LARGE ANIMAL MORTALITY COMPOSTING IN WASHINGTON STATE

Caitlin Price
Washington State University

Large Animal Mortality Disposal in Washington State

In 2007, Washington state was home to 335,000 dairy cows and heifers, and 167,000 cattle on feed (NASS, 2007). Even under the best management, livestock sometimes die on the farm from disease or injury. The USDA Animal and Plant Health Inspection Service (APHIS) reports that during 2006, 5.7% of all dairy cows died on the farm nationwide (USDA, 2008a). The non-predator death loss for beef cattle including both feedlot and range and was 2.4% nationwide in 1995 (USDA, 1997). At these rates, producers in Washington state are faced with disposing of over 24,000 cattle carcasses annually. Catastrophic losses must also be considered, as in the case of the flooding of the Chehalis River in 2007 when livestock losses were estimated at 1600 animals (Farmers Still Struggling, 2007).

Disposal methods for livestock mortalities in Washington as authorized by the Washington State Department of Agriculture include burial, natural decomposition on range land, landfill, rendering, digestion, and composting (WAC 16-25-025). As a result of consolidation within the rendering industry and the mad cow disease (BSE) scare of 1994, there has been a significant reduction in both the number of rendering facilities, and demand for rendering products (proteins, oils, fats, etc.) over the last decade (Petrak, 2007). As the market demand for rendering products decreased, much of the cost was transferred to farmers and prices for rendering services increased (Dininny, 2004). In many areas, the frequency of pick-up and/or availability of service has also been reduced significantly, requiring producers to wait several days for carcass removal from the farm. Washington State currently has two rendering facilities and, as of 2006, Oregon has none (Perkowski, 2007).

On-farm burial and natural decomposition on rangeland are often less costly than rendering but may attract pests or contaminate ground or surface water. These methods may also only be practical during certain times of the year, and require a sufficient land base. Considering the costs and challenges associated with these common disposal options, many producers are seeking alternatives. With proper management and materials, on-farm composting can be an economically viable and environmentally sound method of mortality disposal, and in many cases is just the alternative producers are looking for.

A producer interested in composting mortalities must consider both state and county regulations about composting and dead animal disposal. In Washington , three regulatory agencies have overlapping authority over on-farm composting of livestock mortalities. The Washington State Department of Agriculture has authority to regulate disposal of livestock that have died of disease or an unknown cause. The Washington State Department of Health regulates disposal of other animal mortalities. The Washington State Department of Ecology regulates solid waste management, including composting. Substitute Senate Bill (SSB) 5605, passed during the 2005 Washington legislative session, required the Department of Ecology to develop state guidelines for on-farm composting of routine bovine and equine mortalities at livestock animal feeding operations (WSDOE, 2005). Since then, all three state agencies have made regulatory changes to ensure consistency for mortality management and reduce confusion about how and when livestock mortalities may be composted. SSB 6371, passed during the 2006

Washington State legislative session, required the Department of Agriculture to clarify rules for carcass disposal. These new rules for dead livestock disposal (WAC 16-25-025) were adopted in May of 2007 (WSDA, 2007), and the State Department of Health rules (WAC 246-203-121) were updated in July of 2007 (WSBOH, 2007). Both rules reference the state Solid Waste Handling Standards (WAC 173-350-220) and options for livestock mortality disposal now include composting.

In 2005, changes were also made to the state solid waste statute which affected producers composting bovine and equine mortalities on the farm (RCW 70.95.306). In most cases, mortality composting falls under the same exemptions as other on-farm composting and producers are exempt from any additional permitting or testing. There are additional requirements when compost is distributed off-site (WSDOE, 2005). Washington State producers are fortunate that all three regulating agencies are in agreement on the importance of composting as a mortality disposal option, and have worked to make it both legal and reasonable to manage.

Introduction to the Composting Process

Composting is essentially the controlled microbial decomposition and stabilization of organic materials into a humus-rich substance that can be used as a soil amendment. The process of decomposition and stabilization occurs continuously in nature, but composting reduces the time required by controlling conditions and inputs. For the most efficient decomposition process, compost microbes (predominantly bacteria and fungi) require a balance of moisture, oxygen, and digestible nutrients. When conditions are suitable, the microbes convert raw materials to energy and cell biomass, and in the process produce humified organic matter. Heat produced as a metabolic byproduct accumulates in the compost pile and creates an environment conducive to thermophilic microbial activity. These high temperatures are largely responsible for pathogen and weed seed reduction in compost (Rynk, 1992; Haug, 1993).

The finished, or cured, compost has no traces of tissue or other distinguishable raw materials, and no unpleasant or pungent odors. It is a homogeneous mixture of stable, humus-rich material that is dark brown to black in color and resistant to further microbial decay. Compost is most commonly applied to soil as an amendment to improve soil quality, and as a slow-release nutrient source. Compost application rates will vary with crop needs and nitrogen mineralization rates (Gale et al., 2006), and are dependent on compost and soil characteristics, and climatic conditions.

Extensive information is available for the home and farm composter on the basic concepts of compost management and use. The following commonly available and peer-reviewed information is provided in order to elucidate some of the important management techniques and biological concepts that apply to on-farm composting of organic wastes, including carcasses.

Factors for Successful Compost Management

Composting can be described as "microbe farming" and the requirements for successful composting are the same as for the production of any other crop: available nutrients in sufficient quantities and an environment that supports maximum growth. Table 1 shows the optimum ranges for several compost parameters.

Table 1. Optimum ranges for common thermophilic compost parameters	
Parameter	**Optimum Range**
C:N	25:1 – 30:1
Moisture Content	50% – 60% by weight
Oxygen	> 5% of pore space
Particle Size	1/8 – 2 inches (heterogeneous)
pH	6.5 – 8.0

Adapted from Dougherty 1999; Rynk, 1992.

Microorganisms require a source of organic carbon (C) for energy and growth, and nitrogen (N) for protein synthesis (Fuhrmann, 2005). In composting, C and N, as well as other nutrients, come from the degradation of organic substrates such as celluloses, starches, proteins, etc. To maintain metabolism and increase cellular biomass, compost microorganisms require approximately 1 part N to 25-30 parts C, therefore the ideal ratio of available C to available N (C:N) of raw materials is 25-30:1. Nitrogen is often the first limiting nutrient, as typical compost substrates have a C:N considerably higher than 30:1. When N becomes limiting (high C:N), microbial metabolism is reduced and the compost process slows. Excess N (low C:N) increases N loss from volatilization of ammonia gas and leaching of nitrate. Elevated levels of ammonium ions in solution can also be toxic to microbes. Many other nutrients are important for microbial metabolism such as phosphorus, potassium, and sulfur, but these are rarely limiting in a compost environment (Golueke, 1991).

The key environmental factors that affect microbial activity in a compost pile are moisture and oxygen availability. These two factors are very closely related because both substances occupy the interstitial spaces of the compost pile. Microbial growth and metabolism, and therefore decomposition, occurs in the water films surrounding the particles (Sylvia et al., 2005). The more water that is available to the microbes, both for consumption and habitat, the faster the rate of decomposition. Moisture levels below 25% severely inhibit microbial activity, and levels below 10% prohibit growth altogether (Golueke, 1991).

Aerobic respiration, in which oxygen is required as the terminal electron acceptor and carbon dioxide is produced as a byproduct, is the most efficient form of metabolism for the microbes involved in organic matter decomposition. Most compost bacteria are facultative aerobes, meaning they prefer to use oxygen when available but can also use other compounds such as carbon dioxide and sulfate when oxygen is limiting. Anaerobic decomposition results in less energy for the microbes and produces odorous compounds like methane and hydrogen sulfide gas as byproducts (Fuhrmann, 2005; Haug, 1993). Therefore, sufficient oxygen must also be available in the interstitial spaces to promote the most efficient and inoffensive decomposition.

When managing compost, the goal is to provide the maximum available moisture without compromising available oxygen. This balance will vary slightly based on type of material and particle size, but in general is optimum when the compost is between 50 and 60% water by weight (Rynk, 1992). Available moisture and oxygen in the compost pile are best controlled by the initial moisture content and particle size of the raw materials. Because of the heat produced during the compost process, some of the initial moisture will be lost as water vapor.

The particle size of raw materials affects the compost process in two ways: first it determines the amount of interstitial space available to maintain adequate oxygen levels, and second it determines the relative surface area available for microbial activity. Smaller particles provide a higher relative surface area but limit gas exchange, including oxygen, especially with wetter materials. Larger particles increase the porosity of the compost pile, but provide less surface area available for microbial activity. A uniform mixture consisting of a variety of particle sizes between 1/8 and 2 inches is most effective (Rynk, 1992; Dougherty, 1999).

The compost process functions over a wide pH range due to a natural biological buffering capacity, and in most cases adjusting the pH is not necessary. Initially the pH of the system will drop as organic acids are formed from the break down of carbonaceous material. This will then be followed by a rise in the pH to slightly alkaline conditions as these compounds are consumed by other bacteria (Rynk, 1992). The bacteria involved in composting have an optimum pH range of 6.0-7.5, while most fungi have an optimum range of 5.5-8.0 (Golueke, 1991). A pH above 8.5 favors the mineralization of N in the organic materials to ammonia, which will further increase alkalinity. For this reason, adding lime or ashes to the compost pile to increase pH is not advisable (Rynk, 1992).

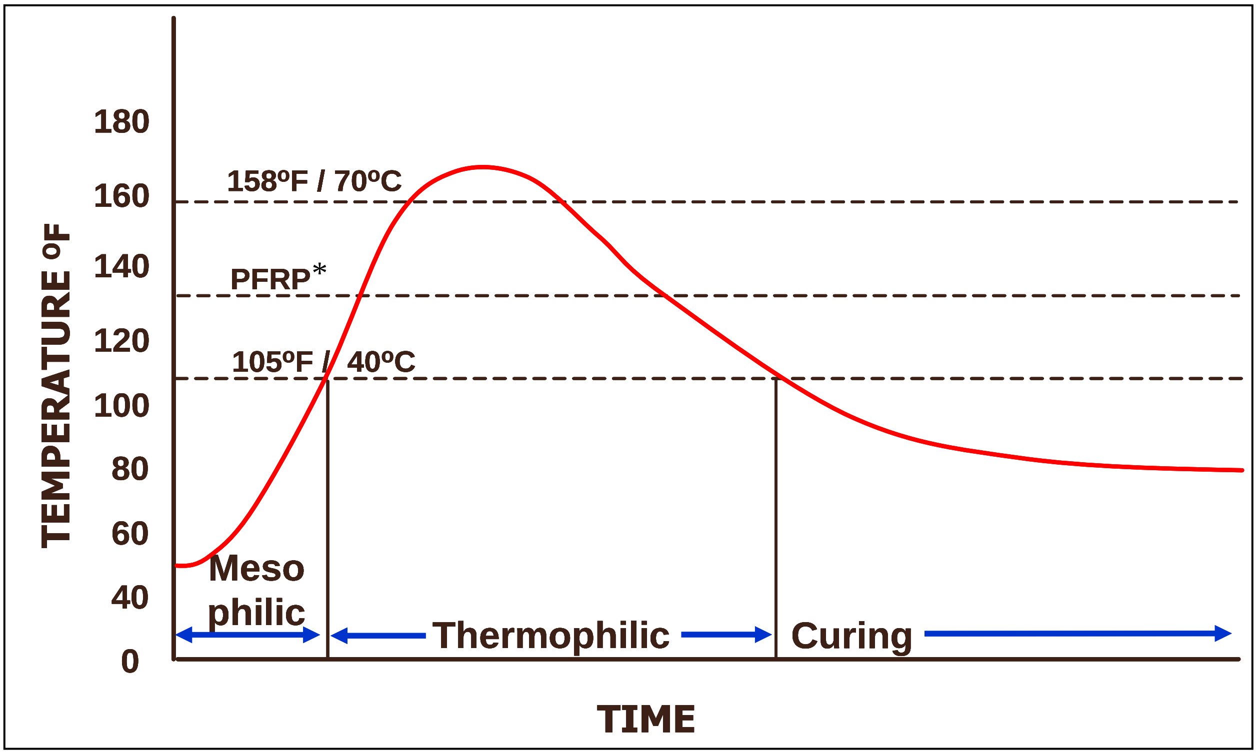
Microbial Succession in the Compost Pile

The compost process can be divided into three distinct phases: 1) the mesophilic active phase, 2) the thermophilic active phase, and 3) the mesophilic curing phase. Figure 1 shows these phases for a typical compost temperature curve. Bacteria, actinomycetes (a class of bacteria), and fungi play important roles in all of these phases. Bacteria are largely responsible for the initial phase of decomposition in the compost pile because of their ability to utilize an array of compounds such as complex carbohydrates, proteins, sugars, and amino acids. (Golueke, 1991). Actinomycetes are important in compost systems for their ability to degrade insoluble, high molecular weight compounds like cellulose, waxes, proteins, rubber, etc. Fungi have a lower nitrogen requirement for biomass production than do bacteria and therefore use high carbon cellulosic compounds more efficiently (Haug, 1993). Most fungi are also obligate aerobes and are more temperature sensitive than bacteria. For these reasons they are most concentrated in the outer 4 to 6 inches (10-15 cm) of the compost pile (Golueke, 1991) and play an important role in the mesophilic compost curing process.

Core temperature is the best indicator of microbial activity within a compost pile. The temperature will rise quickly after pile construction if conditions are right, and can reach temperatures conducive to thermophilic activity within a few days.

The first phase of the compost process is initiated by mesophilic microorganisms that are naturally abundant in the environment and are incorporated into the compost with the raw materials. These mesophiles thrive at temperatures of 10-40^{o}C (50-105^{o}F) (Rynk, 1992). Microbial metabolism is not 100% efficient and some energy is always lost as heat. As the microbial activity increases, heat accumulates in the compost pile faster that it can dissipate.

Figure 1. Typical compost temperature curve



* The Process to Further Reduce Pathogens is a set of time-temperature requirements established by the EPA for the treatment of bio-solids by composting. For a complete description see page 18, "Pathogen Reduction in Compost".

When temperatures reach 40-45°C (105-113°F) the compost environment gets too hot for much of the mesophilic population and selection for the more heat tolerant microbes occurs (Zibilske, 2005; Cooperband, 2002). This is the beginning of the second phase of composting. The thermophiles will continue to break down some of the more complex substrates for energy and biomass and at the same time produce heat. Thermophilic microbial activity will continue as long as there is available water, oxygen and substrate. Frequent mixing of the compost will expose all materials to the thermophilic compost zone at the core of the pile and temporarily improve porosity and oxygen availability. The most effective temperature range for thermophilic microbial activity, and therefore decomposition, is 55-60°C (131-140°F) (Golueke, 1991). At temperatures above 65-70°C (149-158°F) microbial activity is greatly reduced and the process becomes self limiting (Zibilske, 2005).

The thermophilic active phase is followed by the mesophilic curing stage. As most of the available substrates and oxygen are consumed, microbial activity will slow and the temperature in the compost pile will decrease. When the temperature falls back into the mesophilic range, the compost will be re-colonized by a second population of mesophilic microbes that will begin to degrade the most resistant substrates. Though decomposition will not cease, the rate will be greatly reduced. Fungi and actinomycetes play an important role in the decomposition of high carbon substrates such as lignin during the curing phase (Golueke, 1991).

On-Farm Composting of Large Animal Mortalities

Composting has been used for routine and catastrophic mortality disposal in the poultry industry since the 1980s, and was later adopted by the swine industry (Glanville & Trampel, 1997). In more recent years the practice has expanded to include the dairy and beef industries, and is even used to successfully dispose of road kill deer carcasses in several states (Bonhotal et al., 2006). Composting farm mortalities not only reduces the cost of carcass disposal, but also keeps nutrients on the farm and has the potential to improve soil quality by increasing soil organic matter. The USDA National Organic Program does not prohibit the use of mortality compost on certified Organic crops (USDA, 2008b).

Adding a large carcass to the center of a compost pile adds an interesting challenge to the microbial management process. Initially, carcass decomposition is slow, but as tissues begin to decompose, and more oxygen and nutrients become available to the microbes, the process accelerates. When most of the tissue is decomposed, it is possible to mix and aerate the pile, further boosting microbial activity. Eventually, there will be nothing left of a 1500 pound cow but a few brittle bones and a pile of nutrient rich compost. When composting large animal mortalities, there is a smaller margin of error than with non-mortality compost; a mistake has the potential to be messier and is often more difficult to correct. There is also a larger potential for pests, odors, and pathogen transmission.

Despite potential challenges, mortality composting is being used successfully on farms in Washington, and other parts of the country. A recent report by the USDA-APHIS showed that nationwide between 2002 and 2007 the number of dairy cow mortalities disposed of by burial and rendering decreased from 85% to 77%, while the number of mortalities disposed of by composting increased from 7% to 17% (USDA, 2008a).

Literature on the topic of large animal mortality composting is limited, and is primarily in the form of Extension bulletins, magazine or non-refereed journal articles, project reports, and conference papers. Some of the more comprehensive studies include research on such topics as pathogen elimination (Bonhotal et al., 2006; Glanville et al., 2006; Mukhtar et al., 2003), odor and leachate production (Glanville et al., 2006), and comparison of carcass decomposition rates with various materials and compost methods (Glanville et al., 2006; King et al., 2005; Mukhtar et al., 2003).

The Basic Process of Composting Large Animal Mortalities

Generally accepted methods for composting large animal mortalities can be found in the sources mentioned above. They are as follows:

1) Select and prepare the compost site and materials. The site should be well drained, and without risk of ground or surface water contamination. The combination of materials used must provide a proper balance of available nutrients, water, and oxygen, as well as adequate structure to allow gas exchange without promoting excessive drying and cooling of the pile, or release of odors. Materials can include many organic wastes commonly found on the farm (Table 2).
2) Create a base of absorbent compost material 18-24 inches thick and place the carcass in the center of the pile. Puncture the abdomen to reduce bloating and increase microbial access to the body cavity. Cover with another 18-24 inches of compost material, ensuring that all parts of the carcass are completely covered.

3) Monitor the compost for signs of disturbance or settling, and record internal compost temperatures weekly. Add more compost material as needed to keep the carcass covered and insulate the pile.
4) After 2 to 4 months, the pile can be turned to mix the materials and improve aeration. Most of the carcass should be decomposed at the this point, and there should not be an overpowering odor or large pieces of tissue or hide remaining.
5) After the first turning, the pile will reheat and continue composting. Continue to monitor temperatures and turn the pile regularly until the compost no longer reheats after turning and there is no trace of tissue or unpleasant odor.

There are many variations on the basic process, depending on the number of mortalities to be managed, the desired timeline and management intensity, and available equipment and facilities. A static pile system (as described above) is used when one mortality is composted at a time. Compost windrows can be any length and increases the number of mortalities that can be managed within a limited area. In a windrow system, each mortality is added to the row as it occurs. A third method uses large three-sided bins built of hay bales, ecology blocks, or something similar to contain the compost (Mukhtar et al., 2003). A bin system can also be a permanent structure with a solid floor and roof (Keener et al., 2000).

Table 2. Characteristics of common on-farm composting materials

Material	C:N Ratio	%Moisture	Structure	Notes
Animal Carcass	5:1	60	Poor	Very dense. High moisture content.
Cattle Manure	13–20:1	67–87	Poor	High moisture content. Uniform, small particle size.
Horse Manure	25–30:1	55–75	Poor	High moisture content. Uniform, small particle size.
Wheat Straw	100–150:1	10–14	Very Good	Best when chopped and mixed with denser materials. Needs moisture. Easily degradable source of carbon.
Corn Silage	38–43:1	65–68	Good	Good particle size. Poor structure when wet. Strong odor.
Hay	15–32:1	8–10	Very Good	Best when chopped and mixed with denser materials. Needs moisture. Easily degradable source of carbon.
Sawdust	100–250:1	- -	Very Good	Maintains structure when wet but difficult to keep moist in dry climates. Low odor. Absorbent.
Wood Chips	100–250:1	- -	Good	Excellent base under primary compost materials to improve aeration. Large pieces do not absorb liquid or odors.
Finished Compost	20–40:1	- -	Good	Low available nutrients. Good as absorbent base or bio-filter cover.

Adapted from Dougherty, 1999; Rynk, 1992.

Animal carcasses are very dense and high in both moisture and nitrogen, and as a result the core of a mortality compost pile will be anaerobic during the initial phase of decomposition. Therefore, the biological activity and filtering capacity of compost material surrounding the carcass is essential for trapping and reducing odorous compounds that will originate from the anaerobic core (Keener et al., 2000). The use of high-carbon, absorbent materials provided in sufficient quantity will greatly reduce the potential for odors, nutrient leaching, and pests. Finished compost is comparatively low in available nutrients for microorganisms but is useful as a 'bio-filter' when layered over a new pile to reduce odors and insulate in cold weather. Approximately twelve cubic yards of raw material is needed to compost one full-sized cow (CWMI, 2002).

In addition to temperature, the compost pile should be monitored for any strong odors or signs of disturbance. Putrid odors can be a result of insufficient compost material covering the carcass, materials that are too porous to contain odors, or excessively anaerobic conditions and slow decomposition (King et al., 2005).

Current Research in Large Animal Mortality Composting

The liquid storage and transformation potential of active aerobic compost was demonstrated in a large scale mortality compost trial at Iowa State University (Glanville et al., 2006). Each compost windrow (test unit) contained 1.8 metric tons of cattle carcasses at construction, accounting for the addition of approximately 1200 L of water to the system (equivalent to a depth of 90 mm when spread over the entire unit). During the trial, an additional 500-600 mm of water was added as precipitation. The total volume of leachate collected throughout the entire trial was equivalent to only 1-5% of the total precipitation that occurred during that period, illustrating the surprising capacity of active compost to eliminate water from the system through microbial metabolism and evaporation. This liquid storage and transformation potential is especially important in mortality compost systems because of the large amount of water released from the carcass in a relatively short period of time during the initial stages of decomposition. This study also found that of the compost materials used sawdust had the most liquid storage potential, followed by ground corn stalks, then straw, and finally silage.

The time required to completely compost a full-sized cow or horse varies depending on compost materials, weather, and management. Glanville et al. (2006) found that full decomposition of organs and soft tissue was complete within 4-6 months in piles that were constructed during the spring and summer, and in 8-10 months in piles constructed during the winter.

A trial conducted with a full-sized dairy cow at the Washington State University compost facility during the winter showed almost complete decomposition of tissue and hide at 10 weeks of composting with core temperatures maintained at 47-67^{o}C (117-152^{o}F) (see "Phase I: Demonstration"). A second WSU trial was conducted in the spring with similar materials and maintained core temperatures of 58-71^{o}C (136-160^{o}F) for 7 weeks until the pile was turned. Noticeable pieces of partially decomposed hide and tissue remained but the structure had been thoroughly broken down and the pile was easily turned. In both of these trials the compost required a second stage of composting (1-2 months), but by aerating the pile and redistributing moisture and nutrients the rate of microbial metabolism, and therefore decomposition, was increased.

Large bones will require longer to decompose than other parts of the carcass and care must be taken to prevent prolonged exposure to air outside the compost pile. When bones are exposed to the air and begin to dry and harden, remaining decomposition time is greatly increased – as seen in the case of composting butcher waste at the WSU compost yard. Bones that were never exposed to the dry air outside a compost pile decomposed much faster than bones of an equivalent size from the WSU meat processing lab that were exposed to air for several days prior to composting. Murphy et al. (2004) noted that the critical point for bone management is at 2 months of composting. After this, the bones must either be removed from the compost, or the pile must be moistened monthly and composted for an additional 6-9 months. In the WSU field trials it was found that after about 3-4 months of composting, many of the larger bones could be easily broken when driven over by a tractor, and the smaller bones (rib, vertebrae, etc.) were easily broken by hand (see “Phase I: Demonstration”).

Pathogen Management in Compost

Pathogen reduction in thermophilic composting is largely due to the high temperatures caused by microbial metabolism; however, other factors such as microbial interactions and competition (Grewal, 2006), and fluctuating environmental conditions (Glanville et al., 2006) may also play a role. Standards set by the US Environmental Protection Agency for the treatment and handling of biosolids, called the Processes to Further Reduce Pathogens (PFRP), provide several methods for pathogen and vector reduction in biosolids, including thermophilic composting (USEPA, 2002). *Salmonella* spp. and fecal coliform counts are used as indicators when testing for pathogen levels and specific allowable levels have been established. With the exception of biosolids, there are no federal standards for finished compost quality or safety (Cooperband, 2002) but the PFRP time-temperature requirements and allowable pathogen levels for biosolids are generally accepted as the industry standard for all compost. They also provide a useful standard for comparison of compost methods and pathogen levels in laboratory and field experiments.

Following PFRP standards, all compost in an in-vessel (contained in building, reactor, etc.) or aerated static pile system (air circulated via perforated pipes) must be exposed to temperatures $\geq 55^oC$ (131^oF) for at least three consecutive days. For a turned windrow system, the temperature must be maintained at $\geq 55^oC$ (131^oF) or higher for 15 consecutive days, during which time the windrow must be turned five times. The allowable levels under the EPA guidelines for Class A biosolids are a fecal coliform density below 1000 most probable number (MPN) g^{-1} total solids on a dry weight (dw) basis, and a *Salmonella* spp. density of less than 3 MPN in 4 g^{-1} solids (dw) (USEPA, 1992).

Grewal et al. (2006) conducted a study comparing the persistence of *Mycobacterium paratuberculosis*, *Escherichia coli*, *Salmonella*, and *Listeria* in dairy manure at different temperature ranges in lab scale composters. Manure samples were inoculated with *M. paratuberculosis* at a density of 10^6 colony forming units (CFU) g^{-1}. *E. coli*, *Salmonella*, and *Listeria* were identified in all samples at the start of the trial. After three days of thermophilic composting at 55^oC (131^oF), all pathogens had been reduced to undetectable levels. More than 28 days were required to eliminate these same pathogens from samples incubated at 25^oC (77^oF).

Two studies on the persistence of the pathogenic strain of *E. coli* O157:H7 in bovine manure during thermophilic composting in laboratory bioreactors found similar rates of pathogen reduction. In one study (Jiang et al., 2002), bovine strains of *E. coli* O157:H7 were undetectable in the composted manure after 180 cumulative degree days (^oC) of heating (equivalent to 3 days at 60^oC, or 140^oF), while 300 cumulative degree days were required to inactivate the laboratory strains (Hess et al., 2004). In the other study, complete inactivation of laboratory strains of *E. coli* O157:H7 occurred between day 7 and 14 of composting at temperatures of 50-69 ^oC (122-156^oF). It is important to note that both experiments were conducted with a small volume of material in highly controlled conditions with consistent temperatures that simulated the core zone of thermophilic activity in a compost pile. In a field scale system, it is likely there would be more variation in temperature and conditions that would require careful management with regular turning to expose all materials to core temperatures.

Researchers at Texas A&M University (Mukhtar et al., 2003) conducted a field trial with the carcasses of two cows and two horses weighing 1000-2000 lbs. each. After nine months of composting, samples from each pile were tested for both fecal coliform and *Salmonella*. Fecal coliform levels were between 55 and 227 CFU 10 g^{-1} of solid (dw) and *Salmonella* levels were between 0 and 2 CFU 10 g^{-1} of solid (dw) – both well below PFRP standards.

Glanville et al. (2006) conducted a three-year field study with 54 tons of cattle carcasses composted in windrows. To evaluate viral survival in the compost piles, vaccine strains of Newcastle Disease Virus (NDV) and avian encephalomyletis (AE) were added to the piles with the cattle carcass at the time of pile construction. To determine the importance of environmental factors other than temperature in pathogen reduction, a set of samples was placed in sealed cryogenic vials, while another set was placed in gas-permeable dialysis cassettes. Both viral samples in gas-permeable cassettes were inactivated within 2 to 7 days. Viral samples in cryogenic vials survived considerably longer: 1 to 4 weeks and 1 to 7 weeks were required for the complete inactivation of the NDV and AE samples, respectively. This illustrates that exposure to environmental stresses such as fluctuations in moisture and pH, and potentially toxic gaseous decomposition products, may negatively impact viral survival in the compost pile.

Research done at WSU and other universities has shown that composting can safely and effectively decompose large animal carcasses on the farm within a few months. With sufficient time and temperature, most common bacterial and viral pathogens are inactivated during the compost process and the final product is a nutrient rich soil amendment that can be applied to crop and pasture land to increase on-farm nutrient cycling. Due to recent changes and clarification of Washington state regulations, composting can now be used for routine disposal of approximately 24,000 cattle and thousands of other livestock carcasses annually.

REFERENCES

Bonhotal, J., E. Harrison, and M. Schwartz. 2006. Evaluating pathogen destruction in road kill composting. BioCycle. Nov. 2006: 49-51.

Cooperband, L. 2002. The art and science of composting. Center for Integrated Agricultural Systems, University of Wisconsin-Madison.

Cornell Waste Management Institute (CWMI). 2002. Natural rendering: Composting livestock mortality and butcher waste. Available at http://www.cfe.cornell.edu/wmi (Verified 24 March 2008).

Dininny, S. 2004. Mad cow likely to force higher rendering costs: Carcass disposal may be too costly for some farmers. Seattle Times, Seattle, WA. 24 Jan., p. B2.

Dougherty, M. (ed.). 1999. Field guide to on-farm composting (NRAES-114). Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.

Farmers still struggling to recover after devastating floods. 2007. Associated Press. 17 Dec. Available at http://www.komotv.com/news/12561776.html (verified 24 March 2008).

Fuhrmann, J.J. 2005. Microbial metabolism. p.54-84 *In* Sylvia, D. M., J. J. Fuhrmann, P.G. Hartel, D.A. Zuberer (eds.) Principles and applications of soil microbiology, 2nd ed.

Pearson Prentice-Hall, Upper Saddle River, NJ.
Gale, S.G., D.M. Sullivan, C.G. Cogger, A.I. Barry, D.D. Hemphill, and E.A. Myhre. 2006. Estimating plant-available nitrogen release from manures, composts, and specialty products. J. Environ. Qual. 35:2321-2332.
Glanville, T.D., T.L Richard, J.D. Hartmon, D.L. Reynolds, H.K. Ahn, and S. Akinc. 2006. Project Report: Environmental impacts and biosecurity of composting for emergency disposal of livestock mortalities. Iowa Department of Natural Resources. Grant Contract # 03-7141-08. Available at http://www.abe.iastate.edu/cattlecomposting/ (Verified 24 March 2008).
Glanville, T.D., and D.W. Trampel. 1997. Composting alternative for animal carcass disposal. JAVMA. 210(8):1116-1120.
Golueke, C.G. 1991. p.14-27. *In* The Biocycle Guide to The Art and Science of Composting. The JG Press, Emmaus, PA.
Grewal, S., S. Rajeev, S. Sreevatsan, and F.C. Michel Jr. 2006. Persistence of *Mycobacterium avium* subsp. *paratuberculosis* and other zoonotic pathogens during simulated composting, manure packing, and liquid storage of dairy manure. Appl. Environ. Micro. 72(1):565-574.
Haug, R.T. 1993. The practical handbook of compost engineering. Lewis Publishers, Boca Raton, FL.
Hess, T.F., I. Grdzelishvili, H. Sheng, and C.J. Hovde. 2004. Heat inactivation of E. coli during manure composting. Comp. Sci. & Util. 124:314-322.
Jiang, X., J. Morgan, and M.P. Doyle. 2003. Fate of *Escherichia coli* O157:H7 during composting of bovine manure in a laboratory-scale bioreactor. J. Food Prod. 66(1):25-30.
Kalbasi, A., S. Mukhtar, S.E. Hawkins, and B.W. Auvermann. 2005. Carcass composting for management of farm mortalities: A review. Comp. Sci. & Util. 133:180-193.
Keener, H.M., D.L. Elwell, and M.J. Monnin. 2000. Procedures and equations for sizing of structures and windrows for composting animal mortalities. Appl. Engineering in Ag. 16(6): 681-692.
King, M.A., B. Seekins, and M.L. Hutchinson. 2005. Observations of static Pile composting of large animal carcasses using different media. Presentation for Composting Mortalities and Slaughterhouse Residuals Symposium. Available from Mark Hutchinson, University of Maine Cooperative Extension, Waldeboro, ME.
Mukhtar, S., B.W. Auvermann, K. Heflin, and C.N. Boriack. A low maintenance approach to large carcass composting. ASAE Meeting Presentation, Paper # 032263.
Murphy, J.P., J.P. Harner, T. Strahm, and J. DeRouchey. 2004. Composting cattle mortalities. ASAE/CSAE Meeting Presentation, Paper # 044027.
National Agricultural Statistics Service (NASS). 2007. Available at www.nass.usda.gov (Verified 24 March 2008).
Perkowski, M. 2007. Researchers seeking alternatives as rendering plants disappear. The Capital Press. 21 Sept., p. 10.
Petrak, L. 2007. Amazing transformations. The National Provisioner. 221(4):80.
Rynk, R.(ed.). 1992. On-farm composting handbook (NRAES-54). Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.
United States Department Agriculture (USDA). 1997. Cattle and calves death loss 1995. USDA-APHIS-VS, CEAH. Fort Collins, CO. #N232.297.

United States Department of Agriculture (USDA). 2008a. Dairy 2007. Part II: Changes in the U.S. dairy cattle industry, 1991-2007. USDA-APHIS-VS, CEAH. Fort Collins, CO. #N481.0308.

United States Department of Agriculture (USDA). 2008b. National Organic Program. Electronic Code of Federal Regulations – Title 7. Available at http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=%2Findex.tpl. (Verified 17 April 2008).

United States Environmental Protection Agency (USEPA). 1992. Control of pathogens and vector attractions in sewage sludge. EPA/625/R-92/013.

Washington State Board of Health (WSBOH). 2007. WSR 07-14-149, Permanent Rules. Filed 7/5/07. Available at http://apps.leg.wa.gov/documents/laws/wsr/2007/14/07-14-149.htm (Verified 24 March 2008).

Washington State Department of Agriculture (WSDA). 2007. Rule Making Order CR-103. Available at http://agr.wa.gov/LawsRules/Rulemaking/FSAHCS/docs/CR-103_16-25PR.pdf (Verified 24 March 2008).

Washington State Department of Ecology (WSDOE). 2005. On-farm mortality composting of livestock mortalities. Pub. # 05-07-034. Available at http://www.ecy.wa.gov/biblio/0507034.html (Verified 24 March 2008).

Zibilske, L.M. 2005. Composting of organic wastes. p. 587-606. *In* Sylvia, D. M., J. J. Fuhrmann, P.G. Hartel, and D.A. Zuberer (eds.) Principles and Applications of Soil Microbiology, 2nd ed. Pearson Prentice-Hall, Upper Saddle River, NJ.