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Design, Utilization, Biosecurity, Environmental and Economic Considerations of Carcass Composting

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A successful carcass composting enterprise relies on proper design, layout, management, cost analysis, environmental impacts, and quality of the finished product. A well-designed carcass composting process with adequate capacity and a practical layout facilitates an even flow of inputs and outputs. It will also prevent environmental insult (such as wastewater, odors and gases) from compost by-products and the finished product. A well designed system will produce an end product that is free of most pathogens and serve as a soil amendment for agricultural activities.

Introduction

Size and layout are the two most important design criteria for carcass composting facilities. Undersized and oversized carcass composting capacities may cause different process disorders such as environmental contamination (e.g., release of unpleasant gases and odors) and incomplete destruction of pathogens.

Bins, static piles, and windrows are the most common methods of carcass composting. Static piles consist of placing carcasses and cocomposting materials in layers resulting in an approximately hemispherical or conical shape. Because of latent and sensible heat loss through the pile surfaces accompanied often by more rapid drying, cone-shaped piles are not recommended (Manser and Keeling 1996). Windrow composting is essentially a continuous line of multiple static piles with a trapezoidal or semicircular cross-section. Generally three separate bins (primary, secondary and curing or storage) comprise a bin composting system. The storage volume must be greater than or equal to the secondary bin size since it must hold all the material emptied from the secondary bin prior to beneficial use (Dougherty 1999; Keener and Elwell 2000; Morse 2001; Langston *et al.* 2002; McGahan 2002; Tablante *et al.* 2002).

Sometimes an additional bin with dimensions equal to that of the primary bin has been recommended to hold carcass materials without initiation of the composting process (called a waiting or preparation bin). After the preparation process, which may take a few days, the waiting bin becomes a primary bin of composting. A compost facility must be sized and designed so that it can be filled and emptied on a schedule as dictated by the flow of carcasses and at the same time produces an acceptable finished product (Fulhage and Ellis 1996).

Size Estimation

The most important size or capacity parameters for the first two phases of mortality composting and storage of end products include the daily mortality rate, mean carcass weight, composting time (which determines total loading for the primary phase) and appropriate dimensions (Dougherty 1999; Keener *et al.* 2000; Keener *et al.* 2001, Morse 2001, Langston *et al.* 2002; McGahan 2002; Tablante *et al.* 2002).

Based on daily weight loss of the compost, original weight of the carcasses and cocomposting materials, mathematical models have been developed for predicting the time, volume, and/or capacity of primary, secondary, and storage phases of carcass composting. Murphy and Carr (1991) stated that the capacity of bin composting for poultry depends on theoretical farm live weight. They presented the following formula as a model to estimate the peak capacity of dead poultry for the first phase of composting, which was based on market bird age and weight:

Daily composting capacity (kg or lb/day) =
Theoretical farm live weight (kg or lb) /400 day . . (1)

Theoretical farm live weight (kg or lb) =
Farm capacity (number of birds) x
market weight (kg or lb/bird) . . . . (2)

According to the composting experiences of Murphy and Carr (1991) and Underwood (1999), 1 kg (2.2 lb) of poultry mortality requires about 0.062 m^3 (2.2 ft^3) volume each for primary and secondary phases of composting. United States Department of Agriculture-Natural Resources Conservation Service or USDA-NRCS (2002 and 2004) provided the following formula for total bin volume needed for composting of dead carcasses generated in one growth cycle of poultry (broilers, turkeys, layers and Cornish hens) to reach market weight:

$$V = (N*M*W*VF)/T \quad (3)$$

Where: V=volume required for each stage (m^3 or ft^3) per flock, N=number of birds per flock, M=mortality or loss rate (expressed as a decimal fraction), W=average market weight of bird (kg or lb) in flock life, VF=volume factor (based on management skills of operator, local conditions and experiences, and ranges between 0.10-0.16 m^3/kg or 1.5-2.5 ft^3/lb) of dead birds and T=flock life (number of days for animal to reach market weight). The total calculated composting volume is divided by the volume of the individual composting bin to determine the number of bins required. Based on this formula, Table 1 shows data needed to calculate the volume for primary composting of poultry carcasses.

Morris *et al.* (2002) used the bulk density of composting materials to estimate the needed primary and secondary bin volumes and areas for cattle mortality composting using the following equations:

$$A_1 = (n*W)/ (h*Ú_1) \quad (4)$$

$$A_2 = (n*W)/ (h*Ú_2) \quad (5)$$

in which A_1 and A_2 are, respectively, the needed areas (m^2 or ft^2) for the primary and secondary bins, W is the average weight (kg or lb) of each carcass to be disposed, n is the number of dead animals in one fill/empty cycle, h is the height (m or ft) of the bins, and $Ú_1$ and $Ú_2$ are bulk densities of composting material at the beginning of the first and the second phase of composting, respectively. According to Morris *et al.* (2002) these bulk densities were about 37.5 and 56.2 lb/ft^3 (600 and 900 kg/m^3), respectively, although those figures depend strongly on cocomposting materials.

TABLE 1.
Poultry data for calculating primary bin volume if producer or local data is unavailable (USDA-NRCS 2004)

Poultry Type	Loss Rate	Flock Life (Days)	Cycles/ Year	Average Market Weight (WB)
Broiler	.045 - .055	42 - 49	5.5 - 6	4.2
Roasters: Females	05	42	4	4.0
Males	.08	70	4	7.5
Hens: Laying	.14	420 - 455	0.9	4.5
Breeding	.2 - .25	280 - 315	.09	10
Breeders: Male	.2 - .25	280 - 315	1.1	15
Turkey: Female	.05 - .06	91 - 98	3	14
Light Tom	.09	112	3	24
Feather production	.12	126	2.5	28-32

Primary Bin Volume (ft^3) = Number of Birds x (Loss Rate/Flock Life) x Average Market Weight of Bird x Volume Factor/time

Due to different decomposition rates of materials during different stages, the time of primary, secondary and storage phases of composting (T_1, T_2 and T_3) is not the same, and each one determines the total loading for each phase of composting process. To predict the time and volume needed for each phase of composting, Keener and Elwell (2000) used the following assumptions:

- The annual livestock death loss (ALDL) is a key factor to estimate compost volume and facility capacity. In other words, the design compost volume is proportioned to ALDL.
- The primary and secondary composting times for large animals (exceeding 227 kg or 500 lb) is a conservative design basis for calculating the composting time from mathematical models.
- Volume equations for composting small carcasses (less than 23 kg or 50 lb, such as poultry) and medium animals (23-114 kg or 50-250 lb, such as swine) in bin and windrow systems provide reasonable values of V_1, V_2, and V_3.
- Only the windrow system is appropriate for composting large carcasses (more than 114 kg or 250 lb) and very large or heavy carcasses (those exceeding 227 kg or 500 lb), because of difficulty placing individual mortalities of mature cattle or horses inside the primary bins.
- A minimum of 10 days is required for poultry composting.
- If no shrinkage is allowed, the bin volume for secondary phase of composting must be equal or greater than the bin volume for the primary phase of composting.
- The storage volume for the finished compost product should be adequate to hold a minimum of 30 days' production of second stage compost.

The rationale for their assumptions was that land application of the finished compost may not always be feasible at the time of removal from the secondary bin, and as much as 50% of the finished compost could be replaced into the primary bin for fresh mortality composting. Furthermore, they analyzed the mortality composting of different livestock and poultry production facilities including a system with a 10,000 bird broiler operation (average weight of 1.9 kg per bird), a 2,940 head swine finishing operation (average weight of 63.6 kg per pig), and a 154 mature dairy cow operation (average weight of 663.4 kg per cow). To obtain appropriate equations, they used the results of bin composting experiments for poultry (broilers), and windrow composting systems for swine (finishing) and dairy cattle. They determined a specific volume coefficient of 0.0125 m^3 /kg mortality (0.20 ft^3/lb mortality) per one growth cycle for calculating primary, secondary, and storage volumes (V_1, V_2, and V_3, respectively). The growth cycle was defined as the on-farm feeding to marketing period for livestock or poultry. The following models were proposed for calculating composting time (T_1, T_2 and T_3 in days) and volume (V_1, V_2 and V_3 in m^3) needed for primary, secondary and storage phases:

$$T_1 = (7.42)*(W_1)^{0.5} \geq 10 \text{ days} \quad (6)$$

T_1 = time needed for primary phase of composting (days),

W_1 = mortality weight (kg) and

7.42 day/kg $^{0.5}$ is the carcass decomposition rate.

$$V_1 = (0.0125)*(ADL)*(T_1) \quad (7)$$

V_1 = Composting volume for primary phase (m^3)

ADL = Average Daily Mortality in kg of mortality/day

$$T_2 = (1/3)*(T1) \geq 10 \text{ days} \quad (8)$$

$$V_2 \geq (0.0125)*(ADL)*(T2), m^3 \quad (9)$$

$$T_3 \geq 0 \text{ days} \quad (10)$$

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

$$V3 \geq (0.0125)*(ADL)*(T3), m^3 \quad (11)$$

In Equations 6-11, W_1 is the average body weight of a single mortality in kg and ADL is the average daily loss or rate of mortality in kg of mortality/day (within one growth cycle). The recommended mortality rates and design weights of poultry, swine, cattle/horses and sheep/goats have been prepared by Keener *et al.* (2000a, b).

Although different formulas and mathematical models have been suggested to calculate the volumes needed for primary, secondary and storage phases of composting different carcasses, their final results are not very far from each other. For example, Rynk (2003) affirmed that under standard conditions and regardless of the size and volumes of bins, the minimum bin volume needed for the primary, secondary and storage phases of composting for every 4.5 kg (10 lb) of carcasses is 4.25 L (1.5 ft^3). As illustrated below, the same carcass weight (10 lb) in Keener's model (equations 6 and 7), will yield a minimum primary bin volume (V_1) of 2.0 ft^3, a 33% increase over Rynk's suggested volume.

$$T_1 = (7.42 \text{ day/kg}^{0.5})*(4.5 \text{ kg})^{0.5} = 15.7 \text{ day}$$

If we assume constant decomposition rate, then ADL = 0.2859 kg/day

$$V_1 = (0.0125)*(ADL)*(T_1)=(0.0125 \text{ m}^3/\text{kg})*(0.2859 \text{ kg/day})*(15.7 \text{ day})=0.056 \text{ m}^3 \sim 2 \text{ ft}^3$$

It is important to consider that volumes of V_2 and V_3 depend on the number of individual bins chosen for the primary stage. Fulhage and Ellis (1996) recommended two primary bins each in volume equal to V_1, one secondary bin V_2=V_1 and one storage bin V_3=V_1. Therefore, the total bin volume for 3 phases is (2+1+1)*V_1 or 4V_1. Under this scenario, total volume for the three phases of 10 lb mortality composting is 4(1.5) = 6 ft^3 from Rynk's suggestion or 4(2) = 8 ft^3 from Keener's model.

Layout and Construction Features

Proper layout and construction features are two more key aspects of successful carcass composting. The following section provides recommendations for both windrow and bin configuration.

Windrow Composting

Although different cross-section designs for windrow systems have been used in conventional composting, they have had limited applications in composting of intact carcasses. Kube (2002) used ground carcasses as a uniform and consistent raw material for windrow composting. Because of the uniformity in the mixed materials, the turning processes could be carried out in a manner very similar to that of a conventional composting pile. Haug (1993) reported that in a modern windrow process, the composted organic materials are turned at regular intervals by specialized mobile equipment which produces differently shaped cross sections. The cross section may range from haystack to rectangular, trapezoidal, or triangular, depending largely on characteristics of the composting material and equipment used for turning.

While different cross sections (high parabolic, low parabolic, trapezoidal and triangular) have been used for composting different raw materials, the trapezoidal cross-section is normally used for windrow composting of animal mortality. For wet (humid) climates, trapezoidal pile with steep slopes and narrow top will be suitable to drain rain water quickly away from the top of the pile. Conversely, for drier climates, a low angle and wide top trapezoidal pile will keep precipitation on top of the piles. Mescher *et al.* (1997) proposed a trapezoidal windrow for primary and secondary carcass composting. He indicated that the side slopes of windrow composting in most cases were 1:1. While each of the windrow dimensions such as top width, side slopes, biofilter depth along the sides, and base width can change to some extent, their magnitudes depend mainly on the size, weight, moisture content of the carcasses and to some extent rainfall precipitation. For example, poultry carcasses are not heavy and their thickness and moisture content are less than 40 cm (1.3 ft), and 50% respectively; their windrows system can have 3-4 layers of carcasses and consequently a height of 1.8-2.40 m (5.9-7.9 ft) (Carr *et al.* 1998). They found that in order to maintain the desired pile moisture content on the top layers of poultry carcasses, the top width (TW) and bottom width (BW) can be up to 150 cm (5 ft) and 360 cm (15 ft), respectively. By this arrangement, the two equal side slopes and angles of windrow cross section (with a trapezoidal shape) will be about 1.7:1 and 60^{o}, respectively. The situation is different for medium and heavy or large carcasses. Usually their water contents are higher than poultry carcasses, and conserving moisture is less critical.

Keener *et al.* (2001) used trapezoidal windrow systems with a variety of dimensions. For example, medium and heavy carcasses need less top width (up to 30 cm or 1 ft) and more bottom width up to 390 cm (13 ft) and 450 cm (15 ft), respectively. In this system, the narrow top width will not collect moisture from rainfall or manual application of water. The finished windrow has a peak at the top extending along longitudinal axis, creating a chimney effect for heat, odors and gases to escape while drawing air from the bottom to the top.

Bin Composting

A wide range of structures is possible for bin composting. Glanville (1999) and Morse (2001) suggested new facilities, such as poured concrete, pole shed construction, and hoop houses. They recommend that the roof should be built with water-repelling materials to prevent excessive moisture on the composting material and that their dimensions should allow front-end or skid loaders to turn piles easily (3 m or 10 ft wide, 3.6 m or 12 ft deep and designed to be loaded to a depth of 1.5 m or 5 ft). The floor also should be built on an impervious, weight-bearing pad strong enough to withstand the force exerted by the equipment and large enough to maneuver equipment. These bins were housed in a post-frame, metal-clad structure with 0.6 m (2 ft) overhangs (Glanville 1999). The removable drop-boards that slide into a vertical channel at each end of the bin or with doors that hinge horizontally provide easier manual handling of small carcasses.

To decrease the construction cost, existing facilities such as machine sheds, corn cribs and cattle sheds can be used for bin composting. A Minnesota farmer adapted a Cargill open-front swine finishing unit for composting with no remodeling costs (Morse 2001). Fulhage and Ellis (1996) recommended using bins enclosed on three sides with an opening wide enough for a front-end loader.

Quality and Utilization of Finished Carcass Compost

The overall goal of carcass composting is not only to dispose of the carcasses properly, but also to produce an acceptable end-product for agricultural land application. Some researchers, such as Ellis (2001), believe that properly finished carcass compost is similar to plant residue compost and is a good soil amendment. Compost quality and applicability depend strongly on 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 piles.

Compost Quality

A number of different criteria have been established to describe the quality of the end product. According to Haug (1993), these include physical, chemical and sensory properties of compost materials such as particle size distribution, texture, color, odor, moisture content, general appearance, specific oxygen consumption rate (mg O_2/kg volatile solids per hour), phytotoxicity, reduction of biodegradable volatile solids (BVS) across the system, gross nutrient content, nitrate/ammonia ratio and the absence of readily degradable compounds (such as starch). Besides these parameters, the temperature of the composted carcasses at the end of the curing stage and before land application, along with a seed germination test, can be used to measure compost quality.

Compost analysis at the final stage or just before land application is recommended for judging product quality. The beneficial components of finished carcass compost, like finished compost from plant residues, include water, total nitrogen (N), available nitrogen (NH_4-N or NO_3-N), phosphate (P_2O_5), potash (K_2O), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), zinc (Zn), and copper (Cu).

Analysis has shown that with the exception of nitrogen, nutrients found in manure and composted carcasses are very similar. Murphy and Carr (1991) observed that the mineral content of dead bird compost and manure (built-up litter) is comparable. The moisture content of manure was twice that of dead poultry compost and the nitrogen content was one-half that of the compost. Nutrient content of composted poultry carcasses including P_2O_5, K_2O, Mg, Mn, Zn, and Cu was similar to poultry manure. They observed that the 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 the composting process. Ammonia loss, accelerated by warm temperatures, convection and drying conditions, is primary responsible for lower N content in compost as compared to manure or litter. Additionally, phosphorus losses will be minimized if the composting process is managed according to its standard requirements (Henry 2003).

Nutrient analysis of other composted carcasses has shown similar results. Fonstad *et al.* (2003) analyzed finished compost of straw and manure mixture and observed that concentrations of (N) nitrogen, (P) phosphorus, and (K) potassium increased up to 62%, 50% and 46%, respectively as compared to the control compost pile (only straw). By incorporating hog mortalities into straw and manure mixture, N, P and K (dry basis) increased up to 108%, 130% and 51%, respectively. Addition of the mortalities also increased sulfur (S) levels by 43% over the original manure/straw mixture. Harper *et al.* (2002) analyzed piglet mortality compost and showed that the proportions of moisture, N, P_2O_5, K_2O, Ca and Mg were 32.4%, 1.59%, 2.04%, 0.28%, 1.58% and 0.15%, respectively. McGahan (2002) and Kube (2002) reported that the nutrient composition of finished compost depends upon the raw materials used, and the ratio of carcasses to other ingredients in the composting process.

Overall typical nutrient value of composted carcasses including nitrogen, phosphorus (as P_2O_5), and potassium (as K_2O) respectively is about 25 lb/ ton (12.5 kg/Metric ton), 13 lb/ton (6.5 kg/Metric ton) and 7 lb/English ton (3.5 kg/Metric ton) as reported by Sander *et al.* (2002). Additionally, the end-product organic matter and pH can range from 35 to 70% and 5.5 to 8.0, respectively (Dougherty 1999).

One of the quality indicators in the finished compost is the particle size uniformity. Morris *et al.* (2002) indicated that composted carcasses at the end of second phase contained bone material that disintegrated easily once the finished product was spread on land. Mukhtar *et al.* (2003) analyzed the end product of a combined pile of two cow carcasses and one horse carcass after nine months of composting. They observed that most of the carcass material was completely degraded over this time period and very few large bones remained. In their experiments, bones were easily disintegrated, reducing the need for screening or mechanical crushing of bones prior to land application. Fonstad *et al.* (2003) screened about 3900 kg dry matter (11.5 m^3) of finished hog carcass compost and obtained only 1.5 kg (0.04%) of objectionable bone fragments. These bones were less than 150 mm long with a brittle to spongy texture. Rynk (1992) noted that if a separation process is used to remove large particles from finished compost with particle sizes of 13-20 mm, moisture content should not be high as the efficiency of the screening process decreases. Diaze *et al.* (1993) recommended that the moisture content of finished compost be less than 30% to achieve adequate separation of larger particles during screening. On the other hand, the recommended moisture content for compost screening is generally between 35- 45% (Dougherty 1999). Rynk (1992) suggested that this parameter should be less than 40% to prevent clogging. It can be concluded that optimum moisture content of finished compost to prevent clogging and dusting during the screening process depends on the composition of the finished compost and is in the neighborhood of 35%.

Soluble salt content may be measured by electrical conductivity and reported in units of (dS/m) (1 dS/m indicates a salt concentration of approximately 700 ppm). According to Dougherty (1999), soluble salts in finished compost may range from 1-30 dS/m. He suggested that as a soil amendment, the soluble salt concentration of finished compost should be less than 20 dS/m, although this recommendation may be modified to fit the salt tolerance of the crops, the availability of irrigated leaching water or the seasonality of significant rainfall.

Compost Utilization

Nutrients and organic matter in finished mortality compost make it a valuable by-product to be utilized for crop and pasture production. Hansen (2002) applied the mixture of composted carcasses (sheep, swine, and cattle) and conventional fertilizer (based on equal portion of phosphorous content, each one at the rate of 105 lb/A) on a sandy soil to increase its water holding capacity. He reported that the soil moisture of compost-amended plots was higher than the control plots throughout the summer and this was due to an increase in organic matter from 6.5% to 7.7%. Since the sandy soil was well drained, the high salts of composted carcasses leached out without degrading soil quality.

The bulk density of finished composted carcasses is much lower than the intact carcasses (Kube 2002) has a friable structure and if added to agricultural soils, may potentially increase soil porosity. Compost should be spread at agronomic rates so that applied nutrients do not exceed the uptake rate of the crop. Manure spreaders and tillage equipment can be used for spreading and incorporating the compost (Glanville 2002, Hansen 2002 and Sander *et al.* 2002). Finished carcass compost should not be applied near sensitive areas such as watercourses, gullies and public roads, etc. Mortality compost should not be used as animal bedding, feed supplement, or given to others for agronomic use off the farm (Dougherty 1999).

Biosecurity and Environmental Aspects

The by-products (wastewater, odors and gases) of carcass composting process as well as the finished product should be safe and have no negative impact on public safety or the environment.

Biosecurity (Disease Agent)

Although the composted carcasses have plant nutrients that can be used as a soil amendment, the biosecurity of this product is an important concern. Despite the fact that many compostable organic wastes may contain human, animal, or plant pathogens, much concern and attention in this regard have been focused on compost from municipal wastewater sludge (biosolids). Regardless of the difference between the physical and chemical characteristics of sludge and animal mortalities, the microbiological standards applied to composting sludge provide practical insight to procedures that could prove equally useful in composting carcasses (Glanville and Trampel 1997).

During active composting (first phase), pathogenic bacteria are inactivated by high thermophilic temperatures. These bacteria may survive in the compost environment if high temperatures do not persist for a certain time period. Although the presence of *actinomycetes* and *fungi* during first and second phases ensure the production of a variety of antibiotics (Diaz *et al.* 1993) that may destroy some pathogenic bacteria, microorganisms such as *Mycobacterium tuberculosis* and spore-formers like *B. anthracis* (the causative organism for anthrax) may survive. *Mycobacterium tuberculosis* was destroyed in windrow carcass composting when the average temperatures reached 60°C (140°F) for at least 10 days (Tetra Tech, Inc. 2001).

Several conditions such as clumping of solids (which can isolate material from the temperature effects), non-uniform temperature distribution (which can allow pathogens to survive in colder regions), short-circuiting of the feed substrate and reinoculation after the high temperature phase can reduce pathogen inactivation during the composting process (Haug 1993). In order to avoid these conditions, it is important to provide an adequate or effective biofilter. A biofilter is a layer of absorptive and reactive carbon sources, which maintains proper moisture, pH, nutrients, and temperature distribution to enhance the useful microbial activity and deodorizes the gases released at ground level, and treats potential air pollutants generated from compost materials (Hoitink and Keener 1993).

Bollen *et al.* (1989) used static compost piles containing samples of crop residues infested with inoculums such as soil-borne, fungal plant pathogens. Core temperature reached 50-70°C (122-158°F) within 6 days. Of the 17 plant pathogens, only *Olpidium brassicae* and *Fusarium oxysporum* survived the composting process. They concluded that three processes including (a) heat generation during the first phase (b) phytotoxicity in some of compost products formed mainly during the first phase (fungitoxic volatiles have been detected in leachates and extracts from composted hardwood bark) and (c) microbial antagonism during the first phase and second phase (maturation process) may be involved in the eradication of the pathogens and compost microbial activities.

Haug (1993) also reported that high product standards could be achieved with good management practices. Viruses and *Ascaris* ova can be reduced below the detection limits. *Salmonella* and total *Coliform* populations can normally be reduced to levels below 1 and 10 MPN (most probable number)/g dry solid, respectively. Attainment of these standards should assure a very low risk of infection to users of the material. The number of pathogenic viruses including Newcastle, Avian Influenza and Infectious Bursal diseases significantly diminished after one month of primary and secondary poultry composting (Murphy and Carr 1991 and Anderson 2000).

Investigations have shown that composting of infected pig mortalities destroyed *Actinobacillus pleuropneumonia*, *Streptococcus pyogenes* (causing Erysipelas or skin disease), *Salmonella* and Porcine Reproductive and Respiratory Syndrome (PRRS) virus (Underwood 1999 and Garcia-Siera *et al.* 2001). Chaw (2001) measured the population of different pathogens during sheep offal and carcass composting and observed that fecal coliform were consistently high during the first four weeks of in-bin composting with a rotational system (weekly addition of fresh material), but they were no longer present after the contents were adequately exposed to a temperature above 55°C (131°F) for more than 3 consecutive days. Although *Salmonella sp.*, *Shigella sp.* and *E. coli* were not detected after four weeks of composting, *Enteroccocus faecalis* (a heat resistant, Gram-positive bacterium) increased after four weeks, and its growth was independent of the composting temperature (Chaw 2001).

The role of compost microflora in the regrowth suppression of pathogenic bacteria during the second phase has been investigated. According to Millner *et al.* (1987), the antibodies produced by bacteria and actinomycetes were effective in suppression of *Salmonellae*. They reported that colonization of non-*Coliform* and *Coliform* Gram-negative bacteria during the mesophilic curing of a compost pile prevented *Salmonellae* repopulation considerably. Mukhtar *et al.* (2003) measured the pathogenic activities of carcass compost piles after nine months of composting. They observed very low levels of *Salmonellae* and fecal *Coliform* bacteria which were used as indicators of pathogen populations in the compost end product. Lawson and Keeling (1999) used a wooden bin to decompose 125 laying hen carcasses (close to 200 kg) along with carbon sources. After 8 weeks of composting, all the *Salmonella* associated with bacterial pathogens were fully inactivated.

Initially, carcass compost piles are inconsistent mixtures of dead animals (with low C/N ratio, high moisture content and very low porosity) and cocomposting materials (with high C/N ratio, medium to low moisture and high porosity). Improper formulation of these materials and management may favor pathogen survival in the finished composted carcasses. Preparation processes such as grinding and mixing of carcasses with cocomposting materials as well as modifying the composting system (e. g., forced aeration) will provide raw materials with more chemical and physical consistency and better conditions for controlling temperature and inactivating pathogenic bacteria (Keener and Elwell 2000).

Due to the heating phase of composting piles, the pathogens population is reduced considerably. This population may increase due to the cross contamination or recontamination of finished product mainly because of improper handling. To prevent disease transmission, composting facilities should not be located directly next to livestock production units, and the machinery and vehicles associated with the carcass composting operation should be sanitized with appropriate cleaning and disinfecting agents. Yanko (1988) recommended using a steam cleaner or high-pressure disinfectant sprayer to sanitize handling equipment (mainly front-end loaders for feedstock preparation) and to avoid compost end-product recontamination. Alternatively, using separate loaders for the initial stages of composting and separate ones for the curing, final storage, and land application of the end-product may also prevent recontamination. It is also crucial to ensure (1) that raw feedstock does not come in contact with actively composting or curing product and (2) that composting equipment is never used to handle animal feeds unless decontaminated.

Five different compounds have been tested and confirmed for virus inactivation (such as Avian Influenza) and disinfection of carcass composting equipment (Antec International 2004). These compounds include Tek-trol and One-Stroke Environ, which are phenolics; Lysol No-rinse, a quaternary ammonia component; Virkon-S, a peroxy material; and household bleach, a free-chlorine product. To sanitize the processing machinery, immersion or spraying and/or swabbing for at least 30 seconds with clean sanitizing solutions at a temperature of 24°C (75°F) or above has been suggested (Alaska Department of Environmental Conservation 2003). High solution temperatures reduce chlorine activity and should not be used for bleach or other halogen-based sanitizers, including iodine compounds (e. g., iodophor). These sanitizing compounds, moreover, should never be mixed; that is especially true of ammonia and bleach solutions, which react chemically to produce poisonous gases.

According to Schwartz (1997), ill or apparently healthy birds can carry the bacteria of *Infectious Coryza*, a respiratory disease among several avian species. Mosquitoes are also carriers of many diseases. According to the President and Fellows of Harvard College (2002), parasites, mosquitoes and ticks serve as vectors to transmit viruses (such as West Nile) from host to host via blood and serum. Viruses survive within infected animals (alive or dead); mosquitoes can then feed from infected animals and transmit the virus while feeding on other animals or humans. Using biofilter material as a blanket on compost piles during both phases of composting has several advantages including conservation of energy and moisture content of composting materials and exclusion of insects and birds from the compost pile, thus minimizing or preventing transmission of microorganisms from mortalities to livestock or humans.

Although the heat generated during carcass composting results in microbial destruction in as little as 3 days at T> 55°C, it is desirable to achieve longer times for the thermophilic process to minimize potential for survival and regrowth of pathogens. Therefore, researchers have recommended extending the duration of thermophilic temperatures in the carcass composting process. Harper *et al.* (2002) suggested that maintaining the internal stack temperature of a swine compost pile in a thermophilic range for more than a week would be adequate to kill potential disease organisms such as *Pseudorabies* virus, *Salmonella* spp. and *Actinobacillus pneumonia* spp. Although carcass compost pile temperatures are not uniform, the pathogenic bacterial activity is reduced when the temperature in the middle of the pile reaches 65°C (149°F) within one to two days (Glanville and Trampel 1997). That is, a high core temperature enhances compost pasteurization.

Environmental Factors

Proper location of a compost facility helps to protect water and soil quality, increases biosecurity, prevents neighbor complaints, decreases nuisance problems, and minimizes the challenges in operating and managing the composting facility. The site should be downwind from residential and public use areas, should provide a limited or appealing view for neighbors or passing motorists, and should have a pleasing appearance and landscape (Morse 2001).

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. Surface runoff and leaching (including leachate runoff) should also be controlled. 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. This eliminates the need to have runoff storage or a filter area. To control runoff from uncovered composting facilities, 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 and Ellis (1997) indicated that composting facilities should be well-drained and away from sensitive water resources such as streams, ponds and wells, should be accessible in all kinds of weather, and should be located at or near the crest of a hill. Such a location will minimize the amount of surface water accumulating in the composting area.

Site preparation and runoff control structures are essential parameters for a static pile composting system. Mescher *et al.* (1997), Morse (2001) and McGahan (2002) indicated that runoff from the 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 90 cm (approx. 3 ft) above the high water table level and at least 90 m (300 ft) from streams, ponds or lakes in the same drainage area. In addition, all clean surface water must be diverted away from the composting area. This will minimize the volume of water to be treated or stored and keep the composting area dry.

Soil

In order to prevent compost leachate from seeping into and contaminating the soil or base underneath the compost piles, piles should be underlain with a water barrier. Bagley *et al.* (1999) (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), the composting pad should be compacted, but it does not need to be paved. A compacted layer of non-smectitic, clayey soils, including clay loams about 15 cm (6 in) thick should be used when existing soil conditions are not acceptable. USDA-NRCS or Extension soils specialists or geotechnical engineers can recommend regional soil sources to ensure low permeability.

Vegetation

Some of the carbon source materials produce phytotoxins (mainly phenols and short-chain, volatile fatty acids) during the composting process, and if mixed with soil, they may inhibit vegetation growth. On the other hand, if these materials are composted along with animal wastes (such as manure and carcasses), they may prevent the growth of pathogenic bacteria in the compost piles until they are digested by the compost microbes. Sciancalepore *et al.* (1996) measured DNA (deoxyribonucleic acid) content and ATP (adenosine triphosphate) and DHA (dehydrogenase activity) enzyme activities of several microbial groups (including pathogenic bacteria, *E. coli,* and *Salmonellae*) in compost obtained from a mixture of crude olive husks, oil mill wastewaters, and fresh olive tree leaves inoculated with cow manure during six months of composting. Results showed that the compost pile was free of pathogens, and total phytotoxicity encountered in raw composting materials fully disappeared due to enzymatic activities. Ranalli *et al.* (2002) evaluated the effectiveness of bioindicators for the quality and maturity of cured compost obtained by a mixture of different biomass (plant and non-plants) residues. The composting process lasted for five months and microbial, enzymatic activities (ATP, DHA), and the impedance variations expressed as detection time (DT, in hours) of mixed cultures during growth and potential pathogens (E. coli and Salmonella sp.) were determined. The phytotoxicity tests of composted biomass residue samples had more than 90% germination index (GI), and pathogens were not found. In this experiment, GI was defined as the ratio of the total length of roots treated (germinated at specific bed) to the total length of roots controlled (germinated on normal bed), after both were grown at similar temperature and relative humidity (Ranalli *et al.* 2002).

Air Quality

A good composting operation does not generate offensive odors. However, Fulhage and Ellis (1996) and McGahan (2002) explained 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. In addition, traffic patterns required for moving carcasses to the composter and removing finished compost must be considered. Covering the compost pile with carbon-rich, highly porous materials (biofilters) allows air (oxygen) to penetrate the pile, reduces odors and reduces the attraction of pests to the compost pile. Using proper and adequate biofilter materials effectively inhibits odor emissions even in high throughput operations. Looper (2002) and Kube (2002) used windrow systems and successfully composted 16 and 65 large intact cattle at once, respectively, without significant odor production.

Economic Considerations

Like any other agricultural processing activity, the carcass composting process should be economically feasible. The factors involved in cost analysis of carcass composting processes in order of importance include a) volume and weight of mortality produced per established time period, b) frequency of mortality occurrence, c) labor requirements, d) impact on the environment, and e) required facilities and equipment (new and existing) and their useful life expectancy (Mescher 2000). The first four of the above mentioned factors generate variable costs of operation and the last one represents fixed costs of investment.

Variable Costs

Variable costs include the value of carcasses (usually assumed to be zero or negative, depending on disposal alternatives and regulatory requirements), the cost of operating labor, and cocomposting materials (carbon sources).

A report by Sparks Companies Inc. (SCI 2002) showed the operating labor depends on the availability of the farm laborers at the time of composting, type of labor (family-size operation or commercial corporation), and level of composting mechanization. Labor costs are likely to vary across different agricultural operations. In small-scale carcass composting, the extent that family labor can be employed (and is not counted as an expense) has a major effect on the labor cost (SCI 2002). Usually, the average labor costs for large animal carcasses were estimated at $10/carcass.

The value of carbonaceous materials depends on their accessibility in each livestock- and poultry-production area. For example, the values of straw and litter in Alabama, respectively, were about $60 and $20 per ton (Crews *et al.* 1995).

The cost of aeration depends on the system. 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. Continuous aeration of windrow composting piles for 8 weeks not only decreased the operational cost considerably, it also reduced the time and land required for composting. When continuous aeration was applied to windrow composting of 10,000 lbs of raw material for 8 months, the land requirements, time required and operational costs were reduced by 50% (from 6,426 to 3,136 m^2), 60% (from 25 to 10 months), and 70% (from 17.59 to 4.88 Euros /metric ton or about $19.70 to $5.30 per English ton), respectively, as compared to composting a similar mass without forced aeration.

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 (both gross $ and $/head) than smaller operations. Obviously, initial investment will vary greatly among alternative systems. According to a report by SCI (2002), only 30% of the total livestock operations in the U.S. were large enough to justify the costs of installing and operating large-scale carcass-composting facilities. This report indicated that most livestock production operations were 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). However, state or local regulations may prohibit such use.

Fixed Costs

For individual livestock and poultry 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), agricultural machinery and equipment. While a windrow composting facility required more intense management, especially if intact carcasses were composted, it had lower initial cost than a bin system, (Mescher *et al.* 1997).

For fixed cost evaluation, it is necessary to consider the initial investment in machinery and facilities, including facility construction (bin, pile or windrow system), number of bins (or pile area) required for the facility, as well as equipment for handling of animals and cocomposting materials. Additionally, the expected life of the carcass composting facility should be considered.

Equipment, like labor costs, varies across operations based on availability and size of necessary equipment, machinery operating costs, assumptions used in depreciation and opportunity costs of time (SCI 2002). Due to substantial variations of building materials, machinery, and equipment used for constructing composting facilities on-farm, it is difficult to estimate fixed cost. Crews *et al.* (1995) studied the annual costs of six disposal methods for a flock size of 100,000 broilers per cycle. The evaluated disposal methods were burial or disposal pit, bin or large bin composting, incineration, small bin composting (mini-composter), fermentation and refrigeration techniques. It was reported that broiler farms had two options for composting. Large broiler operations (those who grow more than 40,000 birds per 45 days cycle) usually have tractor-loaders in their farming 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 for poultry carcass disposal. While the initial investment cost of large bin composting was more than 3 times that of small bin composting (mini-composter), the variable cost was about 15% less than that of mini-composters. In another study Mescher (2000) provided the fixed cost estimates for construction of bin and windrow composting systems (building, raw materials + construction labor) with the following specifications:

a) Bin system including concrete base + 1.5 to 3 m (5 to 10 ft) front apron, 1.5 m (5 ft) treated sidewalk construction (min 3 sides), steel roof, 15 cm (6 in) square posts, 0.6 m x 1.2 m (2 ft x 4 ft) purlin and 0.6 m x 1.8 m (2 ft x 6 ft) rafter supports, and construction labor was about $1,250-$1,700 per bin.

b) Static pile or windrow system including concrete pad of 10-12.5 cm (4-5 in) thickness, gravel access, geo-textile cloth with gravel base, site development and accessibility was about $625-$850 per windrow.

Total Costs

To estimate the overall cost of composting carcasses of different species, SCI (2002) used the following assumptions:

- Equipment costs (rental or depreciation of a skid-steer loader) at the rate of $35/hour,
- Cocomposting material (sawdust) at the rate of $22/ metric ton ($20/English ton)
- Labor for a typical on-farm facility, 95 hours per year plus 35 hours to use machinery and manage different processes (turn the pile, move material between primary and secondary bins, and remove composted materials), and cutting the carcasses into smaller pieces (at a rate of 10 minutes per mortality and with a labor cost of $10/hour).

Based upon above assumptions, total annual cost/head of composting mortalities of cattle (including calves), weaned hogs, pre-weaned hogs and other carcasses (including sheep, lambs and goats) were $30.34, $8.54, $4.88 and $0.38, respectively. Their analysis also demonstrated that regardless of carcass weight, the cost of machinery (the major fixed cost) per head was almost 50% of the total cost per head. Livestock operations typically have some manure handling equipment that can be adapted for carcass handling by purchasing attachments such as buckets to avoid cross contamination and to reduce these fixed costs.

Kube (2002) used a windrow system to compost intact and ground cattle carcasses each weighing about 450 kg (1,000 lb). The estimated cost (excluding site preparation) ranged from $25 to $52/carcass. Grinding carcasses before composting increased the operation cost by about $6/head but reduced composting time, space and management cost needed for composting by 50% in comparison with the intact carcass system.

Henry *et al.* (2001) estimated the required investment for two types of facilities designed to compost about 18,000 kg (40,000 lb) 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 facilities. The "high investment" option included seven concrete bins at a cost of $15,200. The "low investment" option included six smaller bins and no roof at a cost of $7,850. In both cases, the concrete work and the wooden construction were done by the farm labor.

A cost analysis for windrow composting of cow carcasses by Blender (2003) is provided in Table 2. Based upon his estimates, the total cost for the material, equipment, fuel and labor was $37.60/cow carcass.

TABLE 2.
The cost analysis and total cost of windrow composting per cow mortality (Blender 2003).

Cost Items	Needed Amount/ Carcass	Cost/Unit Metric System	Cost/Unit English System	Primary Cost	Net Cost/ Cow Carcass
Wood mulch (bulking agent)	5 yd^3 (3.8 m^3)	\$7.19/m^3	\$5.50/ yd^3	\$33	\$9.90[a]
Dried sawdust (carbon source)	6 yd^3 (4.6m^3)	\$5.89/m^3	\$4.50/yd^3	\$27	\$8.10a
Labor work	30 min	-	-	10/hr	\$5
Fuel for 100HP Tractor[c]	0.4 gal (1.5L)	\$0.4/L	\$1.5/gal	\$0.60	\$0.60
Tractor rental	30 min	-	-	\$28/hr	\$14
Total cost	-	-	-	-	\$37.60

[a]The cost of bulking materials and carbon sources lost in composting process. The finished product can be reused and only 30% of the cocomposting materials are lost during composting.

Conclusions

Successful carcass composting relies on proper design, layout, cost analysis, environmental impacts, and quality of the finished product. The following conclusions can be derived from the information provided in this review.

• The design volume and carcass loading rate for the primary phase of bin composting is a function of daily mortality rate, mean carcass weight and composting time. The bin system is appropriate only for composting small and medium weight carcasses.

• Generally four separate bins (two primary, one secondary and one curing or storage) comprise the bin composting system. Overall, the minimum bin volume and the composting time needed for the primary, secondary and storage phases of composting for every 4.5 kg (10 lb) of carcasses is 85-113 L (3-4 ft^3), 16 days; 42- 57 L (1.5-2 ft^3), 10 days and 42- 57 L (1.5-2 ft^3), 10 days, respectively.

• Windrow composting is essentially a continuous row of multiple static piles with a trapezoidal or semicircular cross-section. A high angle (sharp) or narrow top surface in trapezoidal cross section pile pushes the water away from the top of carcass windrow composting. Conversely, a low angle (slight) or wide top surface in trapezoidal carcass section will keep the moisture on the top of the piles. All windrow dimensions depend mainly on the size, weight, moisture content of the carcasses, relative humidity and climate in the composting area.

• Organic matter and pH of the final product range from 35-70% (50-60% is optimum) and 5.5 to 8.0 respectively.

• While good management practices during the composting process may destroy many pathogenic bacteria and viruses such as *Mycobacterium tuberculosis, Enteroccocus faecalis* and spore-formers like *B. anthracis* (the causative organism for anthrax) may survive.

• For enhanced biosecurity of carcass composting process, it is important to assure that no composting equipment is used to handle animal feed. A steam cleaner or high-pressure disinfectant sprayer can be used to sanitize handling equipments mainly front-end loaders for feedstock preparation and avoid compost end product recontamination.

• Using biofilter material as a blanket on compost piles during both phases of composting not only prevents excessive odors, but also conserves moisture and keeps insects and birds away from the compost pile, minimizing or preventing transmission of microorganisms from mortalities to livestock or humans.

• Composting facilities should be built on compacted soils or concrete pads, well-drained and away (at least 90 m or 300 ft) from sensitive water resources such as streams, ponds, and wells, located at least 90 cm (3 ft) above the high water table level, and should be accessible year round and in all kinds of weather.

• Less than one third of the livestock and poultry operations in the U.S. justify the costs of installing and operating large-scale composting facilities. The initial investment cost of large bin composting is more than 3 times that of small bin composting (mini-composter); the variable cost is about 15% less than that of mini-composters.

• The total annual costs of composting incurred by the livestock sector is about $30/head for cattle and calves, $9/head for weaned hogs, $0.40/head for preweaned hogs, and $5/head for other carcasses including sheep, lambs and goats.

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