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Contributors:
*Lori **Miller**, United States Department of Agriculture (USDA);*
*Gary **Flory**, Virginia Department of Environmental Quality*

Carcass management for small- and medium-scale livestock farms

Practical considerations

Introduction

Background

In the event of an animal disease outbreak, such as highly pathogenic avian influenza, foot and mouth disease, African Swine Fever, or Lumpy Skin Disease, many animals will die of the disease or may be sacrificed to prevent pathogen spread. The carcasses will then require immediate safe management. Carcass management options include onsite composting, burial or burning, as well as offsite landfill, incineration or rendering, if those technologies are readily available.

Based on local experiences during recent animal disease outbreak responses, carcass management can be very challenging. There may be significant biosecurity and environmental risks from carcass management techniques, depending on how they are implemented. For example, storage of carcasses prior to disposal can risk spread of pathogens through several routes, such as attracting flies; liquids may leach to ground and surface water during storage and burial; burning may produce hazardous air emissions; and improperly constructed compost piles may not inactivate pathogens.

Effective carcass management achieves two primary goals: 1) to contain pathogens to prevent further spread of disease to animals and humans; and 2) to protect drinking water, air and soil. Both of these goals relate to human, animal and ecosystem health, which are part of the One Health concept.

One Health is a mechanism to address threats and reduce risks of infectious diseases at the animal-human-ecosystem interface. Key aspects of One Health include surveillance and disease intelligence at the three health domains, effective biosecurity during infectious disease outbreaks, and other important aspects. Effective carcass management directly supports these aspects and will be discussed in more detail throughout this article.

Carcass management can be performed onsite or offsite by a variety of methods; the selected method depends on the specific site conditions, including locally available resources and type and size of operation. ●

Scope

The focus of this article is on small- to medium-sized operations (up to 5,000 poultry, 128 pigs or 25 cattle, totaling about 11 metric tons of material). However, it should be noted that different considerations, beyond the scope of the current document, must be taken into account for large commercial production operations greater than 5,000 poultry, 128 pigs or 25 cattle. The response is assumed to be stamping out, where all susceptible animals on the farm are destroyed and their remains are disposed of, or a situation where animals died from the pathogen. This article does not address consumption of protein by humans. It is further assumed that access to engineered landfills, controlled incineration and rendering is limited. Therefore, this article will focus solely on burial (traditional deep burial and innovative above-ground burial), open-burning in pyres, and composting. ●

Approaches to Carcass Management

Selecting Site-specific Disposal Options

Ideally, every farm should have a plan for how they would manage carcasses in case of an outbreak. The plan should provide details of how to implement all the disposal options that apply to the specific site and situation to facilitate flexibility for carcass management. The responders may choose to use one or more of the different disposal methods, depending on the circumstances. Detailed information about advantages, disadvantages, applicability, cost factors and other considerations for each disposal option are presented in subsequent sections of this article. A section comparing the options follows the detailed discussion of each disposal option. ●

Description of Disposal Options

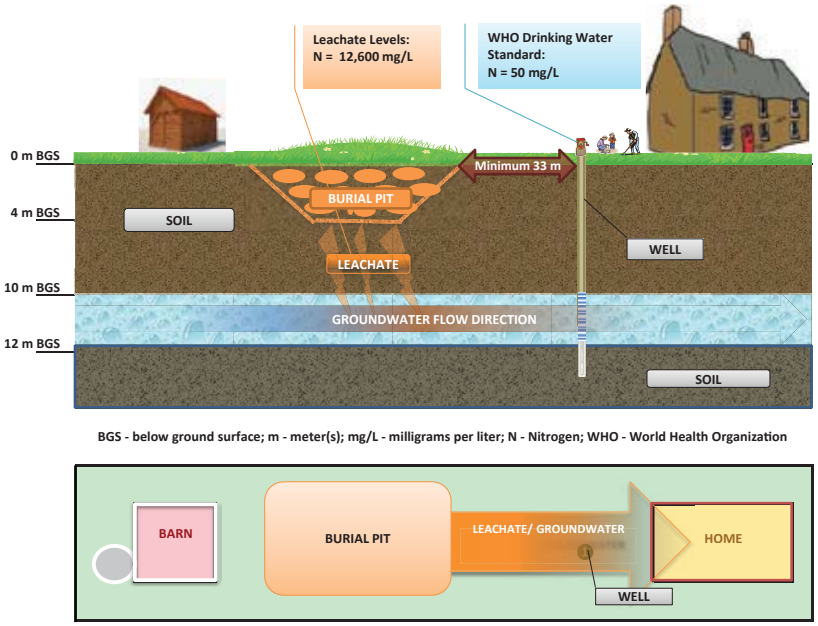
The following subsections provide detailed descriptions of burial (deep burial and above ground burial); burning (pyres, air curtain incinerators, and mobile crematoria); and composting.

Burial

Burial, for the purposes of this article, includes traditional deep burial, as well as a new and innovative above-ground burial process.

Figure 1

DEEP BURIAL SCHEMATIC



Source: Lori Miller, USDA, 2018

Deep burial

Deep burial involves removing soil from the ground to a depth of three to four meters, piling the soil nearby for later use, depositing the carcasses into the excavated area, and then covering the carcasses with the soil that had been previously removed. Once buried, carcasses undergo anaerobic decomposition and break down into minerals and organic material. This is a slow process and may take decades. The anaerobic decomposition process generates body fluids (leachate) which will slowly penetrate into the native soil beneath the burial site and may reach groundwater (see Figure 1).

Depending on the soil type and water table depth, there may be risks to human health and the environment associated with contaminating groundwater. For example, carcass leachate is shown to contain over 12,000 milligrams/liter (mg/L) nitrogen as ammonium, whereas a maximum of 10 mg/L of nitrates in drinking water is deemed safe by some countries. Excess nitrates can cause methemoglobinemia, which is potentially fatal to infants, as well as eutrophication, which kills fish. A variety of physical, chemical or biological processes may, under favourable conditions, reduce the mass, toxicity, mobility, volume or concentration of contaminants in soil or groundwater over time.

Carcass decomposition also generates methane, an explosive gas which can migrate through the soil to enclosed spaces such as sheds and houses, where it can replace the air and create an asphyxiation hazard or accumulate to explosive concentrations in the presence of a spark or flame. Methane is also a greenhouse gas, which contributes to global climate change. Despite these risks, burial has been historically used for mortality management and is familiar to most people.

Trenches and pits are the two most commonly used on-site burial methods. Trenches are much longer than they are wide, whereas pits have a length which is more proportional to width. The photo below shows a typical burial pit.

Deep burial pit

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Table 1 highlights the major advantages and disadvantages of deep burial. A more comprehensive comparison of the disposal options is presented in the section "comparison of options" on page 4.

Above-ground burial

Above-ground burial is a hybrid of deep burial and composting. As with deep burial, above-ground burial involves the disposal of animal carcasses within a trench excavated on the farm. However, the above-ground burial trench is much shallower than the trench for deep burial and includes a base of a carbonaceous material such as straw or wood chips. The trenches are designed to increase microbial activity and minimize the potential for groundwater contamination from carcass leachate.

Above-ground burial includes a shallow trench excavated into native soil to a depth of 60 centimeters (cm) (see Figure 2 and the accompanying photo). Thirty cm of carbonaceous material is placed in the bottom of the trench followed by a single layer of animal carcasses. Excavated soils are subsequently placed back in the trench, forming a mound on which the vegetative cap is established. For the vegetative cap, a plant species should be selected that is readily available and both regionally and seasonally appropriate. Finally, the perimeter of the mound is trenched to prevent the intrusion of surface water into the system. Once the carcasses have decomposed, the disposal site can be leveled and returned to its previous use. In most environments this will take between 9 and 12 months.

Table 2 highlights the major advantages and disadvantages of above-ground burial. A more comprehensive comparison of the disposal options is presented in the section entitled *Comparison of Options*.

Burning

Open burning (see photo on page 4) is a process which involves constructing a bed of combustible materials such as wooden timbers, placing the carcasses on the bed, adding more combustible material over the carcasses, and igniting the pile. There is no containment of materials in this process. Historically, open or uncontrolled burning has been used to thermally destroy animal carcasses and associated materials during animal health crises. Open burning may be termed uncontrolled burning because it has little opportunity for inputs and outputs to be monitored or regulated. Neither the fuel nor air inputs can be reliably or accurately controlled, which can result in incomplete, smoke-filled and relatively low-temperature combustion. The low-temperature combustion may not effectively inactivate all pathogens, and the significant air turbulence caused by the combustion process can transport active pathogens by air, potentially spreading the pathogenic agent.

Carcasses can be burned in open fields, on combustible heaps called pyres, or with other burning techniques that are unassisted by incineration equipment. Because of the significant air emissions and fire safety concerns, some governments specifically prohibit open

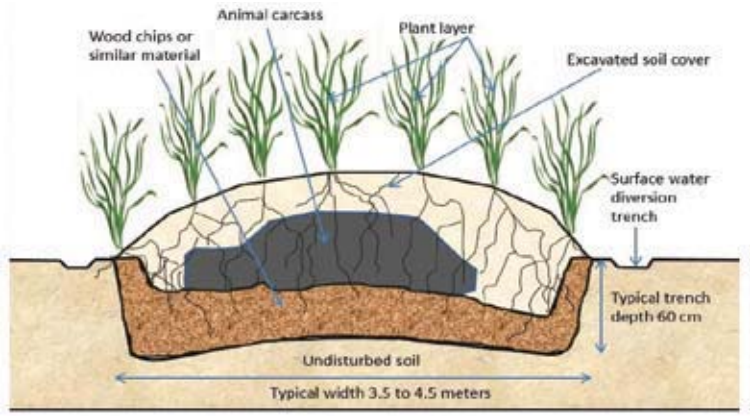
Table 1

DEEP BURIAL ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages	Time/Cost	Considerations
• On-farm • Easy to implement	• Public health risk • Biosecurity risk • Pathogens may survive • Not sustainable • Regulatory limitations • Limits future land use • Requires heavy equipment or excessive labour	Fast Low cost	• Burial may be viable for small numbers of animals in suitable soils, but it is site-specific

Figure 2

ABOVE-GROUND BURIAL SCHEMATIC



Source: Gary Flory

Above-ground burial

Table 2

ABOVE-GROUND BURIAL ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages	Time/Cost	Considerations
• Safe • On-farm • Readily available • Fast to implement • Public acceptance • Efficient	• Pathogens may survive • Scavengers may unearth carcasses	Fast Low cost	• Innovative technology undergoing field trials and validation testing

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Open burning

Table 3

OPEN BURNING ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages	Time/Cost	Considerations
• On-farm • Inactivates pathogens • Reduces volume	• Biosecurity risk • Not sustainable • Public opposition • Inefficient • Difficult to operate • Regulatory limitations	Slow Expensive	• Open burning poses risk of creating wildfires • Air quality • Smell

burning of carcasses; government regulations should always be checked before deciding to use this method.

Table 3 highlights the major advantages and disadvantages of open burning. A more comprehensive comparison of all the disposal options is presented in the section entitled *Comparison of Options*.

Composting

Carcass composting (see photo on page 5) is a process that involves constructing a porous base layer of carbon material such as wood chips, mixing or layering carcasses with carbon material for the core of the windrow, and capping the mixture with a blanket of carbon material to promote decomposition of carcasses at elevated temperatures. Carcass composting consists of two phases: an active phase and a curing phase.

The active phase is characterized by aerobic reactions at relatively high temperatures resulting in a large reduction in the volume of biodegradable solids. This phase has the potential to produce significant odours which are controlled by the carbon cap. Core pile temperature should rise to 57-60°C within 15 days and then be maintained for several days. Intervention, such as turning the pile, may be required to maintain the desired temperature. For intact large-animal carcasses, turning is not recommended, and elevated-temperature aerobic conditions should be maintained for weeks.

In the curing phase, which occurs after the active phase, aeration is not as critical. During this period, a series of slow-rate reactions, such as the breakdown of lignin, occur at temperatures below 41°C. At the end of the curing phase, internal temperatures within the compost pile range from 25-30°C.

The material bulk density is reduced by 25 percent and the finished product appears dark brown to black and is free of unpleasant odours.

For poultry composting, turning the pile can speed decomposition; however, if the pile is constructed correctly, turning is not necessary and is not recommended within the first 14 days for infected carcasses. Larger animals should not be turned before 30 days.

Table 4 highlights the major advantages and disadvantages of composting. A more comprehensive comparison of the disposal options is presented in the section entitled *Comparison of Options*.

Comparison of Options

In the previous sections, each option was described and its major advantages and disadvantages were outlined. This section will compare the various options to each other against a number of criteria (see Table 5, Disposal Options Matrix). As can be seen in Table 5, the first column lists the criteria and subsequent columns represent the disposal options. There are three sets of rows representing the most important criteria, which were weighted three times more than the least important criteria, and the moderately important criteria, which were weighted two times more than the least important criteria.

The discussion following the table contains additional information for each criterion. The numbers shown in each box in the matrix represent the rating for each criterion as it relates to each option. A higher numerical rating indicates a more preferable option. Note that the ratings are subjective, based on the judgment of the authors and subject to interpretation by the user. When the numerical ratings for each option are weighted based on their importance, totaled, and divided by the number of applicable criteria, the average

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Composting

Table 4

COMPOSTING ADVANTAGES AND DISADVANTAGES

Advantages	Disadvantages	Time/Cost	Considerations
• Safe • Sustainable • On-farm • Easy to implement	• Time to complete	Slow Expensive	• Requires knowledgable/ experienced operator to ensure proper construction

Table 5

DISPOSAL OPTIONS MATRIX

Weighting	Criteria	Composting	Above-ground Burial	Deep Burial	Open Burning
Most Important (x3)	1. Public health risk	9	6	3	6
	2. Biosecurity	6	6	3	3
	3. Pathogen inactivation	9	3	3	6
Important (x2)	4. Environmentally sustainable	9	6	3	3
	5. Volume reduction	4	4	4	6
	6. Availability	4	4	6	2
	7. Throughput	6	6	6	4
	8. Speed to implement	6	6	4	6
	9. Public acceptance	4	4	4	2
Less Important (x1)	10. Cost-effectiveness	2	3	3	1
	11. Efficiency	1	2	2	1
	12. Operability	1	2	3	2
Total Points		61	52	44	42
Average Score		5	4	4	4

scores can be compared to determine the relative ranking of the various options. The disposal options are listed from left to right in the table in order of preference, based on the average numerical ranking. Red indicates a less favourable score, yellow a moderate score, and green the most favourable score.

Public health risk (Row 1) - The public health risk rankings in this table were adapted from the United Kingdom (UK) Department of Health (now the Department for Environment, Food and Rural Affairs) document entitled "A Rapid Qualitative Assessment of Possible Risks to Public Health from Current Foot & Mouth Disposal Options, Main Report," published in June 2001. The UK assessment evaluated all risks to human health by all exposure pathways for burning and burial of foot and mouth disease-infected carcasses, as well as rendering, landfill and incineration. The health risks included bacteria, prions, chemical contaminants and airborne particles. Exposure pathways included drinking water, swimming, fishing, inhalation, direct contact, and consumption of crops and shellfish. Composting and above-ground burial technologies were not readily available at that time, so the authors gave qualitative rankings to the newer technologies in accordance with the UK criteria. The UK evaluation and the authors found that composting was the safest option, while above-ground burial and burning were safer than deep burial.

Biosecurity (Row 2) - The level of biosecurity provided by each carcass management option was determined to be high if the carcass management area could be contained and easily disinfected (base rating of 3 points). If the carcass management area was somewhat contained but was difficult to disinfect, such as a compost pile or above-ground burial plot that has an absorbent layer beneath the carcasses which serves to minimize movement of liquids, the option was given a base rating of 2 points. If the carcass management area could not be contained, it was given a base rating of 1 point. Therefore, composting and above-ground burial ranked higher than deep burial and burning.

Pathogen Inactivation (Row 3) - If the carcass management option completely inactivates pathogens, it was given a high rating of 3 points; partial inactivation received a rating of 2 points; and no inactivation a rating of 1 point. Therefore, composting ranked highest because it reaches high temperatures while the carcasses are fully enclosed, open

burning ranked medium because there is significant air turbulence of partially heated particles which could spread pathogens, and above-ground and deep burial ranked lowest because there is no heat generated to inactivate pathogens.

Environmental sustainability (Row 4) – Environmental sustainability is defined as a carcass management option with a low risk of environmental contamination and a useful end product; such options were given a base rating of 3. Those options with a low risk of contamination or a useful end product were given a base rating of 2. Those options with a risk of environmental contamination and no useful end product were given a base rating of 1. Composting was ranked highest because it minimizes environmental impacts while providing a soil amendment. Above-ground burial was ranked moderate because it reduces environmental impacts but provides no useful end product. Deep burial and open burning were ranked lowest because they pose relatively high environmental risks and provide no beneficial by-products.

Volume reduction (Row 5) - This factor relates to the ability of the process to reduce the volume of biomass. If the process reduces volume, it was given a base rating of 3; if the process resulted in the same volume, it was given a base rating of 2; and if the process increases volume, it was given a base rating of 1. Open burning ranked highest for this criterion because it was the only option that significantly reduces waste volume. The other three options were ranked moderately because they neither reduced nor increased waste volume.

Availability (Row 6) – Availability is the ability to acquire all needed inputs to the process. For example, if there is no land available for burying and no way to excavate trenches, then burial would not be readily available. Similarly, if there are no composting experts or carbon material such as wood chips available, then composting would have low availability. For burning, open land and fuel sources could limit availability. If the inputs to the process are widely available, it was given a base rating of 3; if the inputs are regional or somewhat available, it was given a base rating of 2; and if inputs are very limited in availability, the base rating was 1. Deep burial was ranked highest of the options because it is readily understood and implemented. Above-ground burial and composting ranked moderately because they do not require specialized equipment or material, but they do require specialized knowledge. Open burning was ranked lowest because it requires large amounts of wood and fuel, and specialized expertise to perform safely.

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Composting to control avian influenza: workers finalizing compost windrows

Throughput (Row 7) - For the purposes of this comparison matrix, throughput is defined as the amount of biomass that can be processed per day. If more than 90 metric tons of material can be processed per day, the base rating was 3; if the amount processed per day is between 23 and 90 metric tons, the base rating was 2; and if the method can process less than 23 metric tons per day, it was given a base rating of 1. All the options ranked highly for throughput except open burning, which can take considerable time to heat carcasses sufficiently to reduce them to ash.

Speed to implement (Row 8) - This criterion refers to the amount of time it takes for the process to receive the first carcasses, including obtaining government permission if needed. Options that could process carcasses immediately received a base rating of 3; options that could process the first carcasses in five days or less received a base rating of 2; and options that took more than five days to process the first carcasses received a base rating of 1. All the options ranked highly in this category except deep burial, which requires procuring excavation equipment and digging the trenches, which can take some time.

Public acceptance (Row 9) - This criterion refers to the likelihood that the community will have a positive perception of the carcass management option. Options likely to be viewed positively were given a base rating of 3; those likely to be viewed as neither positive nor negative were given a base rating of 2; and those options likely to be viewed negatively were given a base rating of 1. Composting, above-ground burial and deep burial were rated more highly than open burning, which is likely to be viewed negatively.

Cost-effectiveness (Row 10) - In this context, cost-effectiveness refers to the relative cost of a carcass management option. Relatively inexpensive options were given a base rating of 3; options with average costs were given a base rating of 2; and relatively expensive options were given a base rating of 1. Above-ground burial and deep burial were rated the least expensive, composting was rated moderately expensive, and burning was rated most expensive because of the need for large quantities of fuel, labour and time.

Efficiency (Row 11) - Efficiency refers to the relative amount of inputs (utilities, chemicals, fuel, carbon source) to contain and stabilize biomass over a short period of time. Options with low input requirements were given a base rating of 3; options with moderate input requirements were given a base rating of 2; and those options with relatively high input requirements were given a base rating of 1. Above-ground burial and deep burial were rated more efficient than composting and burning based on the length of time to implement and the need for fuel and carbon source.

Operability (Row 12) - This criterion refers to ease of implementation. For example, if the option is simple to do and operators are

readily trained and available, then it is rated highly operable with a base rating of 3. If the option is simple to do or operators are readily available, then it is given a base rating of 2. If the option is difficult to implement and trained operators are scarce, then it is given a base rating of 1. Deep burial was rated easiest, with readily available operators; above-ground burial and burning were rated moderately operable; and composting was rated least operable because of the need for highly trained composting experts.

When taken together and viewed overall, the benefits of composting and above-ground burial outweigh the benefits of deep burial and burning, despite cost or any other single criterion. ●

Example

The example that follows illustrates how carcass management concepts can be applied to an actual situation. Whether a farm raises poultry that become infected with avian influenza, swine affected by African Swine Fever, or cattle affected by Lumpy Skin Disease, a similar approach can be used in all cases. These diseases, as well as others, can cause illness or death in animals and sometimes humans, so the diseases must be contained to protect public health and the food supply. It is important to respond to these outbreaks in a way that minimizes losses to the farmer, protects them from disease or other health impacts, and protects surrounding farms from infection. Table 5 will be used in this example to help with the decision-making process. It will be assumed that (5,000) 2.3 kilogram (kg) birds weigh the same as (128) 90 kg pigs or (25) 454 kg cows, for a total of 11,340 kgs, or about 11 metric tons of infected material that must be managed, regardless of the species or disease.

It is assumed there is a 10 hectare rural farm that raises 128 pigs. An average pig weighs 90 kg. The pigs are infected with African Swine Fever and must be destroyed to prevent spread to neighbouring farms. The next paragraphs discuss how each disposal option might be used in this case.

Starting with the matrix shown in Table 5, composting was the highest-ranked disposal option, so the first step is to determine if composting can be implemented at this farm. USDA has developed a tool based on the matrix that includes a checklist to determine if the carcass management option can be used at a site. The checklist includes considerations for adequate space to build the compost pile, and sufficient distance to drinking-water sources, such as groundwater, neighbours, environmentally sensitive areas, and utility lines. The site should not have standing water and should be on a gentle slope.

Because the example farm has 10 hectares of land and the compost pile for 128 pigs would require about 43 square meters (0.004 hectares) (USDA calculator), there is sufficient space to compost. Soil at the farm is assumed to be sand underlain by limestone, with groundwater less than 10 meters below the ground surface in the sand layer. An Iowa State University study found that compost piles can discharge leachate 1-2 meters below the ground surface in certain soils, so there will likely be several meters of unaffected soil beneath the compost piles, which is likely to be protective of groundwater. It will be important to place the compost pile at least 60-80 meters away from homes, streams or waterways, and drinking-water wells. Selection of the compost site should take into account convenience to the location of the livestock in order to minimize movement of infected animals.

Based on the above considerations, the site appears to be suitable for composting. Next, it is necessary to determine whether trained personnel are available to oversee compost pile construction and periodically monitor it for at least three months to ensure that it becomes hot enough to inactivate pathogens, but not hot enough to combust. During this time, troubleshooting, including pest management, may be required. Heavy equipment, such as a skid steer loader, will greatly simplify and speed the process, which will otherwise have to be implemented manually.

Assuming trained personnel and any necessary equipment are available, it will be necessary to determine whether there is a readily available source of carbonaceous material, such as wood chips, sawdust, rice or wheat hulls, or similar materials. Approximately 2 kg of carbon material are needed per each kg of carcasses; therefore, about 22,000 kg, or 22 metric tons, of carbon material will be needed. A compost thermometer will be very helpful to the process. In addition, strict biosecurity measures, including personal protective equipment such as coveralls and respirators, will be necessary.

When composting infected carcasses, pathogens can be spread if the piles are too close to groundwater or surface water, if the piles are not properly constructed, if they don't become hot enough to inactivate pathogens, or if they are exposed tissue attracts vectors such as flies, birds, rodents or other mammals. Therefore, having trained personnel is critical to the success of composting.

If responders wish to consider other options in addition to composting, and referring back to the matrix in Table 5, the next best option is above-ground burial.

In order to implement above-ground burial, the same site conditions will be needed as for composting. Those conditions are assumed to be met at this site, so the next consideration is access to trained personnel, and any needed materials and

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Burial of cows

Burial of swine

equipment. Trained personnel are ideal for above-ground burial. However, this process can be successful if untrained personnel closely follow a written protocol. Sufficient carbon material for a 30 cm layer at the bottom of the trench will also be needed. Based on USDA calculations, approximately 154 square meters will be required for 128 pigs. If wood chips weigh about 314 kg per cubic meter, then approximately 14,500 kg of wood chips or similar material will be required. As with composting, heavy equipment, if it is available, would facilitate above-ground burial.

Risks of above-ground burial would arise from insufficient cover over the carcasses, which would attract vectors that might spread pathogens. Another risk would be related to constructing the above-ground burial plots in areas where groundwater is less than a meter below ground surface. In that case, leachate may pose a risk to groundwater, especially if the soils are highly permeable, like sand.

Deep burial is the next best option in the matrix in Table 5. Based on the USDA checklist, the first step when considering deep burial is to consider the suitability of the soil. Our example site has sand, which is relatively permeable, meaning leachate can travel quickly from the burial trenches to groundwater. Groundwater is less than 10 meters below the ground surface. Based on the USDA calculator, carcasses generate about 7 liters of leachate per 900 kg of carcasses per day. In this example, (128) 90 kg pigs would generate a total of about 90 liters of leachate per day. The leachate could travel quickly in the sand to the groundwater, so it would be extremely important to ensure that the pigs were buried far from drinking-water wells and waterways or to use a different carcass management option. If deep burial is going to be used, then the next step is to be sure that heavy equipment is available to excavate the trenches or pits. Based on the USDA calculator, about 78 cubic meters will be excavated for 128 pigs. Deep burial will require less land area than composting and above-ground burial; because the example farm had sufficient area for those options, there will be sufficient area for deep burial. The major risk from deep burial is contaminating drinking water and other resources such as aquatic life in streams.

The final option in Table 5 is burning. Based on the USDA checklist, the first step when considering burning is to obtain approval from appropriate authorities that burning is allowed. If it is, the next step is to determine whether the smoke will endanger human health. If it is deemed safe, then it will be necessary to identify an appropriate location for the pyres, air curtain incinerator or mobile crematoria that will minimize risk of uncontrolled spread of the fire. If this condition can be met, then combustible materials, fuel, equipment for building the pyre, trained personnel who can monitor the pyre, and fire safety equipment to extinguish uncontrolled combustion are needed. The primary risks from burning include untreated pathogens drifting off site with smoke, fire hazards to human health and property, and, in the case of air curtain incinerators or mobile crematoria, the ability to disinfect equipment before transporting. Use of air curtain combustors or mobile crematoria mitigate all but the last risk. ●

Conclusions/Recommendations

Composting, above-ground burial, deep burial and burning are suitable options for carcass management at small farms that have limited access to engineered landfills, rendering plants or controlled incinerators. In general, composting has more advantages than above-ground burial, which has more advantages than deep burial and burning. However, multiple options may be safely implemented depending on specific site conditions. Since calculations and data are required to determine if site conditions are suitable for a specific method, planning in advance can greatly expedite a response if an outbreak occurs. ●

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Notes

focus on **CONTACT**

The Emergency Prevention System (EMPRES) is an FAO programme, founded in 1994, with the goal of enhancing world food security, fighting transboundary animal and plant pests and diseases and reducing the adverse impact of food safety threats. EMPRES-Animal Health is the component dealing with the prevention and control of transboundary animal diseases (TADs).

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