate from penetrating and contaminating the soil or base underneath. Bagley (2002) suggested placing a plastic cover over the ground under the composting pile. Since a plastic barrier may complicate turning of the pile or windrow, a concrete or asphalt base (pad) is recommended instead of plastic materials. According to Looper (2002) and McGahan (2002), a composting pad should be compacted, but does not need to be paved. A compacted layer of sand or gravel about 15 cm (6 in) thick should be used when existing soil conditions are not acceptable.

Vegetation

Sciancalepore et al. (1996) measured the biological and enzymatic activity of several microbial groups (including pathogenic bacteria, *E. coli,* and salmonellae) during six months of composting a mixture of crude olive husks, oil mill wastewaters, and fresh olive tree leaves inoculated with cow manure. Results showed that total phytotoxicity encountered in raw composting materials fully disappeared due to enzymatic activities.

Air quality

A good composting operation will not generate an offensive odor; however, Fulhage (1997) and McGahan (2002) remarked that the daily handling of dead animals and compost may not be aesthetically pleasing, and these factors should be taken into account in locating a composter. Additionally, traffic patterns required for moving carcasses to the composter and removing finished compost must be considered. Rynk (1992) indicated that maintaining aerobic conditions is a key factor for minimizing odor release during carcass composting, as there is an increasing likelihood of significant odor when oxygen content is approximately 3% or less.

Organoleptic techniques based on the human olfactory system have been used as the standard method for characterization of odors. Different parameters such as threshold odor concentration (TOC), OU, surface odor emission rate (SOER), odor intensity, hedonic tone, and odor quality are used to characterize odor. According to Haug (1993), TOC is the minimum concentration of odorant that will arouse a sensation. OU is the number of dilutions with odor-free air required to achieve the minimum detectable odor concentration. Odor concentration is usually determined by supplying a number of diluted samples to a number of individuals until the odor is detected by only 50% of the panel members. Finally, SOER is usually expressed in $m^3/min-m^2$ and determined by placing a sample hood over the surface being analyzed. Improper carcass composting will increase the odor emission rates substantially. Haug (1993) reported that measured SOER values in different compost facilities tend to vary from about 0.5 to 10 $m^3/min-m^2$ and in compost with sewage sludge and wood-based amendments, the OU concentrations range from 100 to 1,000.

Fortunately, there has been significant progress on biological and chemical deodorization of compost gases. Currently odor absorption units use multistage chemical scrubbing. These stages include acid scrubbing for removal of ammonia; hypochlorite scrubbing (with a slightly acidic pH and with or without surfactant) for removal of inorganic, organo-sulfides, and other organics such as terpenes; and scrubbing with peroxide or caustic soda to remove residual chlorine odors and refine the gas effluent (Haug, 1993).

Biofilters are widely used in many compost facilities. Although new deodorization technologies have been substituted, biofilters have received a lot of attention. According to Haug (1993), biofilters are now enjoying a renewed interest in the US as more is learned about their proper design and operation. He also reported that blanket materials in a composting process must be used to maintain proper conditions of moisture, pH, nutrients, and temperature to enhance the microbial reaction rates. At this stage, deodorized gases from open biofilters are usually released at ground level.

Section 5 – Critical Research and Training Needs

Research and training are two areas of education that publicize and promote carcass composting techniques. Composting is relatively new, and a majority of livestock producers and others involved in animal agriculture research and education are not familiar with this relatively safe and harmless method of disposing of animal mortalities. They lack knowledge of the carcass composting process as well as the beneficial effects on the environment. Further study is warranted to develop scientific and practical answers for different issues and challenges associated with carcass composting. Deficiencies in research and training, along with active educational centers for carcass composting, are discussed in this section.

5.1 – Research

Extensive research has been conducted in the area of "organic material composting," and a wealth of articles, books, and technical documents have been published or presented on the topic during the last 50 years. At the same time, many academic, governmental, state, and regional institutions and agencies worked to promote this process and helped private sectors produce different organic compost products at the commercial level. The situation for "carcass composting," which has potentially stronger environmental and biosecurity impact, is quite different. Agricultural extension engineers and compost scientists at academic institutions have put forth efforts during the last 20 years to clarify the different aspects of composting this type of material. Although these efforts have furthered the establishment of composting as a practical method of carcass disposal, public health, animal health, and environmental hazards are not fully understood.

A preliminary study of 50 published technical and scientific research articles focused directly and indirectly on "carcass composting" showed that about 70% were generated by government agencies and university extension agencies, with very little information published by the private sector. While the available information was observed to be valuable, few of the informational sources appeared in the form of peer-reviewed journal articles, therefore their scientific validity is not known. A high proportion of published documents written on carcass composting have been concentrated on the definition, general principles, material requirements, and, to some extent, the microbiological aspects of the process. Due to the fact that composting of horticultural residues is safer than carcass composting from the stand point of presence of pathogenic bacteria, much more research is needed to address this safety issue. To compost massive amounts of mortality, produce a compost product free of pathogens, and possibly sell the product for growing horticultural produce, the following related issues should be studied in depth:

1. Investigate decontamination and deodorization of raw materials.

   To ensure that the end products of carcass composting are free of pathogenic and harmful microorganisms, to protect the environment, and to decrease the risk of odor production, extensive research on decontamination and deodorization processes of the raw materials and end product is needed. This research would also consider the fate of transmissible spongiform encephalopathies during composting.

2. Investigate temporary storage scenarios.

   In the case of high mortality losses, information will be needed regarding storage sites, time, and temperature and their appropriate relations to composting.

3. Investigate how to shorten the length of the composting process.

   To diminish the composting time, additional information is needed regarding pre-composting processes (e.g., grinding and mixing), enhanced composting processes (e.g., applicability of rotary vessel system, aerated synthetic tube and using forced air for carcass composting), and post-composting processes. By studying the physicochemical properties of carcass materials, valuable information might be gained and used to design improved composting processes.

4. Study how to improve composting machinery and equipment.

   Although most of the handling, moving, and turning machinery used in organic composting can be applied to carcass composting, certain readily sanitizeable machinery and equipment such as aeration devices and carcass grinders need to be designed specifically for carcass composting.

5. Shift the research focus from bin composting to windrow composting.

   Most carcass-composting studies have mainly focused on bin composting systems for small- and medium-sized carcasses. Such studies have neglected windrow carcass composting, which is seemingly appropriate for massive amount of animal mortalities; windrow carcass composting should be the focal point of future composting research.

6. Investigate economic issues related to composting.

   The current economic value of composted carcasses may not justify the cost of production. Research should focus on both (a) modifying the costs of composting and (b) marketing compost products following sanitation.

5.2 – Training

The facility size and, consequently, staff size, of each livestock operation will determine the extent of and expenditure on training. The allocation of resources between capital equipment and labor is also a factor in the extent of education and training. Diaz et al. (2002) reported that in an organic composting system, the number of personnel ranged from part-time employment for small, seasonal, leaf-composting operations to approximately 30 full-time employees for large compost operations. Labor requirements for manual carcass composting vary roughly in proportion to the plant throughput. Mechanical separation reduces the need for sorters. Diaz et al. (2002) also indicated that the requirements for skilled personnel usually do not vary markedly as facility size increases.

Training should not be limited only to personnel involved with carcass composting activities. This technology should be introduced to different commercial composting companies for producing a non-pathogenic soil-improver and amender while protecting the environment from the possible side effects of improper disposal of animal-carcasses. Educating the market is highly related to public education, which can be accomplished by cooperation with the media. Different presentations of carcass composting may deal with the advantages of using proper procedures and may provide information on the hazards and disadvantages of improper composting or disposal of animal mortalities.

Although some efforts have been made by extension services of academic institutes, and considerable educational materials have been prepared for training farm-animal producers, much more should be done to publicize the composting process among the interested and related parties through short courses, workshops, and training materials. Training tools, such as practical manuals, bulletins, pamphlets, posters, magazines, books, and web guides should be prepared and distributed for continuous education of personnel in livestock and livestock by-product industries.

5.3 – Educational Centers

Agricultural universities and schools which have initiated carcass composting programs in their teaching, research, and extension programs are able and willing to be more active in educational efforts. Of the many universities which are active in conducting research and extension activities on the subject of carcass composting, only a few are involved directly with training programs. Table 1 in Appendix I shows some of the most important centers active in providing education and training relative to carcass composting. These entities have the following training programs:

- Basics of a composting process, including composting methods, site selection, co-composting materials, equipment demonstration, quality control, and use of compost.
- New and emerging regulations and opportunities that impact the future of carcass composting.
- On-farm composting of cattle and poultry carcasses and the application of the end product.
- Environmental aspects of carcass composting.
- Cost management and evaluation.

Furthermore, agricultural universities and schools can provide effective educational and training programs for government personnel at the national, state, or local level. These educated government personnel would then be capable of providing training to managers and supervisors at livestock operations, and could inspect mortality composting operations.

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Appendices

Appendix A

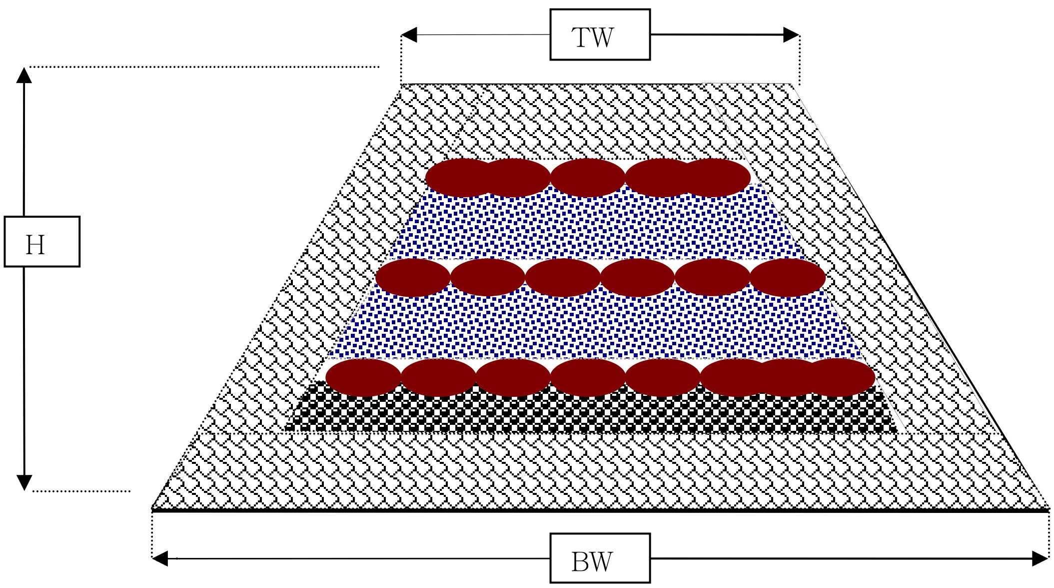
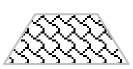
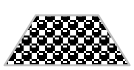


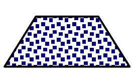
FIGURE 1. Cross-sectional dimensions of a trapezoidal-shaped windrow for small carcasses.



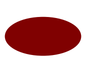
Two layers of carbon source materials are used as a base layer and a bio filter on top and two sides of windrow. Each layer is 30 cm (1 ft) thick.



One 15-cm (0.5 ft) thick layer of bulking agent (such as litter) is used.



Two layers of carbon sources. Each layer is 30-cm (1 ft) thick.



Layers of poultry carcasses.

A 0.6-cm (0.24in) thick plastic liner is used as an impermeable layer underneath composting materials.

Bottom Width (BW) = 360 cm (15 ft), Top Width (TW) = 150 cm (5 ft) and Height (H) = depends on the thickness of carcasses.

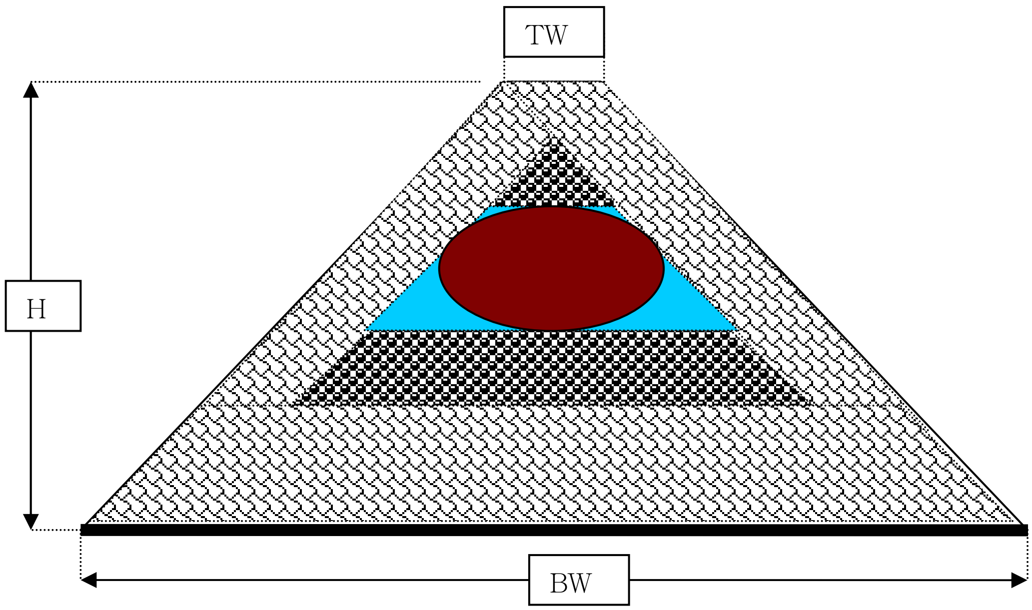
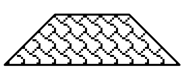
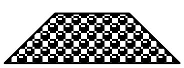


FIGURE 2. Cross-sectional dimensions of a trapezoidal-shaped windrow for medium carcasses.

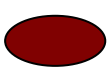
Plastic liner with the thickness of 0.6 cm (0.24in) used as an impermeable layer underneath composting materials.



Two layers of carbon source materials used as a base layer, 45 cm (1.5 ft) thick and a bio filter layer, 30-cm thick on top and two sides of windrow.



Two layers of bulking agent. Each layer is 30-cm (1 ft) thick.



One layer of medium size carcasses.

Bottom Width (BW) = 390 cm (13 ft), Top Width (TW) = 30 cm (1 ft), and Height (H) = depends on the thickness of carcasses.

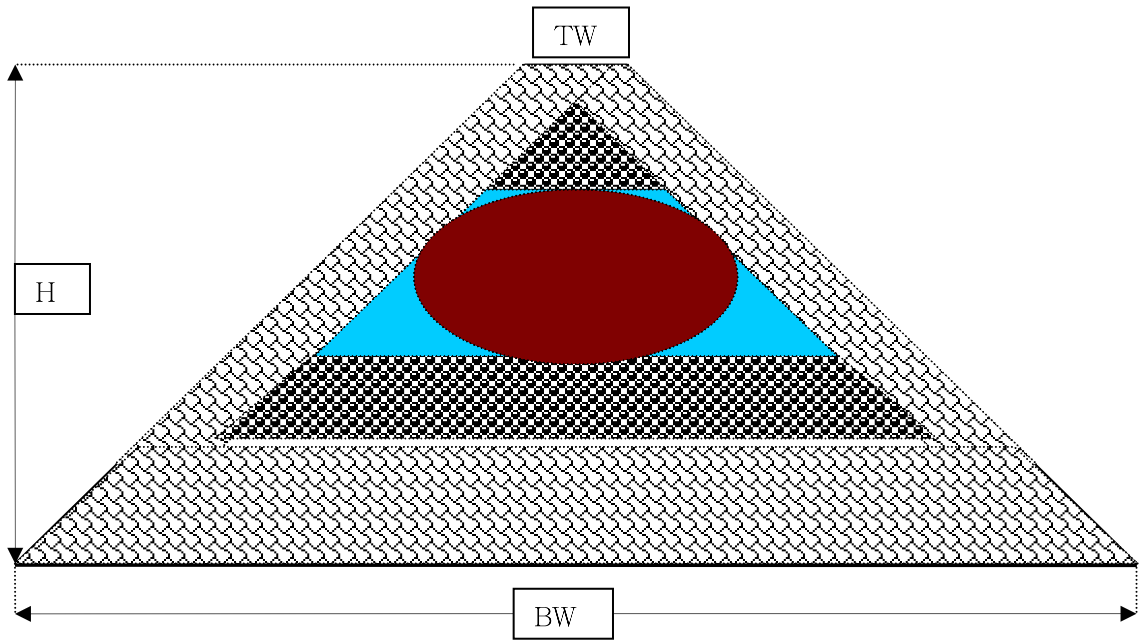
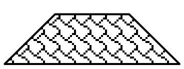
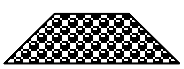
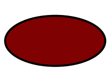


FIGURE 3. Cross-sectional dimensions of a trapezoidal-shaped windrow for large and heavy carcasses.

Plastic liner with the thickness of 0.6 cm (0.24in) used as an impermeable layer underneath composting materials.


Two layers of carbon source materials used as a base layer, 60-cm (2-ft) thick and a bio filter, 30-cm (1-ft) thick on top and two sides of windrow.


Two layers of bulking agent, each layer 30-cm (1-ft) thick.


One layer of large or heavy carcasses.

Bottom Width (BW) = 450 cm (15 ft), Top Width (TW) = 30 cm (1 ft), and Height (H) = depends on the thickness of carcasses.

Appendix B

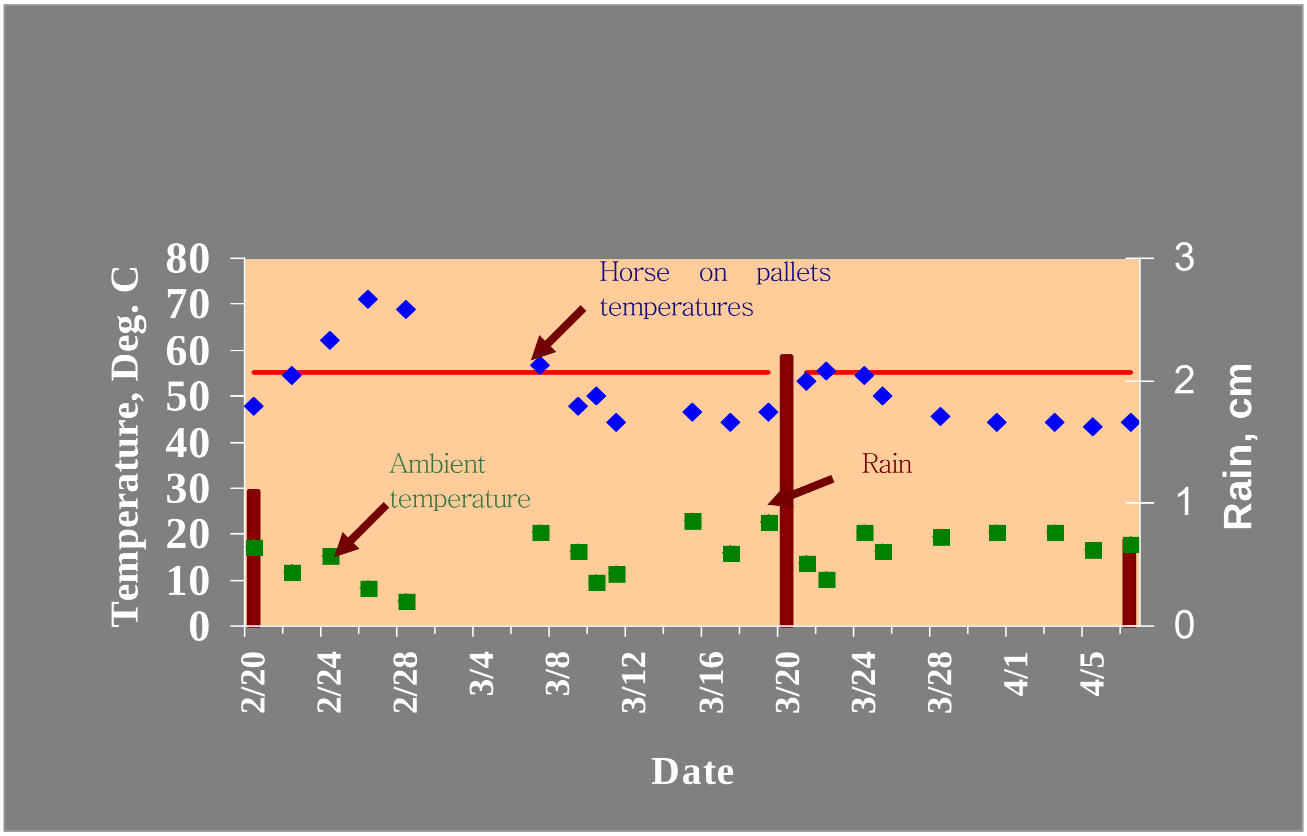


FIGURE 1. Bottom temperatures of horse compost pile (on pallets), ambient temperatures and rainfall data (Mukhtar et al., 2003).

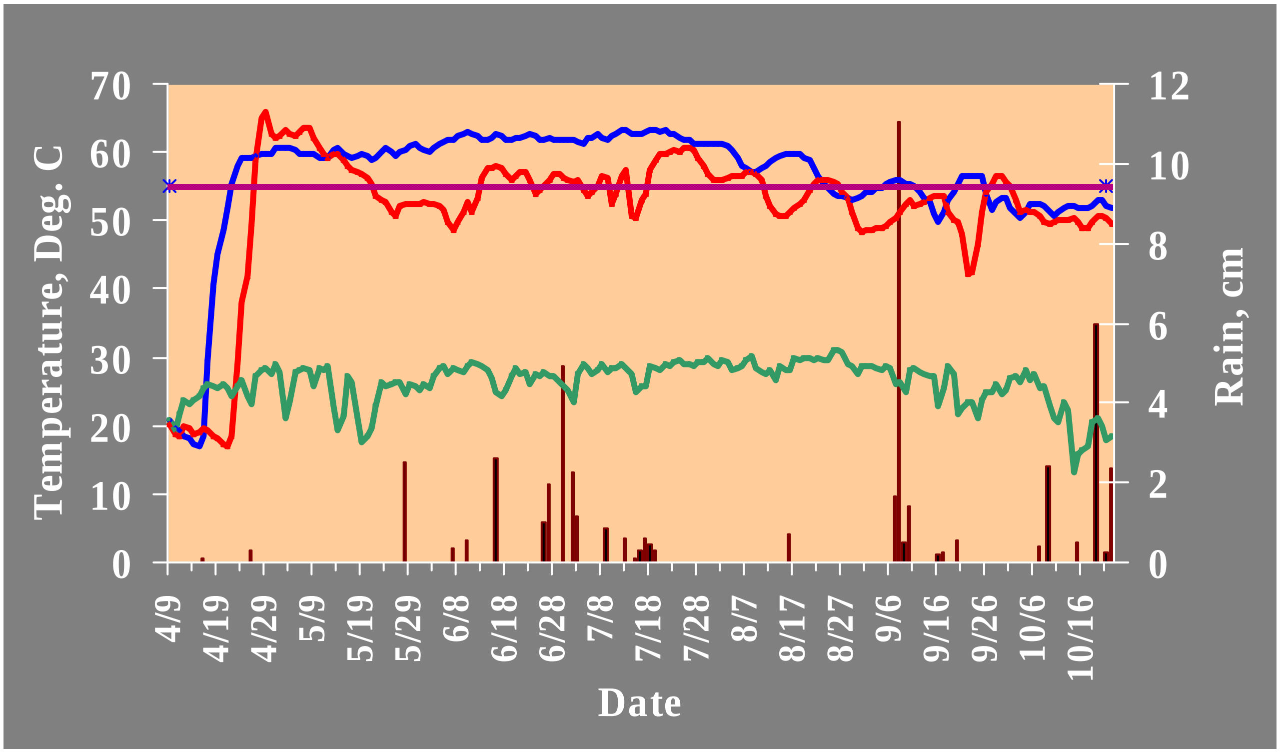


FIGURE 2. Ambient (green), top (red), and bottom (blue) temperatures of cow composting pile (on pallets) along with rainfall data (Mukhtar et al., 2003).

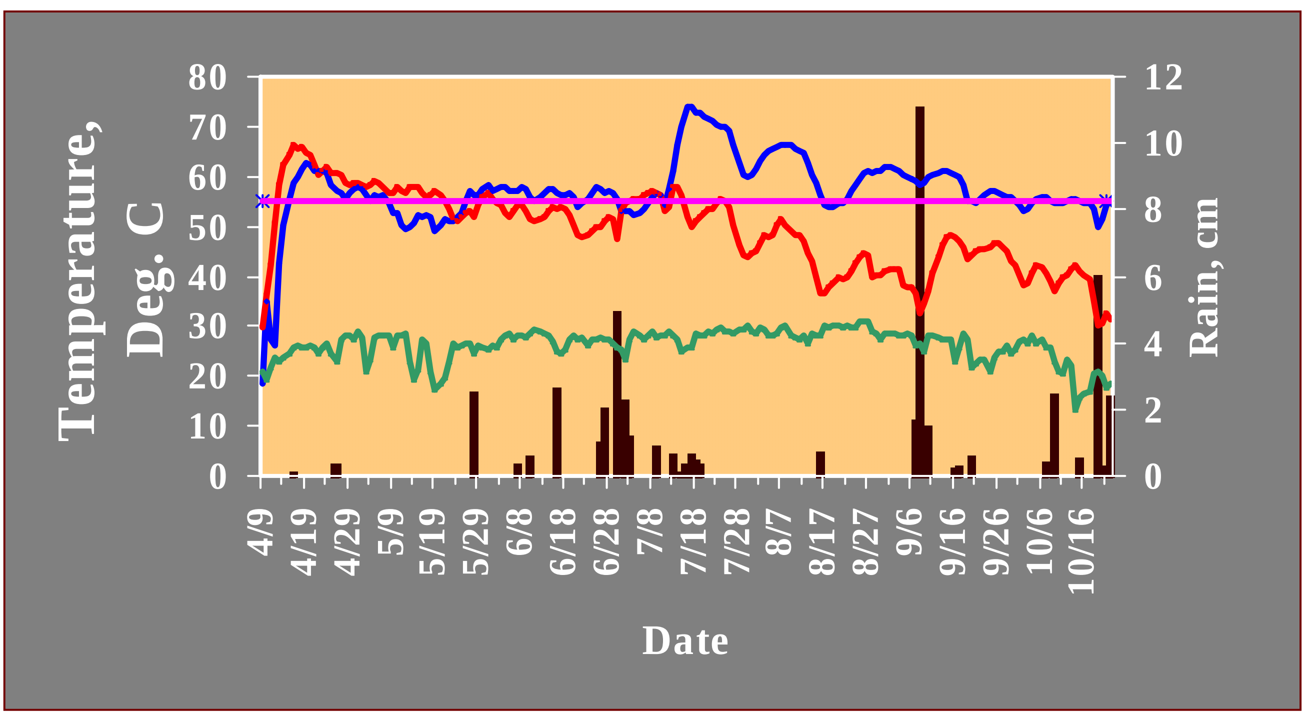


FIGURE 3. Bottom temperatures of cow compost (blue) and horse compost (red) piles (without using pallets) along with ambient temperature (green), and rainfall data (Mukhtar et al., 2003).

Appendix C

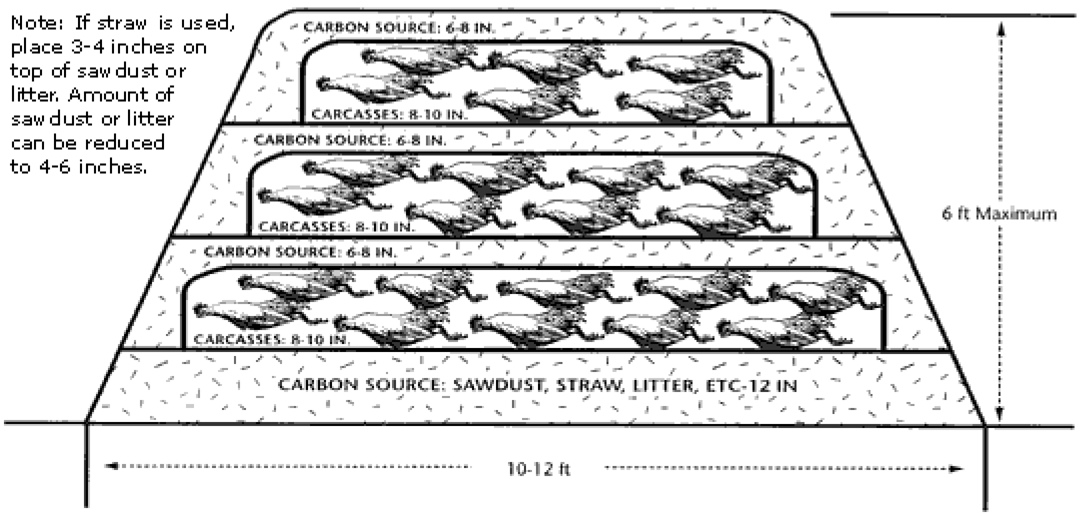


FIGURE 1. Cross-section of carcass composting in a windrow (Carr et al., 1998).

FIGURE 2. A layer of mortality in a compost windrow (Carr et al., 1998).

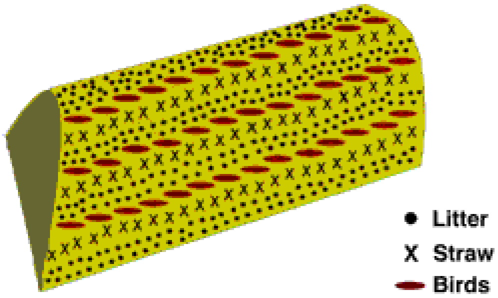


FIGURE 3. Completed windrow composting of poultry mortalities (Carr et al., 1998).

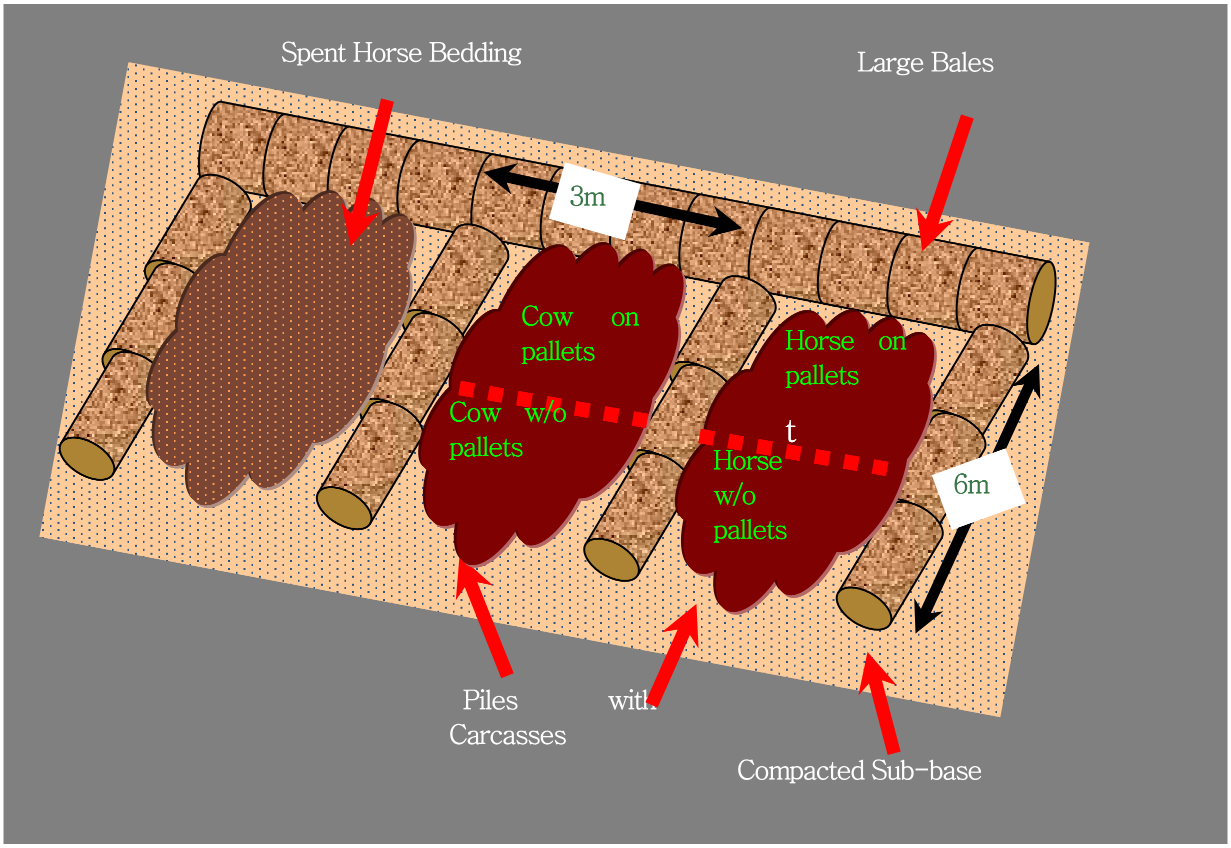


FIGURE 4. A three-bin large carcass composting set-up built with large hay bales (Mukhtar et al., 2003).

FIGURE 5. Layout of a carcass compost site using large round bales (McGahan, 2002).

FIGURE 6. Cow carcass without pallets (left) and the data logger location (right) for this carcass (Mukhtar et al., 2003).

FIGURE 7. Poultry carcasses and carcass parts being added to the inlet section of an aerated synthetic tube (Cawthon, 1998).

TABLE 1. The calculated time based on the original weight of the dead animals and mathematical model predicted for the first, second, and storage phases of composting (Monnin, 2000).

	Days Per Phase								
Mortality size in kg (lbs)	**1.8 (4)**	**4.5 (10)**	**22.7 (50)**	**45.5 (100)**	**100 (220)**	**159.1 (350)**	**227.3 (500)**	**454.5 (1000)**	**681.8 (1500)**
First phase (days)	10	16	35	50	75	95	115	160	195
Second phase (days)	10	10	12	15	25	30	40	55	65
Storage time (suggested minimum days)	30	30	30	30	30	30	30	30	30

TABLE 2. Management schedule for a system using three bins and two turns, with 15 days in primary (first) phase of carcass composting (Morse, 2001).

Days	Primary bin 1	Primary bin 2	Secondary bin
1-15	Filling	Empty	Empty
16-30	1st heat	Filling	Empty
31-45	Filling	1st heat	2nd heat (#1)
46-60	1st heat	Filling	2nd heat (#2)
61-85	Filling	1st heat	2nd heat (#1)

Appendix D

EXAMPLE 1. Bin composting of poultry carcasses (Murphy & Carr, 1991).

Example Calculation:

A poultry farm with 100,000 birds and 4.5 lb (2.02 kg) average market weight to compost carcasses using a bin system.

Available information

0.45 kg (1 lb) of the compost material needs a volume of approximately 0.027 m^3 (1 ft^3)

Daily composting capacity = Theoretical farm live weight **/**400

Theoretical farm live weight = Farm capacity x market weight

Determine daily composting capacity

The needed daily composting capacity will be:

Daily composting capacity =100,000 (birds) x 4.5(lb/birds)/ 400 (day) = 1125 lb/day (506.25 kg/day) or about 1125 ft^3/day

Suggested number of bins and associated dimensions

Based on the experimental data of Murphy and Carr (1991), the most appropriate bin dimensions are 7 ft length, 5 ft width, and 5 ft height Therefore:

N (number of primary treatment bins) = (compost capacity) / (L x W x H of a primary bin)

N = (1,125 ft^3/day) / (7 ft x 5 ft x 5 ft) = 6 primary treatment bins/day

The six bins can be arranged in any of several configurations to suit the needs of a particular situation.

The overall length = (1,125 ft^3) / (7 ft x 5 ft) = 32 ft (9.64 m)

Total area = 7 ft x 32 ft = 214 ft^2 (19.26 m^2)

Area for each primary bin= 214 ft^2 / 6 = 35 ft^2 (3.21 m^2)

EXAMPLE 2. Bin composting of cattle carcasses (Morris et al., 1997).

Example Calculation:

A cattle operation with 60 dead animals/year (average weight of 65 kg) to compost carcasses using a bin system.

Available information

Area of the primary bin or A_1 = n. W /h. d_1 and area of the secondary bin or A_2 = n. W /h. d_2

The recommended height for bin (suggested by many researchers) is 5 ft (1.5 m)

Composting materials had a bulk density of 600 kg/m^3 at the beginning of the first phase, and 900 kg/m^3 at the beginning of the second phase of composting.

Determine areas of primary and secondary bins

A_1 = (60 carcasses/year) (65 kg/carcass) / (1.5 m, bin height) (600 kg/m^3) = 4.33 m^2

A_2 = (60 carcasses/year) (65 kg/ carcass) / (1.5 m, bin height) (900 kg/m^3) = 2.89 m^2

EXAMPLE 3. Bin composting of poultry carcasses (Keener & Elwell, 2000).

Example Calculation:

A poultry farm, which has an average weight of 1.36 kg (3 lb) per carcass and ADL of 13.6 kg/day (30 lb/day), to compost carcasses using a bin system.

Available information

$T_1 = (7.42)(W_1)^{0.5} \geq 10$, days $V_1 \geq (0.0125)(ADL)(T_1)$, m^3

$T_2 = (1/3)(T_1) \geq 10$, days $V_2 \geq 0.0125)(ADL)(T_2)$, m^3

$T_3 \geq 30$, days $V_3 \geq V_2$ $V_3 \geq (0.0125)(ADL) T_3)$, m^3

The relation between bin volumes, width, and length with the constant depth or height of 1.50 m (5 ft).

Determine composting time and volume for primary, secondary, and storage phases.

From the above-mentioned equations, the required information will be:

$T_1 = (7.42)(1.36)^{0.5} \geq 10$ days, T_2 (1/3) $(T_1) \geq 10$ days and $T_3 \geq 30$ days,

$V_1 \geq (0.0125)(13.6)(10) = 1.70\ m^3$, $V_2 \geq 0.0125)(13.6)(10) = 1.70\ m^3$ and

$V_3 \geq 3\ V_2$ (as recommended as a design parameter) = 3 (1.70) = 5.10 m^3

Determine the number of required bins and associated dimensions

The bin volume closest to a calculated value of 1.70 m^3 is 2.26 m^3 (80 ft^3) or a mini bin with dimensions of 1.22 m x 1.22 m x 1.52 m (4 ft x 4 ft x 5 ft).

In other words, there is a need for two primary bins, each with the areas of 1.22 m x 1.22 m =1.5 m^2 (16ft^2) or total of 3 m^2 (32 ft^2) and one secondary bin of 1.50 m^2 (16 ft^2).

The end product storage area will be: 5.10 m^3/ 1.5 m = 3.36 m^2.

TABLE 1a. Poultry mortality rates and design weights (adapted from OSUE, 2000).

Species & Growth stage	Avg. Wt. kg (lb)[a]	Poultry Loss Rate (%)[b]	Flock life (days)	Design Weight kg (lb)[c]
Poultry				
Broiler	1.8-3.6 (4-8)	4.5-5	42-49	Up to 3.6 (up to 8)
Layers	2.0 (4.5)	14	440	2.0 (4.5)
Breeding hens	1.8-3.6 (4-8)	10-12	440	3.6 (8)
Turkey, females	6.8-11.4 (15-25)	6-8	95-120	11.4 (25)
Turkey, males	11.4-19.1 (25-42)	12	112-140	15.9 (35)
Turkey, breeders replace	6.8; 0-13.6 (15; 0-30)	5-6	210	9.1 (20)
Turkey, breeding hen	12.7-13.6 (28-30)	5-6	180	13.6 (30)
Turkey, breeding tom	31.8-36.4 (70-80)	30	180	34.1 (75)

[a]Average weight used to calculate pounds of annual mortality.

[b]For mature animals, the % loss is an annual rate for the average number of head on the farm.

[c]Design weight used to calculate composting cycle periods.

TABLE 1b. Livestock mortality rates and design weights (adapted from OSUE, 2000).

Species & Growth stage	Avg. Wt. kg (lb)[a]	Loss Rate (%)[b] Excellent	Good	Poor	Design Weight kg (lb)[c]
Swine					
Birth to weaning	2.7 (6)	< 10	10-12	> 12	4.5 (10)
Nursery	10.9 (24)	< 2	2-4	> 4	13.6 (35)
Growing/Finishing	63.6 (140)	< 2	2-4	> 4	95.5 (210)
Breeding herd	159 (350)	< 2	2-5	> 5	159 (350)
Cattle/Horses					
Birth	31.8-59.1 (70-130)	< 8	8-10	> 10	59.1 (130)
Weaning	273 (600)	< 2	2 -3	> 3	273 (600)
Yearling	409 (900)	< 1	1	> 1	409 (900)
Mature	636 (1400)	< 0.5	0.5-1	> 1	636(1400)
Sheep/Goats					
Birth	3.6 (8)	< 8	8-10	> 10	4.5 (10)
Lambs	22.7-36.4 (50-80)	< 4	4-6	> 6	36.4 (80)
Mature§	77.3 (170)	< 2	3-5	> 5	77.3(170)

[a]Average weight used to calculate pounds of annual mortality.

[b]For mature animals, the % loss is an annual rate for the average number of head on the farm.

[c]Design weight used to calculate composting cycle periods. The design weight for cattle, horses, sheep, and goats should be verified with the producer.

TABLE 2. Worksheet for calculating annual death loss of livestock (cattle, pig, poultry, sheep, etc.) for use in designing an animal mortality composting system (adapted from OSUE, 2000, and a 1999 Ohio NRCS publication).

Livestock Type:

Death Loss Per Year (use "average weight" to calculate death loss)

Birth Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Weanling Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Yearling Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Mature Stage

(______________)	x	(______________)	x	(______________)	=	______________
Number of Births		Average Weight		(%loss/100)		Weight of annual mortality

Total Weight Death Loss Per Year Per Species = ______________

Average Death Loss Per Day

(______________)	/ 365	=	______________
Total Weight Death Loss Per Year			Weight Death Loss Per Day

Note: For animals weighing less than 227 kg (500 lb), a bin composting system should initially be evaluated. For larger animals, a windrow or compost pile for an individual mature animal will likely be the most practical.

TABLE 3. Composting worksheet for bins.

Step 1 – Calculate volume of primary, secondary, and storage bins:						
Small & medium animals						
Primary Bin						
(0.0125)	x	(__________)	x	(__________)	=	__________ m^3
		kg loss/day		primary stage time		primary bin volume
Secondary Bin						
(0.0125)	x	(__________)	x	(__________)	=	__________ m^3
		kg loss/day		secondary stage time		secondary bin volume
Storage Bin						
(0.0125)	x	(__________)	x	(30 days)	=	__________ m^3
		kg loss/day				storage bin volume
Alternate calculations for large animals						
Primary Bin						
(0.0125)	x	(__________)	x	(__________)	=	__________ m^3
		W1 (kg)		(ADL x T1/W1)		primary bin volume
Secondary Bin						
(0.0125)	x	(__________)	x	(__________)	=	__________ m^3
		W1 (kg)		(ADL x T2/W1)		secondary bin volume
Storage Bin						
(0.0125)	x	(__________)	x	(__________)	=	__________ m^3
		W1 (kg)		(ADL x T3/W1)		storage bin volume

Step 2 – Calculate the number of primary, secondary, and storage bins required:

Note that minimum requirements will be two primary bins, one secondary bin, and one storage bin. In doing calculations always round up to the next whole number (e.g., 2.1 bins = 3 bins, or increase the bin dimensions and recalculate).

Number of Primary Bins:

Based on the required volume calculated in Step 1, and using table 3a below, choose bin dimensions within the capability of the loading equipment. Also, account for the size of the animals to maintain at least 15.3-30.5 cm (0.5-1 ft) clearance between the carcass and the bin walls.

Trial Bin Volume

(__________) x (______________) x __1.52 m (5 ft)___ = ______________m^3

Width, m (ft) — Length, m (ft) — trial bin volume

Number of Primary Bins

(__________) / (______________) + (____1____) = ______________bins

Primary volume — trial bin volume — number of primary bins

Number of Secondary Bins:

Select secondary bin volume. Each secondary bin must be greater than or equal to the volume of the primary bin since volume reduction during the compost stage is neglected. Minimum requirements will be one secondary bin per three primary bins (the 3:1 ratio requires immediate utilization or separate storage of compost following the secondary stage).

(___________) / (______________) = ______________bins

Secondary volume (from Step 1) — Selected primary bin volume — number of secondary bins

Number of Storage Bins:

Select storage bin size. Volume must be greater than or equal to secondary bin volume.

(___________) / (______________) = ______________bins

Storage volume (from Step 1) — Selected storage bin volume — number of storage bins

TABLE 3a. Bin volumes versus width and length (assumes depth of 1.52 m [5 ft]).

Width, m (ft)	1.22 (4)	1.83 (6)	2.44 (8)	3.05 (10)	3.66 (12)	4.27 (14)	4.88 (16)
Length, m (ft)	Bin Volume m^3 (ft^3)						
1.22 (4)	2.27 (80)	3.40 (120)	4.53 (160)				
1.83 (6)	3.40 (120)	5.01 (180)	6.80 (240)	8.50 (300)	10.20 (360)		
2.44 (8)	4.53 (160)	6.80 (240)	9.06 (320)	11.33 (400)	13.59 (480)	15.86 (560)	18.13 (640)
3.05 (10)		8.50 (300)	11.33 (400)	14.16 (500)	16.99 (600)	19.82 (700)	22.66 (800)
3.66 (12)		10.20 (360)	13.59 (480)	16.99 (600)	20.39 (720)	23.79 (840)	27.19 (960)

Step 3 – Calculate annual sawdust requirements:

Note that this assumes no reintroduction of finished compost to the primary bin; however, it is recommended that up to 50% of the fresh sawdust requirements be met with finished compost.

Sawdust volume

(__________)	x	(____0.0116______)	=	______________ m^3 (yd^3)	=	
kg (lb) loss/yr		(use 0.0069 if wt in lb)		sawdust volume		

Additional bins for fresh sawdust storage = ______________bins

Step 4 – Summary of bin numbers and dimensions required

	Primary	Secondary	Compost Storage	Sawdust Storage
Number of bins				
Dimensions (w x l)				

TABLE 4. Composting worksheet for windrows.

Step 1 – Calculate volume of primary, secondary, and storage stages:

Small & medium animals

Primary:

(0.0125) x (______) x (______) = ______ m^3

kg loss/day — primary stage time — primary volume

Secondary:

(0.0125) x (______) x (______) = ______ m^3

kg loss/day — secondary stage time — secondary volume

Storage:

(0.0125) x (______) x (30 days) = ______ m^3

kg loss/day — storage volume

Alternate calculations for large animals

Primary:

(0.0125) x (______) x (______) = ______ m^3

W1 (kg) — (ADL x T1/W1) — primary volume

Secondary:

(0.0125) x (______) x (______) = ______ m^3

W1 (kg) — (ADL x T2/W1) — secondary volume

Storage:

(0.0125) x (______) x (______) = ______ m^3

W1 (kg) — (ADL x T3/W1) — storage volume

Step 2 – Indicate the windrow height and resulting windrow area used.

Windrow height

Assign a windrow height (1.5-2.1 m; 5-7 ft) and continue. Windrow Height = ______ m (ft)

Determine resulting windrow area used from the following windrow section area and base width (assumes 0.305 m top width and 1:1 side slopes).

Windrow Height	Windrow Section Area m^2 (ft^2)	Windrow Base Width m (ft)	Pad Width m (ft)
1.52 (5)	2.79 (30)	3.35 (11)	15.9 (52)
1.83 (6)	3.90 (42)	3.96 (13)	17.1 (56)
2.13 (7)	5.20 (56)	4.57 (15)	18.3 (60)

Step 3 – Calculate the length of the primary, secondary, and storage windrows and the pad.

Primary windrow:

(______________)	/	(______________)	=	______________m (ft)
Primary volume		Primary windrow area		Primary windrow length (round to nearest 0.3 m [1 ft])

If the primary windrow length is less than twice the windrow height, reduce the height and go back to step 2. This indicates the composting configuration will be a compost pile versus a windrow.

Secondary windrow:

(______________)	/	(______________)	=	______________m (ft)
Secondary volume		Primary windrow area		Secondary windrow length (round to nearest 0.3 m [1 ft])

Storage windrow:

(______________)	/	(______________)	=	______________m (ft)
Storage volume		Primary windrow area		Storage windrow length (round to nearest 0.3 m [1 ft])

Pad:

(______________)	+	(3.05 m [or 10 ft])	=	______________m (ft)
Design windrow length**				Pad length (round to nearest 0.3 m [1 ft])

***Design Windrow Length = the longer of the primary windrow length, or sum of the secondary and storage windrow lengths.*

Step 4 – Calculate composting pad width and area.

Pad width:

3 m [10 ft]	+	(____________)	+	3 m [10 ft]	+	(__________)	+	3 m [10 ft]	=	______m (ft)
		Primary windrow base*				Secondary windrow base*				Pad width

**refer to table in Step 2*

Pad area:

(__________)	x	(__________)	=	______m^2 (ft^2)
Pad length		Pad width		Pad area

Step 5 – Calculate annual sawdust requirements:

Note that this assumes no reintroduction of finished compost to the primary windrow; however, it is recommended that up to 50% of the fresh sawdust requirements be met with finished compost.

Sawdust volume

(__________)	x	(0.0116)	=	______________m^3 (yd^3)	=
kg (lb) loss/yr		(use 0.0069 if wt in lb)		sawdust volume	

TABLE 5a. Mortality composting using sawdust – bin system for poultry broilers (Keener & Elwell, 2000).

Bin system for poultry broilers:							
Assumptions:							
Number Animals	**10,000**	Design Wt (kg)	**2.0**	Avg Wt. (kg)	**1.9**	Animal Mortality	**0.045**
		Compost Time (day)	**11**	Growth Cycle (day)	**48.0**	Batches/ yr	**7.60**
Total Mortality (kg/yr)	**6,533**	Daily Mortality (kg/day)	**17.9**	Mortality (kg/bin)	**189.9**	Sawdust/ Mortality, v/v	**12**

Item	**C (%)**	**N (%)**	**C/N**	**Moisture (% w.b.)**	**Density (kg/m^3)**	**Wet volume ratio** m^3	**Wet volume ratio** %	**Wet mass ratio** kg	**Wet mass ratio** %
Mortality	45.0	7.50	6.0	65.0	1038	0.18	8	190	18
Sawdust (fresh)	43.3	0.21	206.0	30.0	274	2.20	.92	601	57
Water	0.0	0.00		100.0				260	25
Averages/Sums	43.5	1.20	36.1	53.6	442	2.38	100	1051	100

Volume = 2.38 m^3	Total volume = 2.38 m^3	Cover depth = 0.305 m
Bin height = 1.22 m	Total volume/cycle = 0.0125 m^3/kg/cy	Composting zone ht. = 0.610 m
Bin length = 1.22 m	Side biofilter depth = 0.305 m	Composting vol. = 0.37 m^3
Bin width = 1.60 m	Base height = 0.305 m	Mortality/non-biofilter compost =0.50 m^3/ m^3

TABLE 5b. Mortality composting using sawdust – windrow system for finishing swine (Keener & Elwell, 2000).

Windrow system for finishing swine:							
Assumptions:							
Number Animals	**2940**	Design Wt (kg)	**95.5**	Avg Wt. (kg)	**63.6**	Animal Mortality	**0.030**
		Compost Time (day)	**72**	Growth Cycle (day)	**135**	Batches/ yr	**2.70**
Total Mortality (kg/yr)	**15,175**	Daily Mortality (kg/day)	**41.6**	Mortality (kg/bin)	**3014.0**	Sawdust/ Mortality, v/v	**12**

Item	**C (%)**	**N (%)**	**C/N**	**Moisture (% w.b.)**	**Density (kg/m^3)**	**Wet volume ratio** m^3	**Wet volume ratio** %	**Wet mass ratio** kg	**Wet mass ratio** %
Mortality	37.5	7.50	5.0	75.0	1038	2.90	0.08	3014	0.20
Sawdust (fresh)	43.3	0.21	206.0	30.0	274	34.83	0.92	9542	0.62
Water	0.0	0.00		100.0				2727	0.18
Averages/Sums	42.7	0.95	45.0	51.4	405	37.74	1.00	15283	1.00

Windrow System (length does not include ends):

Volume = 37.74 m^3	Total volume = 37.74 m^3	Cover depth = 0.610 m
Windrow height = 2.13 m	Total volume/cycle = 0.0125 m^3/kg/cy	Composting zone ht. = 0.810 m
Windrow length = 7.28 m	Side bio filter depth = 0.610 m	Composting vol. = 4.77 m^3
Windrow base width = 4.57 m	Base height = 0.610 m	Mortality/non-biofilter compost =0.61 m^3/ m^3

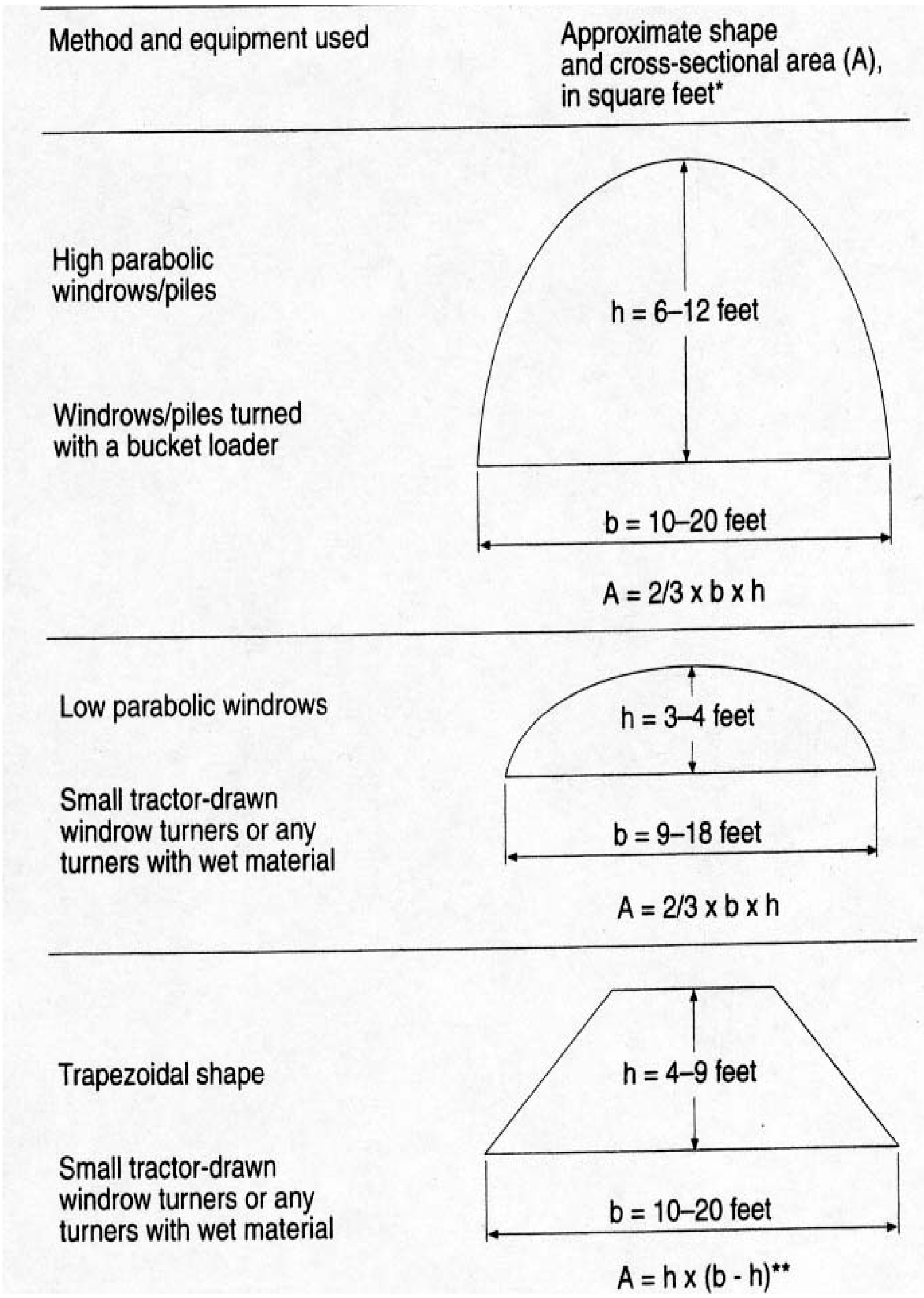
TABLE 5c. Mortality composting using sawdust – windrow system for cattle (mature)

Windrow system for cattle:							
Assumptions:							
Number Animals	**154**	Design Wt (kg)	**636.4**	Avg Wt. (kg)	**626.4**	Animal Mortality	**0.010**
		Compost Time (day)	**187**	Growth Cycle (day)	**365**	Batches/ yr	**1.00**
Total Mortality (kg/yr)	**980**	Daily Mortality (kg/day)	**2.7**	Mortality (kg/bin)	**636.4**	Sawdust/ Mortality, v/v	**12**

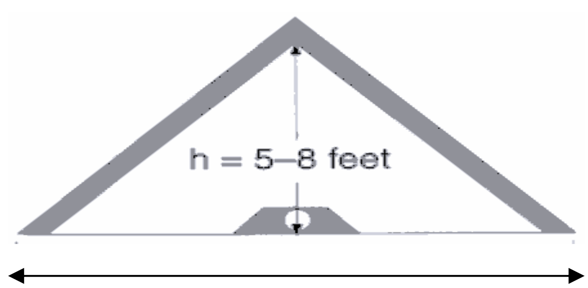
						Wet volume ratio		**Wet mass ratio**	
Item	**C (%)**	**N (%)**	**C/N**	**Moisture (% w.b.)**	**Density (kg/m^3)**	**m^3**	**%**	**kg**	**%**
Mortality	37.5	7.50	5.0	75.0	1040	0.61	8	636	19
Sawdust (fresh)	43.3	0.21	206.0	30.0	274	7.34	92	2015	60
Water	0.0	0.00		100.0				682	20
Averages/Sums	42.7	0.95	45.0	52.9	419	7.95	100	3333	100

Windrow System (length does not include ends):

Volume = 7..95 m^3	Total volume = 7.95 m^3	Cover depth = 0.610 m
Windrow height = 2.13 0m	Total volume/cycle = 0.0125 m^3/kg/cy	Composting zone ht. = 0.810 m
Windrow length = 1.53 m	Side biofilter depth = 0.610 m	Composting vol. = 1.01 m^3
Windrow base width = 4.57 m	Base height = 0.610 m	Mortality/non-biofilter compost =0.61 m^3/ m^3



Triangular-shaped static piles. Individual aerated static piles and other piles with little or no turning.



$A = \frac{1}{2} \times b \times h$, $b = 2 \times h$

FIGURE 1. Selected windrow cross-section shapes and their dimensions (Dougherty, 1999).

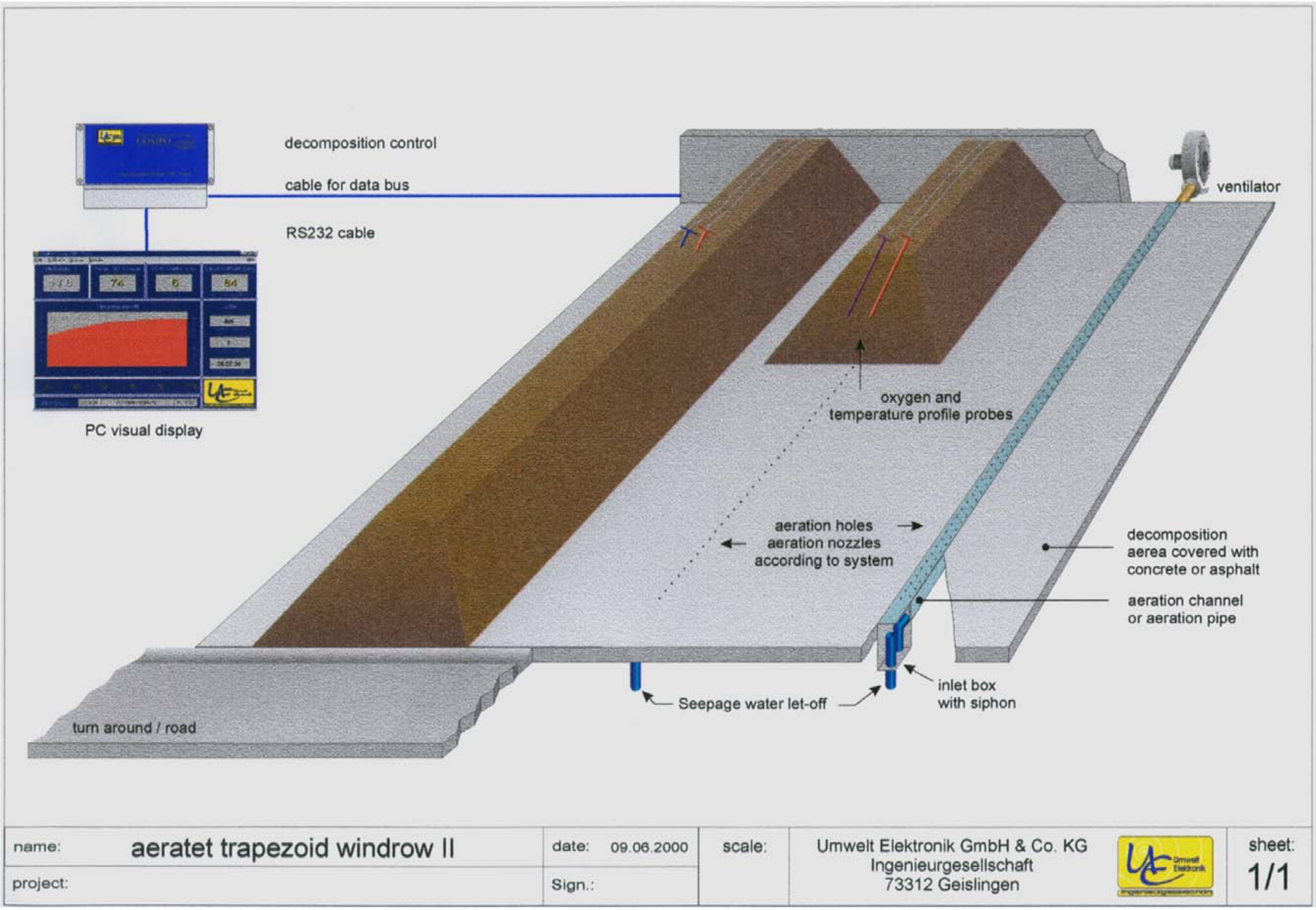


FIGURE 2. The trapezoid cross-section of sophisticated windrow composting along with oxygen and temperature measuring devices and data acquisition system (Umwelt Elektronic GmbH and Co., 2003).

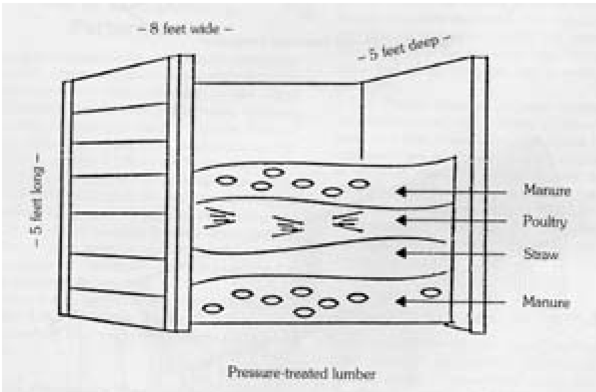


FIGURE 3. A simple poultry composter (Murphy & Carr, 1991).

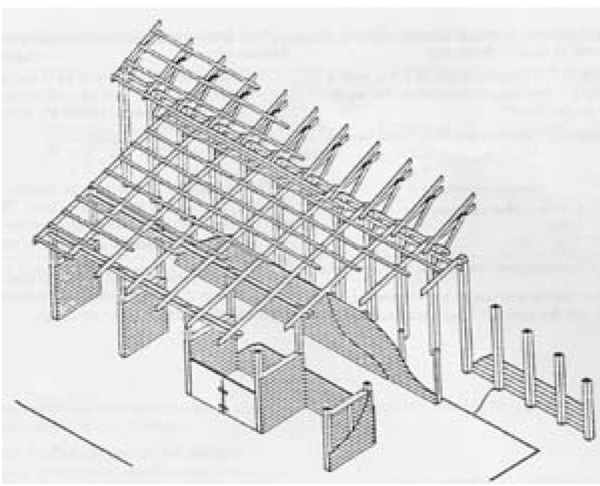


FIGURE 4. Delaware two-stage composter (Murphy & Carr, 1991).

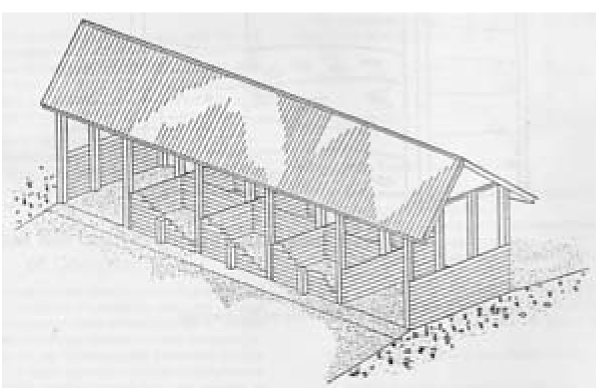
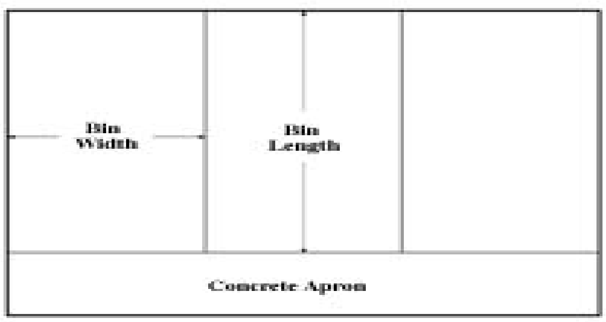
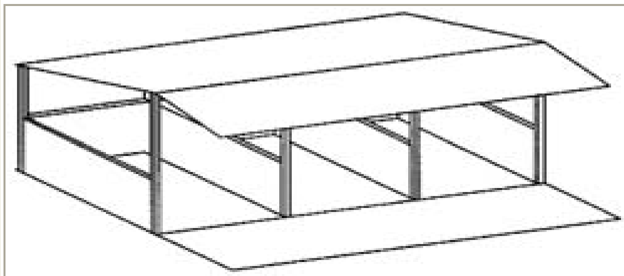


FIGURE 5. Maryland freestanding, two-stage composter (Murphy & Carr, 1991).



a) Bin layout, top view



b) Bin isometric

FIGURE 6. Bin system for composting swine mortality (Mescher et al., 1997).

Appendix E

TABLE 1. Various properties of co-composting materials including C:N ratio, porosity, relative moisture content, degradability, odor level, and treatment required for usage in composting (Dougherty, 1999).

Origin	C:N Ratio, Nutrients	Structure, Porosity	Moisture-as is	Degradability	Treatment Required	Cautions
AGRICULTURAL RESIDUALS						
Poultry manure (fresh, no litter)	10	Poor	Moist	Good	Bulking material	Odor
Poultry manure (with litter)	13-30	Medium	Low-dry	Medium	-	Odor
Slurry(urine) liquid	2-3	Poor	Liquid	Good	Mix with dry matter	Odor
Manure (cattle) liquid	8-13	Poor	Liquid	Good	Mix with dry matter	Odor
Manure (pig)	5-7	Poor	High	Good	-	Odor, moisture
Cattle manure	20	Medium	Medium	High	-	-
Manure with straw	25-30	Good	Good	Medium	-	-
Horse manure	25	Good	Good	Medium	-	-
Vegetable wastes	13	Poor	Moist	High	-	Low pH, odor
Straw: -Oat/rye -Wheat -Barley/pulses	 60; 100; 40-50;	 Good; Good; Good	 Dry; Dry; Dry;	 Medium; Medium; Medium;	 Rough chopping Rough chopping -	 - - -
WOOD AND LUMBER INDUSTRY MATERIALS						
Bark	100-300;low P, Ca; low pH	Very good	Medium; good	Very good	Pre-grind	-
Paper sludge	100-110	Medium to poor	Very moist	Medium	Press cake	Dioxins
Cotton sludge	20-40; N-rich; low P,K	Poor	Very moist	Very good	Pressed	-
Sawdust:	Beech ~ 100 Fir ~230 Aged <100	Very good	≤ 50%; good	Excellent	Already ground	-
Cardboard	200-500	Medium to poor	Very low	Very good	Shred	Boron, colors

Wood ash [a]	n/a; K-Ca$^-$ Rich; High in heavy metals	Poor	Very low	None	None	Metals, high pH
FRUIT PRESSING PRESIDUES						
Grapes	Poor in P, Ca	Poor/medium	Medium	Medium to low	Lime addition	Low pH, seed residues
Fruits	Poor in P, Ca	Poor	Medium	Fair to good	Lime addition	Low pH
GARDEN/ LANDSCAPE MATERIALS						
Wood chips	40-100	Good	Too dry	Low	Grinding	Coarseness
Garden wastes	20-60	Good	Medium	Medium	Grinding	-
Green foliage	30-60	Medium to good	Good/dry	Good	-	-
Leaves	-	Good	-	-	-	Matting
Grass clippings	12-25	Poor	Moist	High	Bulking material, pre-drying	Odor
Reeds/ swamp matter	20-50	Good	Dry	Medium	Grinding	Coarseness
Ditch scrapings	10-15	Poor	Moist	Medium	Occasionally Pressing	Salts/ lead on road-sides
OTHERS						
Peat (dark)	60-80	Good	Medium	Very low	-	Low pH
Peat (light)	60-80	Good	Medium	Low	-	Low pH
Slaughter wastes	15-18	Poor	Moist	High	-	Odor
Mushroom compost	40	Good	Good	Good/medium	-	-
Rock powders [b]	Ca, K, Mg, trace elements	Poor	None	None	-	-
MSW[c]	30-120	Medium to poor	Very low	Medium	Grinding, moisture	Metals, glass,etc
Biosolids(sewage sludge)	<20; high K, salt	Poor	High	Very good	Needs bulking material	Pathogens, metals
Food scraps	<25; high K, salt	Very poor	High	Very High	Bulking material	Pathogens, salt
Coffee grounds	-	Medium	Medium to high	Medium	-	-

TABLE 2. C:N ratios of various supplement materials used for carcass composting (Morse, 2001).

Substance	(W/W)
Sawdust[a]	200-750:1
Straw[a]	48-150:1
Corn stalks[a]	60-73:1
Finished compost[a]	30-50:1
Horse manure[a]	22-50:1
Turkey litter[a]	16:1
Animal carcass[b]	5:1
Swine manure[b]	1-3:1

[a]On-Farm Composting Handbook, NRAES-54, Natural Resource, Agriculture, and Engineering Service, Ithaca, New York.

[b] Compost Materials, 1996, EBAE 172-93, North Carolina Cooperative Extension Service, Raleigh, North Carolina.

TABLE 3. A compost recipe that satisfies the nutritional requirements for composting poultry mortalities (Sussman, 1982).

Ingredient	Volume ratio	Weight ratio	Weight	%	% moisture	C:N ratio
Manure	2.0	1.5	675 kg (1500 lb)	57.7	30	25
Dead birds	1.0	1.0	450 kg (1000 lb)	38.5	70	5
Straw	1.0	0.1	45 kg (100 lb)	3.8	10	85
Total			1170 kg (2600 lb)	100		
Weighted average					44.6	19.6

TABLE 4. Recommended conditions for active composting (Rynk,1992).

Parameter	Target range [a]
Carbon-to-nitrogen (C:N) ratio[b]	20:1-40:1
Moisture content[c]	40-65%
Oxygen concentration[d]	>5%
Particle size (diameter in inches)	0.5-2
Pile porosity	>40%[c]
Bulk density	474-711 kg/m^3 (800-1,200 lb/yd^3)
pH	5.5-9
Temperature (ºF)	110-150

[a] Although these recommendations are for active composting, conditions outside these ranges may also yield successful results.

[b] Weigh basis (w:w). C:N ratios above 30 will minimize the potential odors.

[c] Depends upon the specific materials, pile size, and/or weather conditions.

[d] An increasing likelihood of significant odors occurs at approximately 3% oxygen or less. Maintaining aerobic conditions is key to minimizing odors.

TABLE 5. Selected compost equipment: available capacity and horsepower ranges (Dougherty, 1999).

	Type & Description	Horsepower HP	Approximate Capacity yd^3/hr	Ton/hr
	Grinding/Shredding Equipment			
	Hand-fed chipper(disc-type) – max. diameter of materials 5-6 in	20-30		
	Hand-fed chipper (disc-type) – max. diameter of materials 9-12 in	35-120		
	Hammer mill	30-900	8-450	4-225
	Paper and wood shredder	2-100	1-30	0.5-15
	Rotary auger with counter knife	22-335	2-130	1-65
1[a]	Rotary shear shredder	7.5-600	0.4-200	0.2-100
2	Shear shredder (belt-type)	5-110	10-250	5-125
	Shredder with knives fixed to set of rotating disks	30-60	4-12	2-6
3	Tub grinder	80-990	20-200	10-100
	Vertical grinder	100-400	8-50	4-25
	Vertical grinder- large capacity	1,000-2,000	100-450	50-225
	Whole-tree-chopper-disc-type (towed or self-propelled) – max. diameter of materials 12-17 in	170-250		
	Whole-tree-chopper-disc-type (towed or self-propelled) – max. diameter of materials 19 in	400-500		
	Wood-chipper-cutting disc-type – max diameter of materials 6-9 in	20-40		
	Mixing Equipment			
4	Batch-mixer- auger -type (10-30-cubic-yard capacity while mixing)	75-165	40-100	20-50
	Batch-mixer-reel-type (4-18-cubic yard capacity while mixing)	10-50		
5	Rotating drum mixer		12-160	6-80
6	Continuous mix plug mill	10-100	2-1,000	1-500

[a]1-6 correspond to numbered items in Figure 1, Appendix E, below.

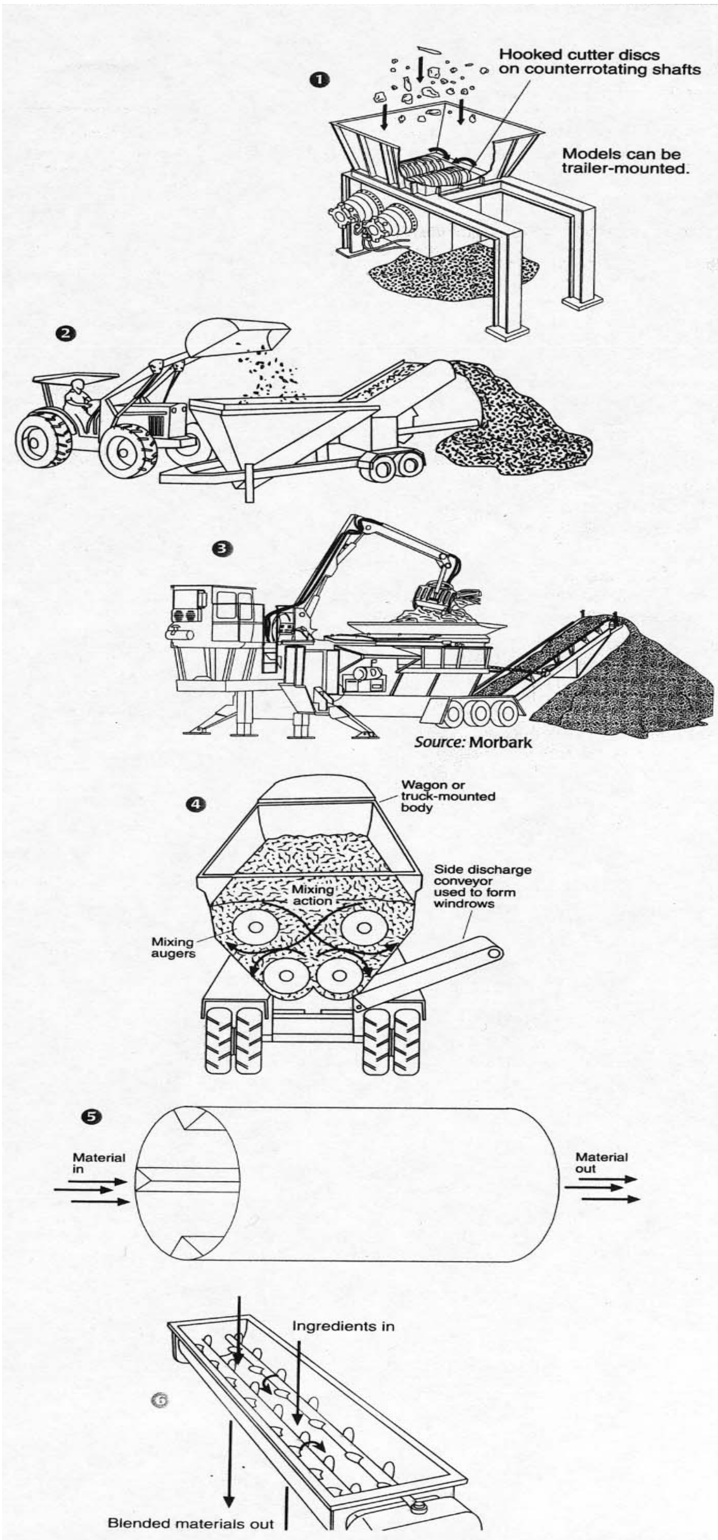


FIGURE 1. Selected compost equipment (Dougherty, 1999). Numbered items correspond to items in Table 5, Appendix E, above.

TABLE 6. Selected self-powered windrow turning equipment and associated cost (Diaz et al., 1993).

Manufacturer	Power (HP)	Capacity (TPH)	Approximate Cost (US$, 1991)
Brown Bear	115	1,500	$118,000
Brown Bear	225	3,000	$181,000
Cobey	225	1,000-2,000	$135,000-185,000
Resource Recovery Systems	300	2,000	$104,000
Resource Recovery Systems	400	3,000	$170,000
Scarab	234	2,000	$104,000
Scarab	360	3,000	$174,000
Scat	107	3,000	$176,000

TABLE 7. Selected PTO-driven windrow-turning equipment and associated cost (Diaz et al., 1993).

Manufacturer	Power (HP)	Capacity (TPH)	Approximate Cost (US$, 1991)
Centaur Walker	90	800	$7,400
Scat	65	2,000	$55,000
Wildcat	70	1,000	$46,500

FIGURE 2. The PTO PA35C-10.5 compost turning unit is designed to be attached to the front of 100-160 HP farm tractors (Brown Bear Corp., 2003).

TABLE-8. Selected compost windrow turning machinery and screening equipment with available capacity and horsepower ranges (Dougherty, 1999).

	Type & Description	Horsepower HP	Approximate Capacity yd^3/h	Approximate Capacity Tons/h
	Windrow Turning Machinery			
1[a]	Aerator-composter (PTO powered, rear-hitch-mounted to 60-130 hp tractor)	Tractor PTO	400-2,400	(200-1,200)
2	Aerator-auger (mounted on front of 40-130 hp tractor)	Hydraulics		
	Auger-style turner (self powered, self propelled)	115-300	2,000-40,000	(1,000-20,000)
3	Elevated face turner (self powered, towed by 40-100 hp tractor)	65-85	3,000-4,000	(1,000-3,000)
	Elevated face turner (self powered, self propelled)	100-150	2,000-6,000	(1,000-3,000)
4	Rotary drum turner (ground-driven, towed by 35-70 hp tractor)		1,200-1,800	(600-900)
5	Rotary drum turner (self powered, self propelled)	65-440	1,600-8,000	(800-4,000)
6	Rotary drum turner (PTO powered, towed by 60-140 hp tractor)	Tractor PTO	400-1,000	(200-500)
7	Rotary drum turner (self- powered, towed by 70 hp tractor)	90-125	1,800-2,200	(900-1,100)
	Rotary drum turner (self- powered, mounted on 3-cubic-yard front-end loader)	170-190	1,800-2,200	(900-1,100)
	Rotary drum turner (self- powered, mounted on 4-cubic-yard front-end loader)	325	5,000	(2,500)
	Screening Equipment			
	Disc Screen		20-80	(10-40)
	Flexible belt screen		30-200	(15-100)
	Oscillating (shaker) screen		Variable	
8	Trommel screen		20-150+	(10-75+)
9	Vibrating screen		50-150+	(25-75+)

[a]1-9 correspond to numbered items in Figure 3, Appendix E, below.

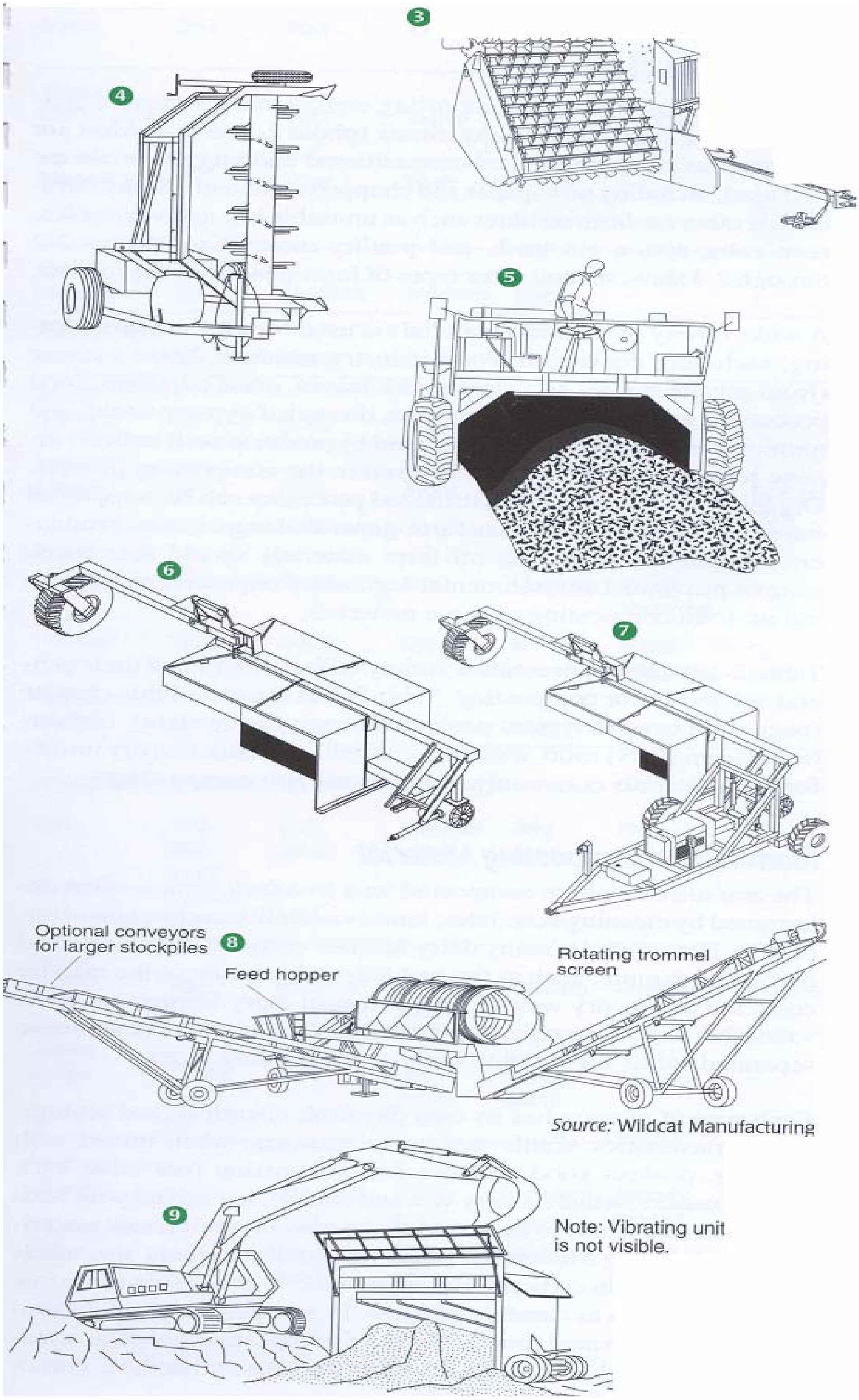


FIGURE 3. Selected compost equipment (Dougherty, 1999). Numbered items correspond to Table 8, Appendix E, above.

Appendix F

TABLE 1. Nutrient content of poultry manure (litter) and composted poultry mortalities (Murphy & Carr, 1991).

Analyte	Built up litter	Dead bird compost
Moisture, %age	21.00	46.10±2.19
Nitrogen, %age	4.15	2.20± 0.19
Phosphorus(P_2O_5), %age	3.80	3.27± 0.23
Potash (K_2O), %age	2.85	2.39±0.13
Calcium, %age	1.70	1.33±0.15
Magnesium, %age	0.91	0.82±0.10
Sulfur, %age	0.51	0.40±0.02
Manganese, parts per million	208.00	122.00±18.00
Zinc, parts per million	331.00	245.00±32.00
Copper, parts per million	205.00	197.00±28.00 <>

TABLE 2. Nutrient content of "active" sawdust–piglet mortality compost from mini-composter (Harper et al., 2001).

Unit	Moisture	Total-N	NH_4-N	P_2O_5	K_2O	Ca	Mg
%	32.4	1.59	.36	2.04	.28	1.58	.15
lbs./US ton (2,000lb)	648	31.75	7.27	40.89	5.58	31.52	2.98
kg/metric ton (1,000kg)	324	15.88	3.69	20.45	2.79	15.76	1.49

TABLE 3. Typical composition of composted carcasses (McGahan, 2002).

Nutrient	%	kg/metric ton
Total nitrogen (TKN-N)	1.28	13.00
Ammonia (NH_3-N)	0.22	2.00
Phosphorus (P)	0.27	2.84
Potassium (K)	0.28	2.90

TABLE 4. Nutrient content of the end product of cattle carcass composting (Kube, 2002).

Nutrients	kg of nutrients/US ton (2000 lb) of compost	kg of nutrients/metric ton (1000 kg) of compost
Total Kjeldahl Nitrogen	10-25	5-12.5
i. Potentially available nitrogen:	5-15	2.5-7.5
ii. Phosphorus:	2-20	1-10
iii. Potassium:	4-20	2-10

FIGURE 1. Condition of large bones at the end of carcass composting trials (Mukhtar et al., 2003).

Appendix G

TABLE 1. Effects of long- and short-term aeration on operational and fixed costs of windrow composting (Umwelt Elektronic GmbH and Co., 2003).

	Example 1	Example 2	Example 3
Input t/a	10.000	10.000	10.000
Period of main decomposition	8 weeks aerated	4 weeks aerated	25 weeks not aerated
Period of subsequent decomposition	2 weeks not aerated	12 weeks not aerated	-
Area of main decomposition	1,870 m^2	918 m^2	4,726 m^2
+ area roads	561 m^2	275 m^2	1,418 m^2
Area of subsequent decomposition	325 m^2	1,900 m^2	
+ area roads	98 m^2	570 m^2	
+ area for storage	282 m^2	282 m^2	282 m^2
Sum area	**3,136 m^2**	**3,945 m^2**	**6,426 m^2**
Capital costs per ton input	€34.60	€29.84	€35.74
(Without site costs)	(Without aeration and control)	(Without aeration and control)	(Without aeration and control)
Re-stacking costs per ton	-	€3.52	€7.03
Energy costs for main decomposition per ton	€0.64	€0.32	-
Necessary sum per ton required for redemption per ton for a plant use of 15 years	€4.24	€6.89	€10.56
OR: reduced redemption period in reference to a plant without aeration	6 years	9.8 years	15 years

TABLE 2. Number of livestock operations assumed large enough to install composting facilities (SCI, 2002).

Species	Total Number of US Operations	Large Operations[a]	
		Criteria	Number
Beef cattle	830,880	>50 Head	177,330
Dairy cattle	105,250	>30 Head	74,140
Hogs	81,130	>500 Head	35,118
Other	71,340[b]	--	20,000
Total	1,088,600		306,588

[a]Based on most recent USDA/NASS cattle, hogs and pigs, and sheep and goat reports.
[b]Estimated number of sheep, lamb, and goat operations.

TABLE 3. Economic analyses (annual net cost) of dead-bird disposal systems for a flock size of 100,000 birds (Crews et al., 1995).

Item	Existing Technologies			Emerging Technologies		
	Disposal Pit	Large-Bin Compost	Incineration	Small-Bin Compost	Fermentation	Refrigeration
Initial investment cost	$4,500	$7,500	$2,000	$2,016	$8,200	$14,500
Annual variable cost	$1,378	$3,281	$4,833	$3,661	$2,862	$5,378
Annual fixed cost	$829	$1,658	$522	$297	$1,190	$2,670
Annual fixed cost	$829	$1,658	$522	$297	$1,190	$2,670
Total cost	$2,207	$4,939	$5,355	$3,958	$4,052	$8,048
Value of by-product	$0	$2,010	$0	$1,860	$1,320	$1,200
Annual net cost	$2,207	$2,929	$5,355	$2,099	$2,732	$6,848
Cost per hundred-weight of carcass disposed	$3.68	$4.88	$8.92	$3.50	$4.55	$11.41

* **Key production and financial assumptions:**
Average weight of carcass (lbs.) 2.00
Length of grow-out cycle (days) 45.00
Cost of compost removal ($/ton) 7.00
Value of straw ($/ton) 60.00
Value of litter ($/ton) 20.00
Value of compost by-product ($/ton) 20.00
Value of fermented by-product ($/lb.) 0.02
Value of refrigerated by-product ($/lb.) 0.02
Mortality (%) 5.00
Flocks/batches per year 6.00
Labor rate ($/hr.) 5.00
Fuel/butane ($/gal.) 0.62
Tractor fuel ($/gal.) 0.83
Cost of electricity ($/kwh.) 0.08
Cost of carbohydrate ($/lb.) 0.07

TABLE 4. Variable costs of composting mortalities on-farm (SCI, 2002).

Species	Deaths		Sawdust		Operating Costs ($1,000)[a]		
	Number (1,000)[a]	Pounds (1,000)[a]	Volume (yd^3)	Cost ($1,000)[a]	Labor	Machinery ($/head)	Total ($/head)
Cattle & Calves	4,131.8	1,932,180	12,945.61	15,728.91	48,758.94	60,863.67 **(14.73)**	125,351.52 **(30.34)**
Weaned Hogs	6,860.0	915,249	6,132.17	7,450.58	21,737.16	28,830.34 **(4.20)**	58,018.09 **(8.45)**
Pre-weaned Hogs	11,067.7	66,406,	444.92	540.58	1,577.14	2,091.79 **(0.19)**	4,209.51 **(0.38)**
Other	832.7	64,105	429.50	521.85	1,522.49	2,091.31 **(2.51)**	4,063.65 **(4.88)**
Total							$191,642.77

[a]Where indicated, multiply values in the table (except $/hd) by 1000 to obtain actual values.

TABLE 5. Fixed investment costs of constructing on-farm composting facilities (SCI, 2002).

Species	Number of Facilities	Investment Cost/Facility	Total Investment Cost x$1,000
Beef Cattle	177,330	$7000	$1,241,310
Dairy Cattle	74,140	$7000	$518,980
Hogs	35,118	$7000	$245,826
Other	20,000	$7000	$140,000
Total	306,588		$2,146,116

TABLE 6. Budgeted annual costs for disposing of mortality from a pork production system with a mortality rate of 40,000 pounds per year – 300-sow farrow-to-finish system (Henry et al., 2001).

	Incineration without afterburner	Incineration with afterburner	Composting High investment	Composting Low investment	Rendering Four pickups/week
Disposal equipment	Incinerator and fuel tank	Incinerator and fuel tank	Compost bins and building	Compost bins	Screen storage area
Capital investment	$3,642	$4,642	$15,200	$7,850	$300
Other equipment needed	--	--	Skid Steer Loader Tractor Manure spreader	Skid Steer Loader Tractor Manure spreader	Skid Steer Loader
Labor hours per year	60.7	60.7	115.0	125.9	60.7
Budgeted Annual Costs	$710.19	$905.19	--	--	$51.00
Fixed costs-disposal equipment	--	--	$2,305.33	$1,190.58	--
Machinery costs	--	--	382.19	447.39	364.00
Fixed Operating	--	--	254.79	298.26	242.67
Other operating costs	572.00	1341.44	320.00	320.00	5,200.00
Labor	667.33	667.33	1,265.15	1,384.68	667.3
Total cost per year	$1,949.52	$2,913.96	$4,527.47	$3,640.92	$6,525.00
Total cost per pound of mortality	$0.049	$0.073	$0.113	$0.091	$0.163

TABLE 7. Estimated costs of composting cattle carcasses with three different options (Kube, 2002).

Item	No grind	Grind compost	Grind deaths
Lime base	$20/hd initial base preparation $5-8/hd after removal of a cured windrow		
Payloader	$3-8/hd		
Sawdust	$10-15/hd		
Grinder	$0	$3/hd	$6/hd
Time	12 months	9 months	6 months
Turns or grinds	3	2	1
Area (sq ft)	60-120/hd/yr	45-90/hd/yr	30-60/hd/yr
Cost of land application	$7-15/hd		
Total cost (excluding site preparation)	$25-52/hd		

TABLE 8. Characteristics and value of final product obtained from windrow composting of cattle carcasses (Kube, 2002).

Characteristic	Value
Density of finished compost	about 652 kg/m^3 (1,100 lb/yd^3)
Volume of compost resulting per carcass	approximately 2.66 m^3 (3.5 yd^3) approximately 0.76 m^3 (1 yd^3) from carcass and 1.9 m^3 (2.5 yd^3) from amendment
Weight of compost resulting per carcass (wet-basis)	approximately 3,000 lb about 1,000 lb from carcass and 2,000 lb amendments
Value of compost from nutrients	$5-$15/ton
Nutrient value of compost per head	$10-$30

Appendix H

TABLE 1. Summary of virus isolations obtained from compost and composted bird samples (Murphy & Carr, 1991).

	Area sampled		
Sample identification	Neck	Bursa	Other
Positive control	2/4[a] (NDV[b])	4/4 (IBDV[c])	--
11 days (primary)	0/8	2/8 (IBDV)	--
18 days (secondary)	Not tested	0/7	--
Compost 3/2/89	--	--	0/3

[a] Number of samples containing viable virus over the total number assayed.
[b] Newcastle disease virus.
[c] Infectious Bursal Disease Virus.

Appendix I

TABLE 1. Some entities (schools and governmental agencies) involved in "carcass composting" training.

Name of the organization and academic institution:	Means of education	Link
Compost Education and Resources for Western Agriculture (CERWA), is a Professional Development Project funded by the Western Region SARE - USDA, 1998-2000.	This site provides the Internet links to course resources that covered everything from safety issues, basic biology, journal articles, compost quality, and videotapes.	http://www.aste.usu.edu/compost/qanda/mortc.pdf
Cornell University: Program Work Team (PWT).	1.Provides information on the internet, 2. Communication with other PWT, providing report to see the progress of the activities about the issues.	http://www.cfe.cornell.edu/wmi/PWTminutes.html
Cornell Waste Management Institute: Cornell University	Videotapes and information on the web.	http://www.cfe.cornell.edu/wmi/Compost/naturalrendering.pdf
Iowa State University (Funded by The Leopold Center for Sustainable Agriculture)	Conferences and workshops for farmers, landowners, educators, and researchers, and facilities construction for the swine hoops systems initiative	http://extension.agron.iastate.edu/immag/pr/Leopold.html
Maryland Cooperative Extension supported by the federal government, research and programs from other universities. They have composting school program (Better Composting School) which provides basic information on dead animal composting	School Program: Classes, tour to the compost facility. The Extension service also provides information on the web regarding animal mortality composting.	http://www.agnr.umd.edu/MCE/Publications/Category.cfm?ID=C http://www.agnr.umd.edu/users/wye/BetterCompSch.html
Michigan Agriculture Environmental Assurance Program (MAEAP).	Meeting, seminar, workshop to provide important updates for farmers across state.	http://www.michigan.gov/minewswire/0,1607,7-136-3452_3457-58142--,00.html
Natural Resource, Agriculture, and Engineering Service (NRAES): An interdisciplinary, issue-oriented program sponsored by cooperative extension of fourteen member land grant universities.	Videos, Hand books, Seminars	http://www.nraes.org/publications/n_pubs7.html
Ohio State University Fact Sheet (Extension). (Food, Agricultural and Biological Engineering Department).	Information on the Web	http://ohioline.osu.edu/aex-fact/0713.html
Texas A & M University, Commerce.	Information provided on web.	http://www7.tamu-commerce.edu/agscience/res-dlc/dairy/dlc-dair.html
Texas A & M University, Extension.	Provides useful links covering basic information including materials and processes of composting	http://agsearch.tamu.edu/cgibin/htserach
University of Arkansas	Information on the web	http://www.uaex.edu/Other_Areas/publications/HTML/MP397/Recipe