14

On-Farm Composting of Dead Stock

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1. Introduction

Rendering and on-farm burial are the predominant methods used by farmers for the routine disposal of domesticated farm animals. However, throughout many developed countries, knackery and rendering services have been contracting and many farmers are seeking alternative stock disposal options. In parts of Australia, for example, where many knackeries have been closing in recent years, the illegal dumping of dairy cattle in waterways has become a serious problem. Bonhotal et al. (2002) reported that the improper disposal of dead stock in New York State and Pennsylvania was becoming more widespread as farmers no longer had access to affordable rendering services. Dumping of stock is not only a risk to water quality but is also a biosecurity hazard and the source of many complaints to environment protection agencies from neighbours and downstream users.

On-farm burial is one of the simplest and most cost-effective methods of carcass disposal, but this too is becoming restricted as environment protection agencies seek to protect water resources from contamination. It has effectively been eliminated as an option for mass disposal in Virginia following the unearthing of intact 15 year old avian influenza-affected poultry carcasses at a trench burial site in the late 1990s (Malone, 2005). On-farm burial is also not possible in many irrigated areas where the watertable is close to the surface or where surface waters are close to the disposal site.

Composting is a natural biological decomposition process that takes place under aerobic, thermophilic conditions. It can be used for the day-to-day management of mortalities on farms and for carcass disposal in emergency animal disease (EAD) outbreaks. In mortality composting, carcasses are placed in piles or bins together with supplemental carbon sources such as sawdust, litter, straw or wood shavings. Composting is particularly suitable for broiler-farm mortalities and litter. In the case of EAD outbreaks, composting can be conducted either inside or outside the poultry house following euthanasia (Kalbasi et al., 2005; Mukhtar et al., 2004).

2. The mortality composting process

2.1 Brief comparison with conventional composting

In conventional composting systems, raw materials are mixed together to form a pile of relatively uniform nutrient content, particle size, porosity and moisture content. Mesophilic microorganisms first use the readily degradable substrates such as sugars, starch and proteins, and provided that the pile is of sufficient volume (usually >1m^3), temperatures rise rapidly. The materials may be turned every few days to move the cooler outside layers into the centre of the pile, and to allow air to move more freely into the pile. In other systems, air is forced into the pile by a thermostatically controlled fan.

This first stage of composting (6–12 weeks duration) is characterised by high temperatures and rapid rates of decomposition and is usually termed the thermophilic stage or period of 'intensive decomposition' (Haug, 1993). These conditions result in the elimination of nuisance odours and destruction of pathogens and weed seeds. It is during this stage that substrates such as fats, hemicellulose and cellulose are degraded. As the composting process proceeds and the availability of substrate become more limiting, temperatures begin to fall. This second stage of composting (lasting for 4+ weeks), called the maturation or curing phase, takes place under mesophilic conditions (under 45°C) and is characterised by lower rates of biological decomposition under which aeration is no longer a limiting factor. During this stage, the biologically resistant substrates such as lignocellulose and lignin are degraded. The maturation phase of composting has a large bearing on the suitability of the end product for a particular use (Brewer & Sullivan, 2003; Wilkinson et al., 2009).

Many authors have defined various optima for the composting process, including a carbon to nitrogen ratio (C:N) of between 25:1 and 30:1, moisture content within the range of 50–60% (w/w), porosity of 35–45% and oxygen levels of >10% by volume (Table 1). But these optima were developed for relatively homogenous organic materials such as manures, green waste, food wastes and biosolids and have questionable relevance to mortality composting.

Characteristic	Optimum	Reasonable range
Carbon to nitrogen ratio (C:N)	25–30:1	20–40:1
Moisture content	50–60% (wet basis)	40–60% (wet basis)
Porosity	35–45%	30–50%
Oxygen concentration	>10%	>5%
Bulk density		<640 kg/m^3
pH	6.5–8.0	5.5–9.0

Table 1. Desirable characteristics for composting (modified from Keener et al., 2006; Northeast Regional Agricultural Engineering Service, 1992).

In contrast, a livestock mortality composting pile is a heterogenous mixture, so strict application of the principles discussed above is not possible. A mortality compost pile may contain an animal of large mass, having a high moisture content, low C:N ratio and nearly zero porosity, surrounded by a material (the carbon source) with a high C:N ratio, moderate moisture level and good porosity (Keener & Ellwell, 2006). Kalbasi et al. (2005) aptly described mortality composting as the above ground burial of dead animals in a mound of supplemental carbon such as sawdust, litter, straw or wood shavings. Sufficient supplemental carbon is required around the carcass to absorb bodily fluids and to prevent odours from escaping from the pile.

The decomposition process is initially anaerobic in and around the carcass layer, but as odorous gasses are produced and diffuse away, they enter an aerobic zone where they are degraded to CO_2 and water (Keener & Ellwell, 2006). In contrast to conventional composting systems, temperatures in mortality composting are initially higher in the outer aerobic layers of the pile compared to the interior (Fig. 1). Oxygen diffuses only slowly into the interior of the pile as the carcass layer degrades, resulting in a delay of 2-3 days before thermophilic conditions are reached.

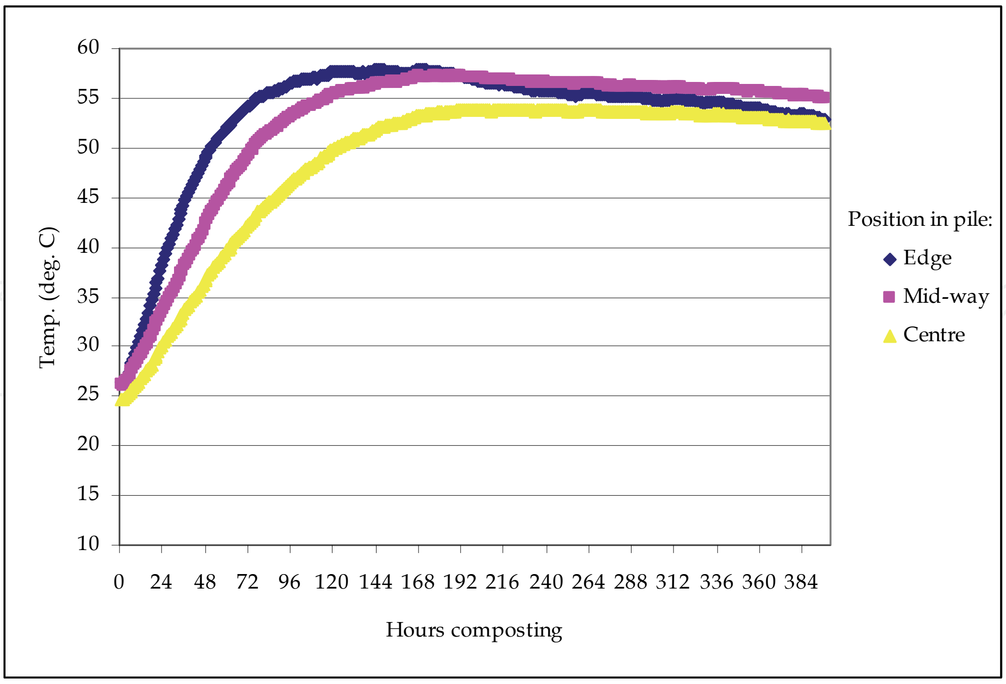

Fig. 1. Temperature development in poultry mortality composting according to position in the pile. Source: Wilkinson, unpublished.

Mortality composting is generally conducted in 3 stages. In the primary stage of composting, the pile is left undisturbed as soft tissue decomposes and bones partially soften. The compost is usually then moved, turned or mixed to begin the secondary stage, during which time the remaining materials (the remaining meat and bones) break down further. Following completion of the secondary phase, the composting process is completed during a curing or storage phase.

Some bones of large mature animals may remain after completion of the secondary and/or storage stages of composting, but these are usually quite brittle and pose no health risk and will not damage farm equipment when applied to land (Keener & Ellwell 2006; Mukhtar et al., 2003). Nevertheless, Murphy et al. (2004) observed that the moisture content of a composting pile has a major bearing on the rate of decomposition of bones from cattle mortalities. If the pile is allowed to dry out, bones become very hard and appear to cease decomposition. Continued decomposition of the bones is achieved by wetting the pile on a monthly schedule for a period of about 6–9 months.

The time to completion of composting varies with the size of the animal, the compost formulation (e.g. type of carbon (C) sources used) and the management of the pile (e.g. mixing, turning and watering). As a general rule, the first stage of composting is complete in as little as 10 days for small animals such as poultry, about 90 days for medium sized animals such as pigs and over 6 months for large carcasses (Mukhtar et al., 2004).

3. Mortality composting system design and layout

3.1 Main systems

Mortality composting began in the poultry industry in the USA in the early 1980s and soon spread to other industries and has also been used for road kill. The basic forms of mortality composting are conducted either in bins or piles/windrows.

Bin composting is usually conducted in a three-sided enclosure on a hard stand (e.g. concrete or compacted soil). It may or may not be covered by a roof, though a roof is usually required in high rainfall areas. Designs are available on-line for purpose-built constructions with concrete floors, roofs and wood or concrete side-walls (Fig. 2). In its simplest form, the walls can be constructed of hay bales or any such material that can adequately confine the composting pile (Mukhtar et al., 2003). Simple bins can also be constructed from pallets or wood and plastic mesh. These are sometimes termed 'mini-composters' and are suitable for small animals such as poultry, rabbits, piglets and fish (Brodie & Carr, 1997).

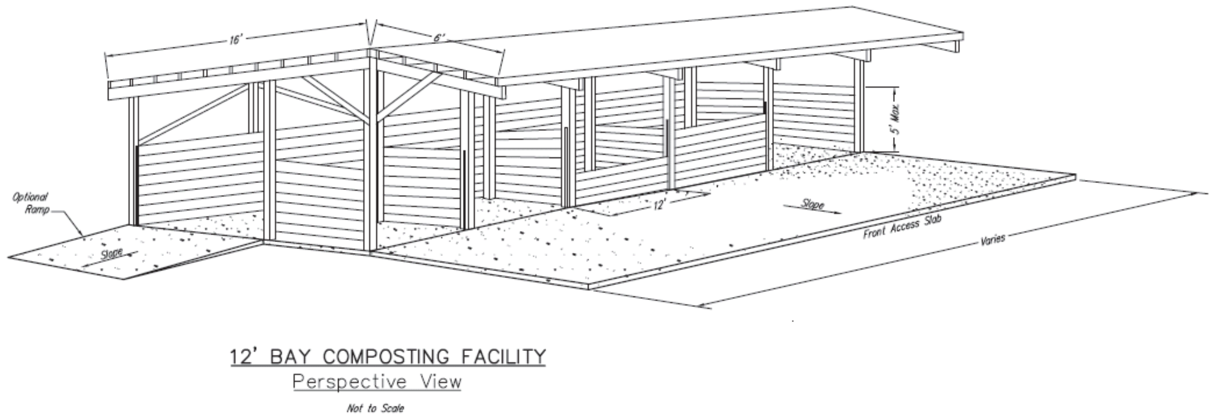

Fig. 2. Diagram of a dead bird composting facility. Additional detailed drawings can be found at the USDA National Resources Conservation Service website, http://www.oh.nrcs.usda.gov/technical/engineering/cadd2_dwg_a_to_c.html.

At least 3 bins are usually in operation at any one time—one being filled, another in the primary stages of composting and the other in the secondary stages of composting. A pile is sometimes substituted for the secondary bin in two bin systems (Keener et al., 2000). Bins are usually only used to compost small-/ and medium-sized carcasses. As a general guide, 10 m^3 of bin space is required for every 1,000 kg of carcass (Mukhtar et al., 2004).

Piles for mortality composting are usually constructed in the open on a hard stand. Placing a plastic or geotextile liner under windrows as a moisture barrier is recommended when a concrete pad is not available. Access to the pile from all sides should be possible and the pile is shaped to shed rainfall. Windrows are formed by continually extending the length of the pile with the addition of further mortalities and supplemental carbon. The length of the windrow is determined by loading rates and site layout. Mukhtar et al. (2004) described the recommended dimensions of windrows according to the relative sizes of carcasses:

- Small carcasses (<23 kg): bottom width, 3.6 m; top width, 1.5 m; and height, 1.8 m.
- Medium carcasses (23–114 kg): bottom width, 3.9 m; top width, 0.3 m; height, 1.8 m.
- Large and very large carcasses (>114 kg): bottom width, 4.5 m; top width, 0.3 m; height, 2.1 m.

New poultry operations in the United States frequently build mortality composting facilities along the side of a manure shed (Fig. 3). The roof-line is simply extended to create a channel down one side of the shed. Piles of compost can then be constructed under it using the manure which is stored in the main shed adjacent to it.

In-vessel composting systems have also been used for composting carcasses. In-vessel systems enclose composting materials in a sealed chamber or vessel where environmental parameters such as temperature and aeration can be better controlled than in a pile or windrow. Examples include rotary composters, the BiobiN™ and the Ag-Bag® in-vessel system. The BiobiN™ system is offered as a contracted service to the poultry industry in Australia. Bins of up to 9 m^3 in size are delivered to the poultry facility and, when full, are transported to a licensed composting facility to complete composting. The BiobiN™ is a fully enclosed system with forced aeration and a biofilter to control odours and leachate.

Fig. 3. Composting facility constructed on the side of manure sheds at poultry facilities, Delmarva Peninsula, USA. Photos: K. Wilkinson.

The Ag-Bag® in-vessel system was used for the disposal of 1 million avian influenza-negative birds during an EAD outbreak in British Columbia in 2004 (Spencer et al., 2005). The poultry carcasses and C source were mixed together and pushed into the Ag-Bag®. The Ag-Bag® composting system was also used to dispose of 43,000 birds in the low-pathogenic avian influenza outbreak in Virginia during 2002.

3.2 Site selection and layout

The following general principles apply to site selection and layout for on-farm composting of mortalities (Mukhtar et al., 2004; Keener et al., 2006):

- The site should be in an elevated area of low permeability, at least 1–2 m above the watertable and not within 100 m of surface waters (e.g. streams, lakes, wells etc).
- The site should have an adequate slope (1–3%) to allow proper drainage of leachate and prevent pooling of water.
- Consideration should be given to prevailing winds and the proximity of neighbours to minimise problems associated with odour and dust.
- Run-off from the compost facility (e.g. from a 25-year, 24 hr rainfall event) should be collected and directed away from production facilities and treated through a vegetative filter strip or infiltration area.
- The site should have all-weather access and have minimum interference from other traffic.
- Maintaining an effective cover of C source over compost piles is usually sufficient to eliminate scavenging animals and vermin. But animals will dig into piles when they know mortalities are contained in them, so fencing should be installed around piles and bins to minimise this problem.

4. The mortality composting process in detail

4.1 Carbon sources

A wide range of carbon (C) sources can be used for mortality composting, including sawdust, wood shavings, green waste, chopped straw, manure, poultry litter and other bedding materials. The three most important properties that influence the performance of different carbon sources in mortality composting are available energy (biodegradability), porosity and moisture absorbency.

Sawdust is probably the most common C source used for mortality composting, as it is highly absorbent, allows high temperatures to be sustained and sheds rainwater when used for uncovered piles. According to Imbeah (1998), carbon sources like sawdust and rice hulls are ideal for mortality composting because their particle size allows them to settle intimately around the carcass to provide optimum contact.

Researchers rarely identify the type of C source beyond the generic term ‘sawdust’ despite the fact that the biodegradability of sawdust between timber species can differ by a factor of more than 10. Data from Allison (1965) showed that hardwoods had significantly higher biodegradability than softwoods but there was considerable variation between various species, especially in the softwood family.

The absorbency of different types of bedding materials is also known to differ greatly (Burn & Mason, 2005; Misselbrook & Powell, 2005). In general, softwood sawdusts are more absorbent than hardwood sawdusts. The absorbency of a C source will influence the depth of the base layer that is needed to absorb liquids during composting, but also the performance of the outer layers as a biofilter.

Research by Ohio State University found that some C sources such as chopped straw or cornstover can be used in mortality composting piles, but they require periodic addition of water to maintain composting conditions (Keener & Elwell, 2006). King et al. (2005) compared the performance of 11 different types of C sources for composting large carcasses (horses and cows). They reported that coarsely structured C sources such as wood shavings or wood chips experienced problems with odour, leachate and vector attraction. Glanville et al. (2005) studied straw/manure, corn stalks and corn silage as C sources for 450 kg cattle carcasses in windrows. From a biosecurity standpoint, corn silage performed best as it consistently produced the highest internal temperatures and sustained them for the longest time but it did not result in noticeably shorter carcass decay times.

In practice, a wide range of carbon sources can be successfully used in mortality composting. The choice of material is likely to be based on cost, availability and performance. It is commonly advised to incorporate up to 50% of finished compost into the base and cover C sources (Kalbasi et al., 2005; Keener & Elwell, 2006; Mukhtar et al., 2004). The recycling of finished compost in this manner reduces the cost of purchase of raw materials, speeds up the initiation of composting conditions and reduces the space required for storage of finished compost. To facilitate faster rates of decomposition, some researchers recommend that carcasses should be added to C sources that are actively composting or those that have an ideal C:N ratio for composting (Kalbasi et al., 2005; King et al., 2005). The inclusion of too much finished compost in the initial mixture sometimes reduces decomposition rates because of a lack of available energy in the compost or reduced porosity in the final mix (Keener & Elwell, 2006; Murphy et al., 2004).

4.1.1 Determining requirement for carbon

Recommendations differ on the amount of carbon required to compost mortalities. These include:

- A 12:1 sawdust to mortality volume ratio for all types of mortality (Keener et al., 2000).
- About 9.5m^3 of C source for fully-grown cattle (Bonhotal et al., 2002).
- A carcass:straw:manure volume ratio for poultry of 1:0–1.2:4–8 (Natural Resources Conservation Service, 2001).
- A 2:1 C-source to mortality volume ratio for poultry, not including the requirement for base layer and capping (Tablante & Malone, 2005).

The requirement for carbon can be estimated for composting all types of mortalities in either bins or static piles/windrows when the annual mass of mortality is known. The annual sawdust requirement in m^3/yr, V_s, is

$$V_s = YL \times 0.0116 \quad (1)$$

where YL is the yearly mortality loss in kg/yr (Keener et al., 2000). Equation 1 gives the total annual requirement, but up to 50% of this can be met by replacement of fresh sawdust with finished compost.

4.2 Pre-treatment of carcasses

The burial of mortalities above the ground in a pile of carbonaceous material does not necessarily result in optimum conditions for composting because of the heterogenous nature of the mix. But leaving the carcasses undisturbed until they are largely broken down has obvious advantages for biosecurity, particularly in an EAD outbreak. Nevertheless, Rynk (2003) demonstrated that chopping large carcasses in a vertical grinder-mixer (the type used for grinding hay and mixing feed rations) produces a homogenous mixture for composting and reverses the normal requirement of C source to mortalities from 4:1 to 1:4 by mass. Finely chopping large carcasses also results in a significant reduction in required composting time from about 180 days down to as low as 75 days. All of this has a significant effect on the economics of mortality composting. The advantages of chopping the carcasses of smaller animals, like poultry, are less clear because they typically break down much more quickly than large carcasses.

Combining chopping and/or mixing of carcasses with the use of in-vessel type composting systems (e.g. the Ag-Bag® system) could be feasible for disposing of non-diseased birds in an EAD outbreak.

Rynk (2003) described the advantages of this sort of approach to include:

- Mortalities are isolated from the environment, reducing the risk of odours and scavengers plus the effects of the weather.
- The containment reduces the amount of C source required because the carcasses do not need to be fully covered and the need to absorb liquids is not as critical.
- The added degree of process control in in-vessel type composting systems (e.g. forced aeration) tends to accelerate the composting process compared to passively aerated systems.

4.3 Bin composting

A base of sawdust or other suitable C source of 20-30 cm thickness should be placed on the floor of the bin to collect liquids that are released during composting. Larger animals may require a deeper base layer (up to 60 cm deep). Mukhtar et al. (2004) suggested that the ideal base layer is pre-heated litter, put in place about 2 days before carcasses are added. Carcasses can be layered within the bin with about 15–30 cm of absorbent bulking material (e.g. litter or sawdust) placed between each layer of mortalities. Mortalities must not be placed within 20–30 cm of the sides, front or rear of the bin. A final cover of damp sawdust or litter to a depth of about 60 cm should be placed on the top of the pile (Fig. 4). This final cover acts as a biofilter for odour control and to insulate the heap. When the cover material is too dry or too wet, odours may be released and scavenging animals may be attracted to the pile (Keener & Elwell, 2006).

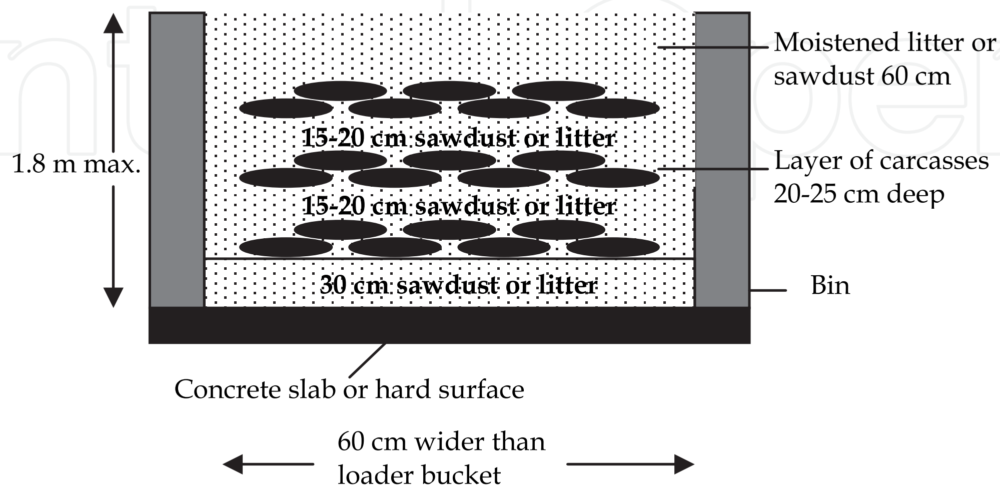

Fig. 4. Typical layout of a mortality composting bin for small animals (adapted from Keener & Elwell, 2006; Tablante & Malone, 2005).

The pile is moved to a secondary bin when the last layer of mortalities is almost completely decomposed. To ensure that the pile reheats, it is watered and re-mixed. An additional 10 cm of co-composting cover material is added to ensure that any carcass pieces remaining are covered and odours are minimised. When additional animals are to be added to a partially filled bin, half of the cover material is removed and a new layer of animals is placed on top. The new layer of mortalities is then covered with 60 cm of damp C source.

Stanford et al. (2000) used a bin (2.4 x 2.4 x 2.4 m) constructed of pressure treated timber to successfully compost lambs and mature sheep in both summer and winter conditions of Alberta, Canada. Alternate layers of composted sheep manure, barley straw and fresh sheep manure were used above and below a layer of mortalities. The expected heating pattern was not observed in one trial due to the excessive moisture content (31% dry matter) of the fresh sheep manure that was added to the bin. In this trial, 6 wethers (mean mass of 97.5 kg) were composted in a single layer over autumn and winter. Foul odours were observed when the contents of the bin were transferred to the secondary bin after 79 days. However, turning the compost into the secondary bin salvaged the pile and temperatures reached over 60°C even though the average ambient temperature was only -6.7°C (with a low of -35°C).

4.4 Pile or windrow composting

Large and very large animals (e.g. mature cattle and pigs) are most suited to the windrow composting method. It is also the system that is most likely to be used in any mass mortality composting process. Keener et al. (2000) stated that for mature cattle or horses, it is preferable to construct a separate pile for each carcass.

Mukhtar et al. (2004) suggested that a base layer of C source should be 30 cm thick for small carcasses, 45 cm for medium carcasses and 60 cm for large carcasses. An ideal base layer for this purpose has been described as absorbent organic material containing sizeable pieces 10–15 cm long such as wood chips (Bonhotal et al., 2002). Another layer (15–30 cm thick) of highly porous, pack-resistant bulking material can be added on top of the base layer to absorb moisture from the carcasses and to maintain adequate porosity. The dimensions of these base materials must be large enough to accommodate the mortalities with >60 cm space around the edges (Figs. 5 & 6).

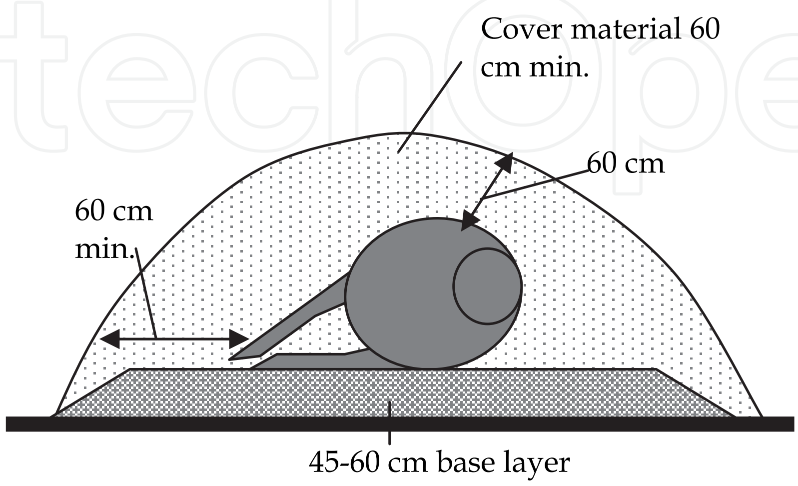

Fig. 5. Cross-section of a typical windrow or static pile for larger carcasses.

An evenly-spaced layer of mortalities can then be placed on top of this and covered with between 30 cm and 60 cm of C source. Some guidelines recommend the use of a dry cover (e.g. Bonhotal et al., 2002), whereas others claim a moist C source reduces odours and assists in the breakdown of bones (Keener & Elwell, 2006; Murphy et al., 2004).

Small-/ and medium-sized carcasses can be layered in windrows with at least 30 cm of C source placed between each layer until the windrow reaches a height of approximately 1.8 m. With larger carcasses, only a single layer of mortalities should be placed in a windrow before it is capped with C source (Fig. 6).

For ruminants larger than 136 kg, it is usually recommended to lance the rumen and/or thoracic cavity to avoid bloating and possible explosion (Bonhotal et al., 2002).

Straw bales were used by Murphy et al. (2004) to confine a U-shaped site of dimensions 2.6 m by 2.6 m and 1 m deep for composting beef cattle (275–450 kg). As base layers and covers, they used straw, manure compost and sawdust separately and in combination (i.e. 2 C sources in equal quantities). All six permutations of C sources produced an acceptable decomposition of the cattle mortality and no odours were observed. However, it was noted that straw and sawdust piles produced a more rapid rise in temperature and shorter times of decomposition.

Mukhtar et al. (2003) investigated a low-maintenance approach to composting cattle and horses in spent horse bedding (pine wood shavings and horse manure). The animals were composted in the bedding with or without wooden pallets under them (both on a 46 cm base layer). It was assumed that the air spaces between the pallets and the bedding layer underneath them would continue to aerate the static pile and that these piles would require less turning. The effect of the pallets was inconclusive as both methods worked successfully and the animals composted were of different sizes. Nevertheless, the trials showed that peak temperatures were often associated with the moist bottom layers of the pile as the upper layers dried out. Temperatures in the upper layers of the pile increased in response to rainfall.

Fig. 6. Construction of compost pile for a large carcass. Photos: J. Biala & K. Wilkinson.

In static piles of poultry mortalities, straw and hen manure, González & Sánchez (2005) found some influence of ambient temperatures and different mixes on the progress of composting. During summer, the carcasses were exposed to temperature above 60°C for between 4 and 20 days depending on the particular mix used. In winter, peak temperatures were lower, but still exceeded 55°C in each pile.

4.5 Monitoring composting conditions

The progress of composting is monitored primarily with a temperature probe. Temperature is the single most important indicator of the stage of degradation, the likely pathogen kill and the timing of turning events (Keener & Elwell, 2006). Temperatures should be taken at several points near the carcasses in a pile—for example with the use of a stainless-steel temperature probe 90–100 cm in length. A logbook should also be used to record data such as dates, mass of carcasses, temperature, amount and types of C sources used and dates when compost is turned (Mukhtar et al., 2004).

4.6 Managing environmental and public health impacts

Improper carcass disposal may cause serious environmental and public health hazards, including:

- Generation of nuisance odours resulting from the anaerobic breakdown of carcasses.
- Leaching of nutrients from carcasses to ground and surface water.
- Spread of pathogens from infected carcasses via equipment, personnel, air, soil or water.

- Flies, vermin and scavengers disrupting operations and acting as potential vectors of harmful diseases.

Many of these potential hazards are managed by paying careful attention to site design and layout. The biological risks associated with mortality composting are principally managed by proficient operation of the composting process.

The environmental impacts of cattle carcass composting were investigated by Glanville et al. (2005). Trials were conducted in 6 m x 5.5 m x 2.1 m windrow-type test units containing four 450 kg cattle carcasses on a 60 cm thick base layer of C source. C sources included corn silage, ground cornstalks or ground straw mixed with feedlot manure.

During the first 4–5 weeks after construction, air samples were collected on a weekly basis from the surface of the test units and compared with stockpiles of cover materials (i.e. not containing mortalities). Threshold odour levels were determined by olfactometry using experienced odour panellists and standard dilution procedures. It was found that 45–60 cm of cover material was generally very effective at retaining odorous gasses produced during composting. Threshold odour values for the composting test units were often very similar to the odour intensities found in the cover material stockpiles.

Chemical analysis of the leachate collected in PVC sampling tubes installed at the base of the test units showed that it had high pollution potential (Glanville et al., 2005). The leachate had mean ammonia concentrations of 2,000–4,000 mg/L, total organic C of 7,000–20,000 mg/L and total solids of 12,000–50,000 mg/L. Nevertheless, the base and cover materials were highly effective in retaining and evaporating liquids released during composting as well as that contributed by seasonal precipitation. Following a 5-month monitoring period after the set up of the trial, the test units received nearly 546 mm of precipitation yet released less than 9 mm of leachate each.

In Nova Scotia, Rogers et al. (2005) investigated the environmental impacts of composting pigs in sawdust and pig litter (manure plus bedding). Leachate and surface run-off were collected and analysed for various water quality parameters. Highest temperatures and better carcass decomposition were observed with sawdust in both the primary and secondary stages of composting. The sawdust cover also had lower leachate and surface run-off volumes and annual nutrient loadings compared to the pig litter treatments.

Finished mortality compost should be applied to land in a manner similar to manure so that the nutrient uptake capabilities of the crop being grown is not exceeded. A comparison of the nutrient composition of poultry litter and mortality composts is shown in Table 2.

Poultry mortality compost often has a higher nutrient content than other composts, probably as a result of the high nutrient content of poultry litter (Table 2). During composting, much of the available nitrogen is converted to organic forms and becomes unavailable in the short-term to plants.

Murphy & Carr (1991), for example, demonstrated much slower rates of N mineralisation in a loamy sand amended with poultry mortality composts compared to manure. Thus there is a lower risk of nutrient leaching with compost compared to uncomposted manures and mortalities. Nevertheless, it is advisable not to spread mortality compost in sensitive areas such as watercourses, gullies and public roads.

5. Mass mortality composting

The use of mortality composting as the main method of carcass disposal on a mass-scale (known as mass mortality composting) is probably only likely for small/- to medium-size carcasses. Until recently, most mass mortality composting operations were conducted after

	Lamb mortality compost[1]		Sheep mortality compost[1]		Poultry litter[2]	Poultry mortality compost[3]	Poultry mortality compost[4]
	Starting compost	Finished compost	Starting compost	Finished compost	Un-composted	Finished compost	Finished compost
	Mean (SD)		Mean (SD)		Mean (SE)	Mean (SD)	Mean (SD)
DM (%)	52.7 (8.1)	65.3 (5.5)	64.6 (1.4)	50.6 (5.4)	80.5 (0.58)	85.41 (11.31)	63.8 (10.62)
Total C (%)	23.5 (0.8)	23.1 (2.0)	23.5 (1.4)	28.3 (2.9)		27.40 (15.75)	36.3 (3.83)
Total N (%)	1.6 (0.1)	1.8 (0.2)	2.00 (0.2)	2.3 (0.2)	4.00 (0.72)	2.42 (0.93)	3.80 (0.55)
C:N ratio	14.3 (0.8)	12.7 (2.1)	11.9 (0.4)	12.2 (2.0)		10.96 (2.01)	9.8 (0.16)
Total P (%)	0.6 (0.0)	0.8 (0.1)	0.8 (0.1)	0.9 (0.1)	1.56 (0.047)	3.1 (0.91)	1.8 (0.55)
Total K (%)	2.42 (5.0)	12.16 (2.28)	14.31 (2.62)	13.55 (1.35)	2.32 (0.059)	2.88 (1.82)	2.1 (0.55)

[1]Stanford et al. (2000). Compost composed of mortalities, straw, manure and composted manure. Number of samples not given.
[2]Stephenson et al. (1990). Analysis of 106 broiler litter samples collected in Alabama, USA.
[3]González & Sánchez (2005). Analysis of 8 samples of compost with different ratios of straw, hen manure and poultry mortalities.
[4]Cummins et al. (1993). Analysis of 30 poultry mortality composts collected from farms in Alabama, USA.

Table 2. Nutrient composition of lamb and sheep mortality compost, poultry litter and poultry mortality compost.

catastrophic events such as poultry flock losses due to heat stress or herbicide contamination (Malone et al., 2004). However, it is now increasingly being used to successfully manage the disposal of carcasses in EAD outbreak, particularly in North America.

5.1 Mass poultry mortality composting[1]

Composting is particularly suitable for the emergency management of broiler-farm mortalities and poultry litter. Composting can be conducted both inside and outside the poultry house following euthanasia. Additional litter, sawdust or other carbon source can be delivered to the farm when the volume of litter in the poultry house is insufficient to complete the composting process. As a general rule, 4 to 5 mm of litter is required per kg of carcass per m^2 of poultry-house floor space (Tablante & Malone, 2005).

Poultry carcasses can be layered in windrows using essentially the same procedure as described above for the routine management of mortalities. A skid-steer loader is used to layer carcasses in a windrow with dimensions of 3-4 m at the base and up to 1.8 m high. Each layer of mortality should be no deeper than 25 cm with 15 to 20 cm of litter/sawdust between each layer. The final windrow is capped with 15 to 20 cm of litter/sawdust and to ensure that all carcasses are covered. Each layer of birds is moistened with water at a rate of 1 litre/kg of carcass (Tablante et al., 2002).

Alternatively, birds can be mixed and piled up together with the available carbon source. Firstly, the birds are spread evenly across the centre of the shed. The carcasses are rolled up together with litter to form windrows 3-4 m wide at the base. The litter from along the sidewalls (or additional supply of carbon, if needed) is then used to cap the windrows (15 to 20 cm thickness). Experience in the United States has shown that this method involves the least time, labour and materials. In addition, current research in Australia has confirmed anecdotal evidence that windrows constructed in this manner result in faster carcass

[1] This section has largely been adapted from Wilkinson (2007).

decomposition and higher temperatures than windrows constructed using the layering method (Wilkinson et al., 2010; Fig. 7).
Where larger birds such as turkeys are involved, or where there is a desire to speed-up decomposition, carcasses can be shredded by rotary tiller or crushed by loader prior to constructing the windrows. Bendfeldt et al. (2005b) demonstrated that temperatures above 60°C were achieved within 5 days in windrows constructed with crushed or shredded turkeys and 16 days for whole carcasses. In addition, they reported that to compost crushed or shredded carcasses, 30% less carbon material was required compared to whole carcasses. Windrows formed from crushed or shredded carcasses also do not require additional water to be added.

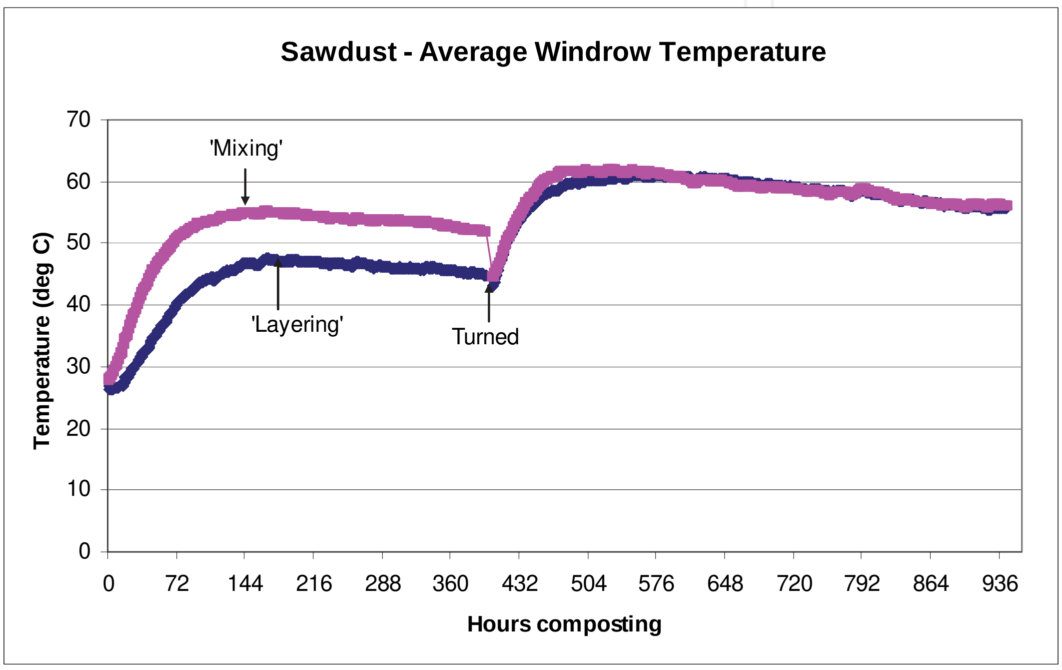

Fig. 7. Average temperatures in poultry mortality composting windrows constructed using the layering and mixing method and sawdust as the carbon source (Wilkinson et al., 2010).

Temperatures in excess of 55°C are usually reached within 5 days of windrow construction. When temperatures begin to decline after 10 to 14 days, the windrows can either be turned inside the poultry house, or reformed outside. If windrows are moved outside, they are covered, for example with tarpaulin. Following turning, windrows are capped again with litter or other carbon source to a minimum depth of 10 cm. After an additional 2 to 3 weeks the compost can be applied to land with the approval of the relevant authorities.

5.1.1 Biosecurity of mass poultry mortality composting

The biosecurity of mass poultry mortality composting has been reviewed recently by Wilkinson (2007) and Berge et al. (2009). Although composting is a well-established pathogen reduction technology, process management and heterogenous pile conditions pose particular challenges for validating the microbiological safety of mortality composting. Biosecurity agencies in Australia, New Zealand, United States and Canada have recognised the potential benefits of using composting for both routine and emergency management of mortalities, and have identified it as a preferred method of carcass disposal (Department of

Agriculture, Fisheries & Forestry, 2005). However, the lack of a scientifically validated process is likely to be a major barrier to its widespread adoption in many countries (Wilkinson, 2007). Research projects are currently underway in the United States, Canada and Australia to bring scientific validation to a process that has been successfully used in a number of EAD outbreaks in North America (e.g. see Bendfeldt et al., 2005a,b; Malone et al., 2004; Spencer, 2005a,b). A growing body of studies published to date (e.g. Senne et al., 1994; Wilkinson et al., 2010; Xu et al., 2009; Xu et al., 2010) confirms that the process is a feasible and biosecure alternative to landfilling of EAD-affected poultry carcasses.

6. Conclusions

On-farm mortality composting is likely to play an increasing role in carcass disposal due to a general contraction in the availability of rendering services and tightening regulations governing on-farm burial. It is a relatively simple and effective process and, if done properly, it meets the biosecurity, environmental, and public health objectives of safe carcass disposal. It can be used successfully for the routine management of farm animal mortalities of all sizes. Mortality composting is particularly suited also to the broiler industry for management of mass mortalities in the event of an emergency disease outbreak.

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