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Swine Carcass Disposal Options for Routine and Catastrophic Mortality

Swine in various stages of production: sow with nursing litter (photo courtesy of USDA Online Photography Center), market hog (photo courtesy of CHS, Inc., St. Paul, MN), and replacement gilts (photo courtesy of Dr. Allen Harper, Virginia Tech).

ABSTRACT

The purpose of this CAST Issue Paper is to provide a critical assessment of information available on methods of swine carcass disposal under routine and catastrophic conditions. In developing this review, the authors have focused on efficiency and effectiveness of available methods as well as potential animal health and environmental protection considerations.

As in all types of food-animal production, some pigs and breeding swine die at the farm level and must be disposed of in a safe and environmentally sound manner. These death losses, also referred to as mortalities, may be classified broadly as either routine or catastrophic. Routine mortalities represent a small proportion of overall herd size and occur throughout the normal course of production. Catastrophic mortality events involve greater death losses within a distinct period of time.

The four predominant methods of routine swine mortality disposal developed to the present time are on-site burial, incineration, rendering, and composting. Additional technologies such as alkaline hydrolysis and anaerobic digestion have shown potential for swine carcass disposal, but use of these methods currently is limited because they require specialized facilities and equipment.

Catastrophic losses present unique challenges because of the large volume of swine carcasses that require disposal within a short time. Events that can lead to catastrophic swine mortality include barn fires, hurricanes or floods, and extreme heat waves coupled with ventilation system failures. In addition, the introduction of a highly infectious swine disease can lead to losses on an epidemic scale.

Each of the established swine mortality disposal methods has potential strengths and limitations under routine and catastrophic conditions that will be discussed in this paper. The methods chosen for any given farm will depend on farm circumstances, regulatory requirements,

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operational costs, and producer preferences. Further research and development has the potential to improve the efficiency and effectiveness of methods currently in practice and to make emerging technologies applicable on a wider scale.

INTRODUCTION

Swine production represents an important form of animal agriculture in North America and throughout the world. As with other types of food-animal production, a proportion of pigs and breeding swine will die on the farm before being marketed. These death losses, also referred to as mortalities, may be classified broadly as either routine or catastrophic. Routine mortalities represent a relatively small percentage of the total herd but can be expected to occur and fluctuate throughout the course of production. Catastrophic mortality events involve death losses of greater magnitude resulting from a single event such as a barn fire, hurricane, or flood, or the introduction of an epidemic swine disease. Safe, effective disposal of swine carcasses is essential for reasons related to human and animal health, environmental protection, and aesthetics.

Routine Mortality

Four predominant methods of routine swine mortality disposal have been developed to the present time: on-site burial, incineration, rendering, and composting. Transport to landfill sites or alkaline hydrolysis and anaerobic digestion are additional technologies that potentially may be used for mortality disposal, but widespread availability of specialized facilities and equipment for these processes currently are limiting factors. If necessary, technologies such as fermentation, acid preservation, refrigeration, or freezing could be used for biosecure storage of mortalities until disposal can occur by more traditional methods.

The use of predominant methods will depend on, and be influenced by, individual farm circumstances, regulatory requirements, operational costs, and producer preference. For example, on-farm incineration is biosecure and reduces carcasses to inert ash, but in some states, added operational costs associated with state regulatory requirements may decrease cost-effectiveness. Transport of carcasses to rendering plants continues to be a viable method and has the added advantage of converting an essentially valueless waste product into commercially useful by-products. But the limited number of independent rendering plants coupled with remote farm locations and changing market conditions for meat and bone meal may decrease access to rendering for some farms.

On-farm composting has evolved more recently as a disposal method for swine mortality. Although positive results have been demonstrated, regulations dealing with composting vary considerably from state to state. A readily available source of carbon (C)-rich cover material is needed, and, as with all methods, proper equipment and technical management are essential for good results.

Recent evidence indicates that routine use of burial on larger swine farms poses greater environmental risk in the form of potential groundwater contamination from excess nitrogen (N) or other pollutants. Given the potential for negative environmental impact, moving away from burial as a method of mortality disposal seems warranted.

Catastrophic Mortality

Catastrophic losses present unique challenges because of the large volume of swine carcasses that require disposal in a compressed time frame. Based on limited reports of instances in North America and reports of catastrophic events that have occurred in Taiwan and Europe, some general points can be made. With the exception of engineered sanitary landfills, disposal by mass burial should be avoided because of the risk of groundwater pollution. In situations where burial is the only viable option, preplanned sites with the lowest potential for environmental impact should be used. Small-capacity, on-farm incineration units would be completely inadequate, but if biosecurity risks could be controlled and cooperative agreements established, carcasses could be transported to commercial-scale refuse-incineration facilities. In addition, air-curtain incineration equipment may be transported to a central site for high-volume mortality disposal. Because of pollution potential and public discontent, open burning also should be avoided as a disposal method.

Transport of carcasses to rendering plants also may play a contributory role in catastrophic disposal. Use of this method assumes that animal and public health risks associated with transporting the carcasses are minimal and that the processing capacity of the rendering plant would not be overwhelmed.

Data on the use of composting for catastrophic swine mortality disposal are limited. Several studies do indicate that resident swine disease organisms (enzootic organisms) seem to be confined and controlled with on-farm composting of routine mortalities. In principle, large-scale windrow composting would be effective in disposal of a large volume of swine carcasses. Currently, however, little is known about the potential for disease spread or transfer from the compost matrix. Consequently, additional research is needed to determine the potential biosecurity risk associated with composting for mass disposal of swine carcasses.

As demonstrated during epidemic disease outbreaks in Taiwan and Europe, the use of several disposal methods in combination may be required to deal with catastrophic mortality disposal. Furthermore, a rapid, coordinated response of federal and state animal health, public health, sanitation, and environmental agencies, along with segments of the private sector such as renderers or commercial landfill operators, is critical when a massive disposal event occurs. Advanced planning for mass mortality disposal should be implemented among these agencies, swine producers, and industry as part of an emergency preparedness plan. Preparations should include development of decision-tree or action plan models based on local and regional conditions.

Mortality Rates

One major database of U.S. swine records indicates that routine preweaning pig mortality rates range from 8.18 to 17.43%, postweaning pig mortality rates range from 2.06 to 7.19%, and breeding sow mortality rates range from 4.30 to 15.90% (Olson 2005). Routine mortality disposal is important regardless of farm size, but as individual swine farms have become increasingly more specialized and larger in size, the issue of routine mortality disposal has received increased public concern and greater regulatory scrutiny.

After a catastrophe, individual farms and larger geographic regions also may be faced with the need to dispose of very large quantities of animal carcasses at one time. This situation differs from routine mortality disposal in that much larger numbers of animals may die or need to be euthanized. Barn fires, hurricane or flood events, and extreme heat waves coupled with ventilation system failure are examples of events that can lead to catastrophic amounts of swine mortality.

Another potential cause of catastrophic mortality is the introduction of swine disease that results in losses on an epidemic scale. In 1997, an outbreak of foot-and-mouth disease (FMD) in Taiwan resulted in death or euthanasia of more than 4 million pigs (Yang et al. 1999). A classical swine fever (or hog cholera) outbreak in 1997–98 caused death or required the destruction of 3.8 million swine in the Netherlands (Stegeman et al. 2000). And in 2001, an outbreak of FMD in the United Kingdom (U.K.) resulted in death or the required destruction of 144,941 pigs along with 3.9 million sheep, cattle, goats, and deer (Scudamore et al. 2002).

Despite individual and regulatory biosecurity measures, unintended entry of these or other epidemic swine diseases into a country or geographic region could occur as a result of the general movement of people, animals, or animal products. The potential for entry of an epidemic food-animal disease through an intentional act of bioterrorism also has been raised (Moon et al. 2003). The need for effective, well-organized carcass disposal methods after such catastrophic events is crucial.

The purpose of this CAST Issue Paper is to provide a critical assessment of the body of information available on methods for routine and catastrophic swine mortality disposal. The scope of material considered for this assessment has been broad, but for brevity purposes, the paper is presented as a condensed review. An extensive review of food-animal carcass disposal recently was published by a consortium of experts (NABCC 2004), and readers are encouraged to use this web-based document for more extensive information on individual carcass disposal methods. Exclusion of certain published work from direct citation in this paper does not imply lack of useful and relevant information on this important topic. In developing this review, the authors have focused particularly on the efficiency and effectiveness of swine carcass disposal methods as well as potential animal health and environmental protection considerations.

PREDOMINANT METHODS OF MORTALITY DISPOSAL IN COMMERCIAL SWINE PRODUCTION

Burial: Routine Mortality Disposal

A U.S. Department of Agriculture–Animal and Plant Health Inspection Service (USDA–APHIS) survey (NAHMS 2001) indicated that 37.8% of swine operations in the United States used burial for routine disposal of carcasses of weaned pigs, and that 11.5% of weaned pig mortalities overall were buried (Table 1). In states where rendering services are readily available or mortality com-

Table 1. Disposal methods for swine mortalities[a]

Method of carcass disposal	Preweaning deaths: Farm sites[b]	Preweaning deaths: Carcasses	Postweaning deaths: Farm sites	Postweaning deaths: Carcasses
	Percentage		Percentage	
Burial (on-site)	45.3	15.0	37.8	11.5
Incineration	15.4	14.5	11.6	6.0
Rendering	22.2	53.1	45.5	68.0
Composting	23.2	15.4	18.0	12.7
Other	4.4	2.0	2.5	1.8
Total		100.0		100.0

[a] Source: NAHMS 2001.

[b] Some farm sites use more than one method, so total percentage of farm sites exceeds 100.

posting has been adopted, use of burial is considerably less than the national figures. For example, Iowa is served by five major rendering plants, and 5% of respondents in a 2001 mail survey indicated that they used burial as their sole method of disposal; an additional 20% of survey respondents reported that they used burial in combination with rendering or composting (Schwager et al. 2001). Transport of carcasses to an approved landfill is another means of disposal by burial, but availability of landfill burial will vary with circumstances of farm location and landfill regulations.

On-farm burial of routine mortalities typically is done using the trench method, which involves excavating a narrow and relatively shallow trench with a backhoe, placing a single layer of carcasses in the trench, and covering them with the excavated soil. According to Nutsch and Spire (2004), excavation volumes reported by several authors vary considerably, ranging from 0.9 to 2.3 cubic meters (m) for five mature swine. Traditionally, burial is considered to be a convenient method for routine mortality disposal with minimal environmental impact when used sparingly by relatively small livestock operations.

With widespread growth of concentrated animal feeding operations, however, the potential impacts of routine burial on shallow groundwater resources have become a greater concern. In a comprehensive evaluation of the potential environmental impacts of mortality disposal, Engel and colleagues (2004) concluded that burial had significant potential for impacting water and air quality negatively. Environmental risks listed for burial included contamination of soil and shallow groundwater with N, chloride, and coliform bacteria.

Freedman and Fleming (2003) noted the scarcity of research data on the impacts of livestock burial. They observed that although many U.S. states and Canadian provinces have regulatory guidelines on minimum burial depth, minimum depth to groundwater, minimum distances to wells and watercourses, and maximum burial quantity, there is little evidence that these rules are based on research involving livestock mortalities.

Glanville (2000) took monthly samples of leachate from the base of a 6-m-long trench in which six 14-kilogram (kg) pig carcasses were buried. Although the carcass burial volume was small, the mean biochemical oxygen demand (BOD, a measure of organic pollution), ammonia-nitrogen (NH_4-N), and total dissolved solids (TDS) concentrations in monthly samples collected during the 20-month study were 732 milligrams (mg)/liter (l), 416 mg/l, and 975 mg/l, respectively. These concentrations were much greater than background concentrations in shallow groundwater at the site and would be considered significant pollutants if allowed to percolate into groundwater. Evolution of carcass decay products slowed considerably after 18 months, suggesting minimum carcass decay times of roughly 1.8 years for relatively small swine carcasses.

Burial: Catastrophic Mortality Disposal

Although burial is used commonly for emergency livestock disposal, there are few published accounts detailing its use specifically for emergency disposal of swine. An intensive search by Ehrman and Holl (2004) revealed only three emergency burial cases specific to swine, including (1) burial of swine and other animals in North Carolina after Hurricane Floyd in 1999, (2) a pseudorabies outbreak in Pennsylvania in 2002 that required burial of 15,000 hogs, and (3) burial of 800 hogs in Iowa in 2003 after a swine barn ventilation failure and fire.

With emergency burial, the number of carcasses deposited in a location is greater than for routine burial; therefore, the potential for soil and groundwater pollution is greater as well. Animal carcasses are approximately 2% N by weight. Consequently, single-layer high-density burial can impose exceptionally high N loading rates. Long-term persistence of high concentrations of N near mass burial sites also can be a concern. In a 6-year study, Glanville (2000) monitored shallow groundwater pollution near two burial pits containing approximately 28,000 kg of turkey carcasses resulting from an accidental barn ventilation failure. Mean NH_4-N concentrations in groundwater at the edge of the burial pits were more than 2,000 times the background concentrations in shallow groundwater nearby. In addition, the BOD, TDS, and chloride concentrations were 38, 2, and 12 times the background concentrations, respectively.

The use of modern engineered landfills equipped with leachate collection and treatment facilities can decrease significantly the amount of pollution that moves into groundwater resources. But use of landfills relies on the preplanned cooperation of owners of existing industrial and public landfills, because these types of facilities are difficult to design and construct during an emergency. Such cooperation between landfill operators and animal and human health agencies cannot be taken for granted. For example, during an avian influenza (AI) outbreak in 2004, landfill operators in British Columbia closed their gates to trucks carrying dead poultry after learning that AI is transmissible to humans (Stepushyn 2004).

Similarly, Nutsch and Spire (2004) noted that the available capacity of licensed commercial landfills in the U.K. easily could have accommodated all carcass material disposed during the FMD outbreak in 2001. But opposition by the local public, local authorities, pressure groups, and farmers near the landfill sites greatly limited the use of this disposal method, forcing the British government to construct several very large emergency mass burial sites.

Recognizing that engineered landfills may not be available during certain emergencies, several state and national agencies have begun to develop geographic information systems that permit rapid identification of potential emergency mass burial sites. The combination of topographic, geologic, soil, and water resource databases enables such systems to identify and map burial sites that are least likely to impact environmentally sensitive areas such as flood plains, wetlands, fault zones, shallow groundwater, and public or private water supplies. Similar preplanned sites could be identified by producers and local officials for on-farm burial as part of an emergency preparedness plan.

Incineration: Routine Mortality Disposal

Incineration refers to the burning of material to the point that the resulting end products are heat, gaseous emissions, and residual ash. Kastner and Phebus (2004) have described three broad types of animal carcass incineration: (1) fixed-facility incineration, (2) air-curtain incineration, and (3) open-air burning. Fixed-facility units range from commercial units designed specifically for animal incineration to large incineration plants intended for solid waste disposal. Air-curtain incineration describes a specific incineration process that involves the use of mechanically forced air through a refractory fire box or a constructed earthen trench. Open-air burning refers to simple open burning, usually by constructing a “pyre” with the carcass or carcasses placed on a solid fuel source such as wood or straw. Each type has distinct characteristics that may increase or limit its potential for use as a swine mortality disposal method in specific circumstances.

Fixed-facility incinerators fueled by diesel, natural gas, or propane continue to be recommended as an option for routine mortality disposal on swine farms (Henry, Wills, and Bitney 2001). Advisory publications stress the importance of using a properly engineered unit designed to meet the body size and quantity of routine mortalities experienced on a given farm. Incinerator manufacturers have responded to the need for effective mortality disposal on intensive swine farms by developing livestock incinerators equipped with thermostatic controls and refractive burn chambers that allow for decreased fuel use and more efficient carcass reduction. One-time loading rates for commercial units range from models with a 45-kg capacity to large units with up to a 680-kg capacity.

Modern incineration equipment is designed to reduce carcasses to residual ash. If properly maintained, the equipment requires only moderate amounts of training and labor to operate. Dead stock is loaded into the incinerator, and the controls are set for complete burning according to manufacturer recommendations. Periodic observation, routine maintenance, and clean-out of ash are required. Operational fuel use varies with incinerator design and loading rate. An independent advisory publication estimates 3.8 to 11.4 l of diesel fuel use per 45 kg of mortality (Henry, Wills, and Bitney 2001).

The predominant consideration affecting use of on-farm incineration for mortality disposal on swine farms may be the regulatory requirements. In many states, operation of an on-farm incinerator for livestock mortality disposal requires a permit from the appropriate state environmental agency. This permit may be separate from, and in addition to, any permits required by a swine farm for waste management purposes. In some states, regulations stipulate that permitted mortality incineration equipment must contain a secondary burn chamber or “afterburner” to decrease particulate matter (i.e., “fly ash”) and other emissions. Such additional permit and equipment requirements increase the initial investment and operational costs. The requirements seem to be warranted, however, based on the potential for on-farm incinerator equipment to emit hydrocarbon pollutants and heavy metals associated with fly ash (Chen, Hsieh, and Chiu 2003; Chen et al. 2004).

Neither air-curtain incineration nor open-air burning has high potential for routine mortality disposal on individual swine farms. Air-curtain technology has been developed principally as a means of incinerating large quantities of combustible refuse resulting from land clearing or a disaster such as a hurricane or major flood (Ellis 2001). It seems plausible that the technology could be modified in the future for applications similar to those of fixed-facility units. But current large-capacity and fuel-use characteristics of air-curtain incineration limit its routine use on individual swine farms.

Open-air burning cannot be recommended for routine on-farm mortality disposal for a number of reasons, most notably the potential to generate excess pollutants in the form of smoke and odor, the possibility of creating a public nuisance, the risk of causing unintended fires, and the violation of regulatory restrictions. Most state regulatory agencies do not permit open-air burning for routine disposal of livestock mortality (Henry, Wills and Bitney 2001; Morrow, Ferket, and Middleton 2000).

Incineration: Catastrophic Mortality Disposal

Limited-capacity, fixed-facility incinerators designed for routine on-farm use are not adequate to handle the large-volume disposal needs associated with a catastrophic mortality event. In theory, municipal or industrial solid waste incineration plants have the potential capacity to assist with catastrophic swine carcass disposal. The accessibility of incineration plants for carcass disposal is limited, however, (Ellis 2001) and, in many situations, would require long-distance transportation of carcasses. In the 2001 outbreak of FMD in the Netherlands, incineration was used successfully in combination with rendering as a catastrophic disposal method (de Klerk 2002). In this instance, large numbers of swine and cattle destroyed in the eradication program were first processed at rendering plants, with most resulting meat and bone meal subsequently incinerated at a central plant.

The characteristic feature of air-curtain incineration is that a high-velocity “curtain” of air is fan-driven through a manifold system over the burn chamber of an aboveground firebox or in a constructed earthen burn trench. The air curtain serves to contain smoke and particulate matter in the burn zone and provides greater airflow for hotter temperatures and more complete combustion. Use of an air-curtain incineration system to dispose of swine carcasses after euthanasia of several small herds for brucellosis eradication has been reported (Ford 1994). The number of carcasses incinerated in the test was modest by catastrophic standards (504 swine weighing 41,300 kg in total), but the potential for larger volume disposal was demonstrated. Air-curtain incineration also was used to a limited degree for carcass disposal during the 2001 FMD outbreak in the U.K. (Scudamore et al. 2002) and for dead poultry disposal in Virginia after an AI outbreak in 2002 (Brglez 2003).

From these and other reports it may be concluded that air-curtain incineration can play a contributory role in catastrophic swine carcass disposal if adequate equipment, trained operators, and fuel in the form of pallets, dry wood debris, or other dry wood sources are available. Carcass disposal with air-curtain incineration is a fuel-intensive process (primarily wood and diesel fuel), but its use may be warranted in situations in which strategically located incineration is necessary for biosecurity purposes (Ellis 2001).

It has been suggested that in disaster circumstances, state restrictions on open-air burning might be waived (Ellis 2001). Even in catastrophic circumstances, open-air burning is an unfavorable choice for swine mortality disposal, for several significant reasons (Kastner and Phebus 2004). Disadvantages include labor and fuel intensity, dependence on favorable weather conditions, potential for environmental pollution, public nuisance, and negative public perception. These factors led to the discontinuance of open-air burning of large carcass pyres during the 2001 FMD outbreak in the U.K. (Scudamore et al. 2002).

Rendering: Routine Mortality Disposal

Rendering has long been a viable option for disposal of by-products from food-animal processing as well as farm animal mortalities, and the resulting animal fat and protein products derived from the process are valuable ingredients for animal feeds and other uses. The North American rendering industry processes approximately 26.7 billion kg of raw material annually, with dead stock representing nearly 5% of this total (1.3 billion kg) (Meeker 2006).

In 2002, it was estimated that approximately 299 million kg of swine mortality was being processed by rendering each year (Sparks 2002). Shortly thereafter, Hamilton (2004) estimated that swine mortality in the United States totaled approximately 445 million kg annually, indicating that rendering was accommodating the disposal of approximately 67% of typical swine mortality produced. This assessment is in general agreement with survey data taken by the USDA–APHIS in 2000 indicating that 53% of preweaning swine death losses and 68% of postweaning swine death losses were being disposed of by rendering (Table 1; NAHMS 2001).

Rendering is a process of both physical and chemical transformation using a variety of specialized equipment at centralized rendering plants (Hamilton 2004). All rendering processes involve the application of heat, the extraction of moisture, and the separation of fat. Rendering system technologies include the collection and sanitary transport of raw material to a facility where it is ground into a consistent particle size and conveyed to a cooking vessel using either continuous-flow or batch configuration. Cooking generally is accomplished with steam at temperatures of 115 to 145ºC for 40 to 90 minutes, depending on the type of system and materials. The melted fat is separated from the protein and bone solids, and a large portion of the moisture is removed. As an industry, rendering is regulated closely by state and federal agencies, both of which routinely inspect rendering plants for compliance to applicable regulations and finished product safety tolerances. (For a detailed overview of rendering processes, see Anderson [2006]).

Clearly, rendering is established as a viable means of disposal and transformation of routine swine mortality, but interrelated developments are altering the general availability of this method to some commercial swine farms. Rendering is a manufacturing business and, as such, is dependent on reliable sources of raw materials and production of marketable products to finance the system. Independent plants are those not directly associated with food-animal processing plants, and they obtain raw materials for processing from various sources including dead stock from livestock and poultry operations. Integrated or dependent plants are those that operate in conjunction with meat processing plants and use animal by-products from the processing plant as the principal source of raw processing material (Auvermann, Kalbasi, and Ahmed 2004).

The overall number of rendering plants in the United States has declined, and there has been a shift toward greater overall production of rendered end product (meat and bone meal and fat products) from integrated renderers (Bisplinghoff 2006). Although overall rendering capacity on a national basis seems adequate to handle routine swine mortality needs, strategic access to a plant or routine renderer truck routes may not be available to all farms.

Related factors include a 1997 ruling by the U.S. Food and Drug Administration (FDA) and alterations in the use and value of rendered product feed ingredients, particularly meat and bone meal. The FDA action was taken to assure that bovine spongiform encephalopathy (BSE) would not occur in the United States as it had in the U.K. in the 1980s. The ruling is based on evidence that BSE cases in the U.K. could be traced to transmission of infectious proteins (prions) in ruminant-derived meat and bone meal that had been fed to cattle (Dormont 2002; UKDEFRA 2000). There is no evidence that production and feeding of meat and bone meal from pigs or other nonruminant animals poses any risk of transfer of BSE or other types of transmissible spongiform encephalopathy (TSE). Furthermore, the FDA ruling prohibits use of rendered meat and bone meal of ruminant origin for feeds intended for ruminant animals and does not apply to feeding or production of meat and bone meal as related to nonruminant animals such as swine. Nevertheless, the proportion of U.S. feed mills using meat and bone meal and the overall value of meat and bone meal as an animal feed ingredient has declined since the FDA ruling (Hamilton 2004). Indirectly, these developments may hinder availability of rendering for swine mortality disposal for some farms.

Rendering: Catastrophic Mortality Disposal

Advantages associated with rendering for disposal of routine swine mortality also could apply to catastrophic disposal situations: namely, rendering is closely regulated to be environmentally safe; the end product is considered biosecure; and, in instances where the end product is marketable, rendering allows for process cost recovery. Limitations for the use of rendering in catastrophic losses seem most likely to be related to logistical concerns that are unique and inherent to large numbers of swine deaths within a compressed time frame. For example, if a disaster such as a hurricane or flood causes large swine losses on farms within a region, the processing capacity of rendering facilities in the region might be overwhelmed—even if the plants remained fully functional—unless carcasses could be preserved by refrigeration or other means. In instances where large numbers of swine die or require euthanasia in the wake of an epidemic disease outbreak, the risk of further spread of the disease to other farms and regions should be considered when transporting carcasses to distant rendering locations (Ellis 2001).

Indications of the role of rendering for disposal of catastrophic swine losses may be found in part from recent documented cases in Asia and Europe. During the 1997 FMD outbreak in Taiwan, controlling the disease depended on an intensive vaccination program along with euthanasia of 3.85 million pigs from infected farms. Including pigs that died of the disease, disposal needs during the 4-month epidemic reached 4.18 million. Veterinary and government officials selected carcass disposal methods based on availability of public and private landfill sites, incinerators and rendering facilities, water table considerations, and residential locations. In these catastrophic conditions, rendering was used to dispose of 15% of the carcasses, accounting for 26.1% of total disposal cost. By comparison, burial and landfill were used for 80% of the carcasses, representing 32.5% of total disposal cost, and incineration was used for 5% of carcass disposal, representing 41.4% of total disposal cost (Yang et al. 1999).

During the 2001 FMD outbreak in the U.K., rendering and fixed-facility incineration within the affected region were identified as preferred methods, but even when fully used, these methods could not meet the intensive disposal needs during the epidemic. Despite concerns about impacts to groundwater, on-farm carcass burial had to be used to bring the epidemic under control (Scudamore et al. 2002).

Limited rendering capacity also was an issue in the 2001 FMD epidemic in the Netherlands. Dutch officials dealt with the problem by implementing a strategic vaccination program and transporting animals to slaughterhouses to be killed. This action allowed carcasses to be frozen in cold-storage facilities and rendered later as capacity became available (de Klerk 2002). The rendered product was subsequently incinerated at a fixed-facility incineration plant. In each of these cases, an exceptional level of public and private collaboration was essential to overcome the carcass disposal problems, and rendering was used to the degree that was logistically feasible.

Composting: Routine Mortality Disposal

Composting is a natural biological process of decomposition of organic materials in a predominantly aerobic environment. During the process, bacteria, fungi, and other microorganisms break down organic materials into a stable mixture called compost while consuming oxygen and releasing heat, water, carbon dioxide (CO_2) and other gases (Keener, Elwell, and Monnin 2000). The use of composting for disposal of routine swine mortalities was first reported in livestock industry and university extension publications in the mid-1990s after widespread adoption of mortality composting in the poultry industry (Fulhage 1994; Henry 1995; Morrow and Ferket 1993; Morrow et al. 1995). Since that time, use of composting for disposal of routine swine mortalities has grown (NAHMS 2001; Schwager et al. 2001).

Reports indicate that many U.S. states and Canadian provinces permit the use of composting for disposal of routine mortalities, but policies governing mortality composting vary considerably. Iowa, for example, permits composting of any size or species of livestock or poultry without obtaining a special solid waste disposal permit, as long as the animals are disposed of on property belonging to the livestock owner. In contrast, California permits composting of poultry carcasses, but prohibits composting of mammalian tissues (Higginbotham, G. E. 2006. Personal communication). Some states, such as Georgia, require producers to obtain a permit from the State Department of Agriculture (Sander, Warbington, and Myers 2002), whereas other states impose carcass size restrictions (Ehrman and Holl 2004; Nebraska 2003). As with most agricultural practices, state regulatory policy will influence the adoption and use of composting as a swine mortality disposal method.

Four variables are considered critical to successful composting: (1) moisture content (40 to 60%), (2) temperature (45 to 60ºC), (3) oxygen concentration (10% desirable level), and (4) C:N ratio (20:1 to 30:1 desirable range) (Chiumenti et al. 2005; Haug 1993; Rynk et al. 1992). Temperatures of at least 55ºC generally are needed to kill pathogens; destruction of weed seeds that can make finished compost undesirable for agronomic purposes generally requires temperatures of at least 60ºC.

To control costs, farm mortality composting operations typically use static-pile techniques that do not involve specialized mixing, grinding, turning, aeration, and screening equipment often used in industrial composting. In its simplest form, on-farm mortality composting may be considered a managed process of placing dead stock in a mound of carbonaceous material followed by decomposition of carcass tissues resulting from aerobic action of microorganisms (Mukhtar, Kalbasi, and Ahmed 2004). Carcasses within a compost matrix are characterized by high moisture, low C:N ratios (excess N), and no porosity, whereas the layers of plant material surrounding them have relatively low moisture, high C:N ratios (low N), and sufficient porosity.

Carcass degradation is initiated by naturally occurring anaerobic bacteria within the carcass and aerobic bacteria at the outer surfaces. Odorous gases and liquids diffuse into drier and more aerobic plant materials where they are ingested by microorganisms and degraded into simpler organic compounds and ultimately to CO_2 and water (Keener, Elwell, and Monnin 2000).

The success of static-pile mortality composting relies on careful construction of a layered pile using appropriate quantities of plant-based cover materials below, between, and above the carcasses. Characteristics of effective cover materials include sufficient water-holding capacity, gas permeability or porosity, biodegradability, wet mechanical strength, and adequate available C. These physical characteristics determine the ability of cover materials to absorb excess liquids, prevent release of leachate and odor, produce and retain heat, and permit entry of sufficient oxygen for microbial activity (Harper and Estienne 2003; King, Seekins, and Hutchison 2005).

A variety of plant-based residues have been used as cover materials. The selection includes sawdust, wood shavings, wood chips, ground cornstalks, ground straw or hay, oat hulls, peanut hulls, poultry litter, used livestock bedding, dry manure, green waste, and ground-up shipping pallets (Glanville et al. 2006; Keener, Elwell, and Monnin 2000; Mukhtar, Kalbasi, and Ahmed 2004).

Guidelines for routine on-farm swine mortality composting have been presented in several instructional publications (Fulhage 1994; Glanville 2002; Harper and Estienne 2003; Keener, Elwell and Monnin 2000; Langston et al. 1997). These publications typically describe a static-pile, passively ventilated composting process using primary, secondary, and storage or curing phases. Early definitions of these phases were based on the observation that initial carcass decomposition was accompanied by moistening, weakening, and compaction of the cover materials, leading to decreased diffusion of oxygen into the pile and declining temperatures and decomposition rates.

At this stage, it became necessary to turn the pile to break up wet zones and to introduce more oxygen and moisture, if needed, to reactivate aerobic microbial activity and stimulate a "secondary" cycle of heat production. After the secondary heating cycle finished, soft tissue decomposition generally was complete and the compost was sufficiently stable to be stockpiled before land application. Based on a review of composting studies published by several authors, Keener, Elwell, and Monnin (2000) concluded that decomposition times largely are a function of carcass mass, and they published weight-based prediction equations for the duration of the primary and secondary phases of composting.

In practice, most swine mortality compost is turned only once or twice. Turning speeds carcass decay, but research has shown that turning is not essential if the C material used to cover the carcasses is sufficiently permeable for oxygen diffusion into the pile (Glanville et al. 2006). Another means used to accelerate carcass decomposition involves partitioning or opening of large carcasses to expose more surface area (Sander, Warbington, and Myers 2002). But Murphy and colleagues (2004) commented that opening of large carcasses could increase personnel injury risks and exposure to pathogens that may not be justified by small decreases in decomposition time. Grinding whole carcasses and carbonaceous bulking materials before composting has been reported to decrease decomposition times by 30 to 60% and to decrease the amount of carbonaceous materials needed by a factor of approximately 16 (Colorado 2003).

Static-pile swine mortality composting usually is performed in constructed bins or open windrow piles. Bins confine the compost ingredients, allowing stacking to a depth of approximately 1.5 m. Three-sided bins are typical, with the open end allowing access for placement, turning, and removal of compost components using a tractor or skid loader. Temporary low-cost bins have been constructed using large straw bales (Fulhage 1994). Permanent roofed structures are constructed with treated lumber or concrete and usually are built on a concrete platform to provide a firm, all-weather working surface. Roofed structures may require more frequent water application to maintain proper moisture, because contact with rainwater is blocked.

Windrow composting involves construction of long, narrow piles having a parabolic or trapezoidal cross section. Because of their shape, windrows have a large exposed surface area that encourages passive aeration and drying (Mukhtar, Kalbasi, and Ahmed 2004). Because windrow dimensions are not constrained by walls, their dimensions can be adapted to any size and number of carcasses, making them particularly useful for large carcasses.

Although windrows do not require construction of a structure to contain the compost, a low-permeability base is recommended to prevent leachate contamination of underlying soil. A windrow pad consisting of concrete or asphalt, a plastic or geo-textile fabric-lined gravel base, or compacted soil generally is recommended (Keener, Elwell, and Monnin 2000).

Pile proportions are important in windrow composting because pile dimensions affect oxygen entry, moisture retention, and pile stability. For optimal performance, Mukhtar, Kalbasi, and Ahmed (2004) recommended a maximum windrow base width of approximately 3.9 m and a pile height of 1.8 m for medium-sized carcasses (sheep and young swine), and a 4.5-m base width and 2.1-m pile height for larger animals, up to and including mature swine.

The total volume of primary composting capacity needed for routine swine mortality management depends on the type, size, and mortality rate of the swine operation. Based on early experience with composting swine mortalities, Fulhage (1994) recommended 0.567 cubic m of primary bin capacity for every 0.45 kg of average daily mortality, and an equal amount of secondary bin volume. Keener, Elwell, and Monnin (2000) assimilated information from numerous reports on mortality composting and developed prediction equations for sizing of bins or piles. Other practical considerations such as efficient use of available loading equipment also factor into pile or bin size determinations.

Two types of mechanical in-vessel composting methods also have been reported. The benefit of these technologies is that they can provide improved control of moisture, aeration, and C:N ratios, thereby increasing microbial activity and decreasing carcass decomposition times.

Included in the mechanical technologies are aerated synthetic tube systems. With this method, the materials to be composted are blown into a 1.52- to 3.05-m-diameter plastic tube that can be as long as 61 m. Aeration of the composting process is accomplished with mechanical blowers that force air through distribution pipes and ventilation ports installed inside the tube at the time it is filled (Mukhtar, Kalbasi, and Ahmed 2004). Other in-vessel methods include rotary drum composting systems, in which a mixture of carcasses and bulking materials is tumbled on a frequent schedule to introduce oxygen, or the breaking up and mixing of wet and dry materials to achieve more microbial activity. To date, both of these technologies mainly have been used for disposal of poultry carcasses, but either method would seem to be applicable for disposal of small swine carcasses originating in farrowing or nursery operations.

Use of in-vessel technologies for larger carcasses has been hindered mainly by size limitations of the equipment and by difficulties in mechanically aerating heterogeneous mixtures containing large intact carcasses. A more successful means of using in-vessel composting technology with large carcasses has been to grind the carcasses along with a bulking material before placing them into the vessel. Rynk (2003) reported that carcass degradation time was decreased to 75 days for large carcasses that had been simultaneously ground and mixed with a C source and subsequently processed in a rotating drum composter. This method required only about one-fourth of the composting material needed for bin or windrow composting.

Composting: Catastrophic Mortality Disposal

State agency records of mass carcass disposal events have been characterized as “at best fragmentary and incomplete” (Ehrman and Holl 2004). Consequently, detailed information on using composting for catastrophic mortality disposal is sparse, and the most well-documented incidents have occurred in the poultry industry. In 2003, Iowa Department of Natural Resources staff reported use of windrow composting with wood chip cover material for disposal of a large number of swine carcasses resulting from a barn fire (Peccia, J. 2003. Personal communication). And in 2005, approximately 150 mature cattle in Iowa were composted in cornstalks after a poisoning incident (Olson, D. 2006. Personal communication).

Although there are few well-documented incidents of emergency composting of large species, several factors suggest that it should be considered and studied in more detail. The most obvious factor is that composting already is used widely for routine swine mortality disposal. Therefore, many swine producers are familiar with the fundamentals of composting and own the necessary equipment, thereby improving the likelihood that producers can implement composting procedures quickly and effectively during an emergency.

Public concern regarding the potential impacts of burial on groundwater quality also has increased interest in composting, because composting allows contaminated organics to be biologically stabilized and disposed of aboveground. Leachate from large-animal compost windrows can cause shallow soil contamination when carried out on uncompacted soil, but recent research has shown that the risks to groundwater from emergency composting are lower than those posed by burial, which places a much heavier contaminant load into the soil and at depths closer to groundwater (Glanville et al. 2006).

Bin composting systems designed for routine swine mortality disposal are not large enough to handle catastrophic losses. If sufficient amounts of cover material are available, however, windrow composting operations can be expanded and therefore have greater potential to be adapted for emergency disposal of large numbers of mortalities. In some situations, in-vessel composting systems also may be expanded to handle large quantities of compost.

Other than calling for a degree of emergency preparedness that facilitates a sudden increase in composting capacity, non-disease-related catastrophic losses are quite similar to routine mortalities and can be handled using routine windrow composting techniques. Disease-related death losses, however, pose increased biosecurity risks. Dealing with this type of incident calls for use of construction and operating procedures that maximize the likelihood of pathogen retention and inactivation. Examples include use of highly biodegradable cover materials that produce large amounts of pathogen-killing heat, use of plastic biosecurity sheeting or thicker layers of envelope material over the composting operation to help ensure retention of pathogens before their inactivation, delaying and decreasing compost turning to minimize pathogen release, and implementation of a comprehensive temperature-monitoring and compost-sampling program to document pathogen inactivation.

ALTERNATIVE AND NON-TRADITIONAL METHODS AND TECHNOLOGIES

Stabilizing and Extended Storage

Fermentation, acid preservation, and refrigeration or freezing of swine mortalities provide means for storing, stabilizing, and potentially decreasing pathogens. Although these methods will not decompose or dispose of mortalities, they can provide short-term storage before traditional rendering. The majority of available research data has used poultry mortalities for determining efficacy of these methods, but similar methods and outcomes could be expected when applying these technologies to swine mortalities. Although implementing one of these technologies for large-scale operations may not be practical, smaller operations may benefit from storing carcasses to minimize removal charges from a single pick-up by a rendering service.

Fermentation

Fermentation is an anaerobic process that can occur in any sealable, noncorrosive container, provided it is vented to release the CO2 produced (Parsons and Ferket 1990). To obtain more uniform and effective fermentation of mortalities, carcasses need to be ground to 2.5-centimeter (cm) or smaller particles and be mixed with a fermentable carbohydrate source (lactose, glucose, sucrose, whey, whey permeate, molasses, or ground corn) and inoculated with a bacterial culture (Erickson et al. 2004). Carbohydrate sources and ground carcasses should be added in a 1:5 ratio by weight (Erickson et al. 2004). The source of inoculant generally is *Lactobacillus acidophilus*, a strain of bacteria that produces lactic acid from fermentation of sugars.

These conditions will allow for a decrease in pH of fresh tissue from approximately 6.5 to less than 4.5 within 48 hours. Also, the temperature of the fermentation material should be above 30°C to obtain a biologically safe product with a pH less than 4.5 (Tamim and Doerr 2000).

Acid Preservation

Acid preservation of mortalities through the inclusion of inorganic acids such as sulfuric acid (Malone 1988) or phosphoric acid (Middleton and Ferket 2001; Middleton, Ferket, and Boyd 2001) has proved effective. Because of safety concerns with handling sulfuric acid stock solution, however, use of phosphoric acid may be more practical (Morrow and Ferket 2001). Effective carcass preservation involves grinding carcasses to allow for even distribution of acid and requires a corrosion-resistant storage structure capable of handling the desired quantity of mortalities before delivery to a rendering facility.

Refrigeration or Freezing

For some producers, the ability simply to store swine mortalities until enough are accumulated for a standard pick-up from a rendering facility is beneficial. Although cooling or freezing carcasses may have little implication for decreasing pathogens, these methods can be effective in extending the storage time while eliminating or minimizing the decomposition process. To justify this practice at the farm level, the cost savings of less-frequent renderer pick-up costs would need to be greater than equipment and utility expenses of the storage system.

Alkaline Hydrolysis

Alkaline hydrolysis is a process in which biological materials (i.e., protein, nucleic acids, carbohydrates, lipids) are converted into a sterile aqueous solution consisting of small peptides, amino acids, sugars, and soaps (Thacker 2004). The process typically relies on alkaline metal hydroxides such as sodium or potassium hydroxide for hydrolysis, and the process can be accelerated by the application of heat (150º C) (Thacker 2004). The aqueous solution typically can be released into a sanitary sewer system; the only solids produced are minerals from bones and teeth (Shearer 2006).

Alkaline hydrolysis has proved effective in destroying a wide range of potentially infectious agents from various livestock mortalities, including swine (Kaye et al. 1998). The alkaline hydrolysis process destroys pathogenic organisms listed by the U.S. State and Territorial Association on Alternative Treatment Technologies, and the process can digest carcass material effectively in 3 to 8 hours (Thacker 2004). For bacterial- and viral-contaminated waste, 4 hours generally is sufficient, but material potentially infected with a TSE agent requires 6 hours (European Commission 2003).

Lack of available alkaline hydrolysis units for disposal of swine carcasses is a current limitation. Although this process is very effective in destroying pathogens and producing a limited amount of final waste, more operating units are needed to handle large volumes of mortalities.

Anaerobic Digestion

Anaerobic digestion involves the transformation of organic matter by a mixed-culture bacterial ecosystem without oxygen (Erickson et al. 2004). Heat, CO_2, and methane are generated from this process. The technology for anaerobic digestion is complicated and requires substantial investment in equipment. Although many different types of anaerobic digestive systems are available, the systems are used almost exclusively for processing animal waste, not animal mortalities. Systems can be designed and managed, however, to dispose of carcasses effectively.

Anaerobic digestion can serve as an effective means to decrease pathogen levels in mortalities. Destruction of bacteria and viruses is effective during the digestion process and is accelerated with increased heat (Couturier and Galtier 2000a, b). Depending on the organisms desired for digestion and destruction of pathogens, temperature can be altered. In mesophilic or moderate-temperature digestion, the digester is heated to 35ºC with a retention time of 15 to 20 days. In thermophilic or high-temperature digestion, the digester is heated to 55ºC with a retention time of 12 to 14 days (Vandeviviere, De Baere, and Verstraete 2002).

Anaerobic digestion of carcasses would be best suited for large-scale operations because of construction and overall management costs. This process is more typical for processing waste, and little is known about the implementation and effectiveness for large-animal carcasses.

Gasification

Commercial gasification units have been tested for manure and swine mortality disposal (van Kempen 2004). The gasification process for mortality disposal has similarities to incineration in that carcasses are reduced to ash through a confined high-temperature burn process. But with gasification technology, the biological material heated within the chamber generates carbon monoxide and hydrogen, or “synthesis gas,” which in turn fuels further combustion of the original material. Properly operated, the process is more fuel efficient and produces less air emission than traditional incineration equipment. Commercial adoption has been limited, however, perhaps because of high initial start-up costs.

Homogenization

For routine disposal of piglet mortalities, producers can grind or homogenize the carcasses and dispose of them in the existing manure system. Johnston and colleagues (1997) reported that this process seems to have little potential to increase the rate of solid accumulation in waste storage structures or to promote widespread distribution of pig pathogens in the environment.

BIOSECURITY AND DISEASE CONTROL WITH TRADITIONAL METHODS

The risk of disease transmission associated with various methods of swine mortality disposal has not been studied extensively. As individual farms have become larger in size, however, disease risk associated with mortality disposal is a major concern for swine herds as well as for human populations. Lacking scientific studies, investigators have developed and used risk assessments. In some instances, the only available data come from other food-animal species, but the data may be extrapolated to swine mortality procedures to assure biosecurity and disease control. Specifically, risk assessments require information on (1) infectivity of the mortality-processing waste material, (2) likely dispersion of waste material, and (3) infective dose needed to cause disease in healthy pigs or their human caretakers.

The potential for spread of disease through carcass disposal should be considered differently when the disease is caused by an enzootic (local) organism than when it is caused by an exotic foreign animal disease agent. Enzootic disease agents include bacterial, viral, and parasitic agents routinely present at low levels within the herd. These agents occasionally may overwhelm an animal’s immune system, causing disease and, in severe instances, death. In the course of ordinary events there is a normal concentration of an enzootic pathogen on the farm that can be shed into the air, water, or ground on or surrounding the farm. These possible routes of entry to other farms are dealt with by routine biosecurity measures (siting distance, disinfection procedures, visitation and quarantine regulations, etc.).

Compared with the shedding stage during early infection, the amount of infectious agent released from an animal after its death is decreased greatly. The temperature of the carcass moves out of the optimal range for pathogen replication, and rigor mortis causes the pH in muscle tissue to decline, which inactivates many viruses (Gloster et al. 2001).

Regardless of the method of carcass disposal, the quantity of infectious agents released from a dead animal is dramatically less compared with that shed from the operating farm. Therefore, assuming reasonable biosecurity measures are taken, the risk of disease spread from enzootic farm disease mortalities is less than the risk associated with swine mortalities resulting from exotic foreign animal disease agents—situations in which the escape of one or only a few infectious organisms can cause new introduction of disease to a farm.

Burial

In states that permit burial of dead livestock, regulations typically dictate how close a burial pit can be to wells, water lines, the seasonal high water table, embankment edges, and surface water (Sander, Warbington, and Myers 2002). One study indicated that more than 70% of groundwater samples taken around six dead poultry disposal pits were free from fecal coliform or *Streptococci* bacteria (Ritter and Chirnside 1995). The authors concluded that a properly sited broiler mortality disposal pit should not cause any more groundwater contamination than an individual septic tank and soil absorption bed.

In contrast, Davies and Wray (1996) reported that buried mortality from cattle experimentally infected with the pathogenic agents *Salmonella typhimurium, S. enteritidis, Bacillus cereus*, and *Clostridium perfringens* caused extensive contamination in the soil and a nearby drainage ditch within 1 week of burial. Furthermore, the organisms used to infect the cattle continued to be isolated from the site for another 15 weeks. Burial also is not satisfactory for disposal of animals killed by anthrax, a bacterial disease (*Bacillus anthracis*) that can infect most domestic animals including swine. Anthrax spores can migrate to the soil surface after a soil disruption such as plowing, but the spores also may reach the surface even without any mechanical disturbance (Turnbull 2001).

Incineration

In general, complete incineration destroys all bacteria and viruses, and even persistent spores such as those from *B. anthracis* are destroyed by the burning process. Yet during the 2001 FMD epidemic in the U.K., there was concern that open-pyre burning of infected carcasses might spread the disease. A report by Gloster and colleagues (2001) indicated that FMD virus contained in an animal's respiratory tract can be expelled during incineration, and virus may be viable at the start of the open-pyre burning process. But a subsequent study showed that none of the FMD spread throughout the area during this epidemic could be attributed to the spread of virus from open pyres (Champion et al. 2002).

Rendering

The elevated temperature and time conditions associated with the cooking process of rendering (115 to 145°C for 40 to 90 minutes) (Hamilton 2004) are considered sufficient for destruction of pathogenic microorganisms (Franco 2002). In addition, the sterilizing effect of rendering has been demonstrated on *C. perfringens* (Thiemann and Willinger 1980) and other potentially pathogenic bacteria (Troutt et al. 2001).

The fact that rendering does not cause complete destruction of resistant prion proteins associated with transmissible encephalopathies such as BSE does not seem to pose a risk associated with production of rendered product from swine mortality, because porcine-derived material was excluded from the 1997 FDA ruling on meat and bone meal. Furthermore, experimental transmission of BSE could not be produced by feeding BSE-infected material to pigs (Wells et al. 2003).

After rendering, however, the potential for recontamination of carcass meals with potentially pathogenic organisms such as *Salmonella* species has been documented (Bisping et al. 1981). Safeguards to prevent such recontamination include implementation of good manufacturing practices by renderers and routine inspection by state feed control officials.

From a practical standpoint, the movement of swine mortality from farms to rendering facilities raises concerns for biosecurity and disease transfer risk. But intensively managed farms typically use certain practices to minimize this risk. For example, farm employees may place routine mortalities in steel boxes at a security fence along the outer perimeter of the farm, and scheduled renderer pick-up with specialized trucks can occur without actual entry onto the farm premises. In heavy swine concentration areas, it may be possible for multisite swine operations to contract with, or independently operate, dedicated collection vehicles for transport to rendering.

For each unique situation, it is important that producers and animal and public health professionals make critical assessments of disease transfer risk associated with transport of carcasses to a rendering facility under routine or catastrophic situations and determine the most biosecure approach. In some instances, physical or chemical pretreatment before rendering has been used to enhance biosecurity. For example, during the 2001 FMD outbreak in the Netherlands, freezing of carcasses at slaughterhouses before rendering not only solved a rendering capacity issue but also decreased disease transfer risk (de Klerk 2002). Pretreatment of animal tissue waste by fermentation using lactic acid or *Lactobacillus acidophilus* has been shown to destroy bacterial and viral pathogens and offers another potential method to preserve mortalities and enhance biosecurity before rendering (Deshmukh and Patterson 1997; Gilbert et al. 1983).

Composting

Temperature and temperature duration are important factors in destruction of potential pathogens. It has been proposed that a temperature of 54°C for 3 days, typical in mortality compost piles, should kill all pathogens except spores and prions (Sander, Warbington, and Myers 2002). But there is only limited research on the survival of potential livestock pathogens in mortality composting systems.

Recovery of three common swine pathogens was examined after composting in a two-part study. In part one, composted pigs that had been experimentally infected 7 days earlier were negative for *Actinobacillus pleuropneumoniae* and pseudorabies virus. In part two, *Salmonella choleraesuis* was recovered from samples collected on composting days 0, 1, and 3, but not from samples collected on days 7 or 10 (Garcia-Siera et al. 2001). Another study incorporated culture tubes of bacterial pathogens including *Salmonella* species and *Erysipelothrix rhusiopathiae* along with vials or biohazard bags containing pseudorabies virus in a swine compost pile. At day 127, the *Erysipelothrix* and pseudorabies agents were destroyed, and 9 of 15 *Salmonella* cultures were negative (Morrow et al. 1995).

Similar microbiological studies involving poultry mortality composting support the limited findings seen in swine. In general, the organisms responsible for routine mortalities on poultry farms are destroyed by the composting process (Connor, Blake, and Donald 1991; Murphy 1990; Senne, Panigrahy, and Morgan 1994).

Available information indicates that on-farm composting for routine swine mortality disposal can be performed in a biosecure manner with minimal disease transfer risk. Successful use of composting during catastrophic disease emergencies in the poultry industry suggests similar use in the swine industry as well. Some important considerations and questions remain, however. For example, it is recommended that emergency composting of diseased poultry carcasses be performed within poultry houses (Tablante et al. 2002) to decrease the likelihood of windborne or vector-borne transport of pathogens. But penning and other equipment in confinement swine barns restrict the potential for in-house mortality composting for catastrophic disease losses on swine farms.

There also may be concerns associated with regrowth of pathogens as the physical and biochemical conditions in compost change. For example, Hussong, Burge, and Enkiri (1985) found that absence of competing flora permitted rapid regrowth of *Salmonella* in biosolids compost, and Soares and colleagues (1995) found that although very dry compost seemed to be low in pathogens, on rewetting it was able to support repopulation of *Escherichia coli.* Given that experiential and controlled research information is limited, the biosecurity risk associated with the use of composting for swine carcass disposal in response to a catastrophic or foreign animal disease event is relatively unknown.

CONCLUSIONS AND FUTURE CONSIDERATIONS

On-site burial, incineration, transport to rendering facilities, and on-site composting are established swine mortality disposal methods, and each has potential strengths and limitations. The fact that burial has a relatively high potential for groundwater pollution, however, makes it a less sustainable method, especially on large, more intensive farms. Likewise, incineration should be performed only with properly designed incineration equipment, because open-air burning has high potential for pollution and public discontent.

Incineration, rendering, and composting can be safe and effective means of swine mortality disposal, although the method or methods chosen for any given farm will depend on farm circumstances, regulatory requirements, operational costs, and producer preference. Alternative technologies such as alkaline hydrolysis and anaerobic digestion have shown promise as well, but research and development are needed to make these technologies more applicable on a wider scale.

Past experiences of epidemic disease outbreaks in Taiwan and Europe indicate that use of several disposal methods in combination may be required to deal with catastrophic mortality disposal. In some instances there is inadequate research or experiential information to determine the safety or biosecurity of certain methods, particularly if the catastrophic loss is associated with entry of a high-risk foreign animal disease. More research related to this aspect of catastrophic disposal is needed.

In the event of a catastrophic loss within a locality or region, a rapid coordinated response involving animal health, public health, sanitation, and environmental agencies, along with segments of the private sector such as renderers and commercial landfill operators, is critical. Advanced planning for mass mortality disposal among these agencies, swine producers, and industry should be implemented as part of an emergency preparedness plan.

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