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Poultry Carcass Disposal Options for Routine and Catastrophic Mortality

Various types of poultry: baby chicks, a white male turkey, and young chickens. (Photos courtesy of the USDA Agricultural Research Service Image Gallery.)

Abstract

Carcass disposal remains one of the major problems facing poultry meat and egg producers. As in all types of food-animal production, some poultry 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. This paper evaluates the practices and strategies for routine and catastrophic disposal of poultry carcasses.

Current methods for routine disposal of carcasses include burial, incineration, composting, and rendering. Burial currently is not permitted in some states, and its use will diminish with increased regulatory pressures and concerns for groundwater quality. Incineration is a biologically safe method, but it tends to be slow and expensive and may create air quality issues. Composting serves as a suitable and innovative technique and has gained favor in areas where burial and incineration have become restricted. Removal of poultry carcasses from the farm and subsequent transport to a rendering facility offers great potential, but the spread of pathogenic microorganisms during transport is a significant concern.

Emerging methods for disposal of poultry carcasses—including acid or base preservation, lactic acid fermentation, and yeast fermentation—may be used for safe and realistic on-farm storage. These methods provide long-term stabilization of the carcasses, contribute to a dramatic decrease in the level of pathogenic microorganisms, and result in a transportable product that can be processed by a rendering facility into a suitable animal feed ingredient. Alkaline hydrolysis is well adapted and serves as a premier choice for the treatment and elimination of highly infective wastes where there is need for pathogenic

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microorganism destruction rather than preservation of carcass materials destined for rendering.

Methods used for normal mortality losses have been adapted to deal with the large volume of carcasses that generally result from catastrophic events. These adopted methods vary in their degree of success, cost, or logistics. In this paper, descriptions of losses encountered from flooding, chemical residues, disease outbreaks, and elevated temperatures are presented as case studies to provide "real world" examples. Emerging methods for catastrophic disposal offer little in technological advances and are based on refinements of existing methods, especially equipment improvements capable of dealing with large volumes of carcasses in a timely and efficient manner. Other important tools that will maximize emergency response efficiency include an early detection and warning system, a plan of action, and contingency options.

A comprehensive understanding of the wide array of carcass disposal technologies will facilitate the identification and implementation of effective disposal strategies. Such understanding implies a broad awareness of numerous factors for each technology, including principles and logistics of operation, personnel requirements, estimated costs, environmental and disease agent considerations, advantages and disadvantages, public perception, and lessons learned from the past. Learning, planning, cooperation, implementation, and evaluation are necessary keys to success.

Introduction

Among the most critical problems currently facing the poultry industry are those of waste management and associated environmental issues. Today's poultry industry is more technically advanced than it was 10 or 20 years (yr) ago, and its high level of concentrated production involves large volumes of by-products including manure, mortalities, and hatchery/processing wastes requiring regular and prompt disposal. Although the poultry industry continues to consolidate, it also continues to expand production. Therefore, poultry meat and eggs will continue to be an abundant source of relatively inexpensive protein.

Carcass disposal is one of the major daily problems facing poultry meat and egg production facilities, posing a never-ending task as birds succumb to congenital defects, diseases, accidents, equipment failures, and natural disasters. On-farm death losses, also referred to as mortalities, can result in a considerable volume of carcasses by the end of a growing cycle. For example, a flock of 50,000 broilers grown to 49 days (d) of age averaging 0.1% daily mortality (4.9% total mortality) will produce approximately 2.18 tonnes (2.4 tons) of carcasses. A turkey flock of 30,000 birds averaging 0.5% weekly mortality (9% total mortality during an 18-week [wk] period) will produce approximately 12.61 tonnes (13.9 tons) of carcasses (Blake et al. 1990).

In 2007, production in the United States accounted for 8.90 billion broilers with an average live weight of 2.51 kilograms (kg) (5.52 pounds [lb]) and 271.70 million turkeys with an average live weight of 13.14 kg (28.96 lb) (USDA 2008). Assuming average mortality losses of 5 and 9% for broiler and turkey production, annual mortality losses can be estimated at 468.4 million and 26.9 million birds for broilers and turkeys, respectively. Assuming average weight is approximately half of total end weight as an estimate of mortality losses, then annual mortality weight is 587 million kg or 587,000 tonnes (1.296 billion lb or 648,100 tons) for broilers and 177 million kg or 177,000 tonnes (390.3 million lb or

195,100 tons) for turkeys. These estimates do not account for catastrophic losses that could be encountered during periods of disease outbreaks, natural disasters, or other unexpected occurrences. Regardless of the accuracy of these estimates, there is a tremendous volume of organic matter that requires environmentally and biologically safe disposal or use during the course of a normal production cycle. On average, a fresh broiler carcass contains approximately 34.2% *dry matter*[1], of which 51.8% is protein, 41.0% is fat, and 6.3% is ash (Malone et al. 1987).

Current methods used for disposal of poultry carcasses include burial, incineration, *composting*, and *rendering*. Burial is no longer permitted in some states because of concerns for groundwater quality near burial sites and intact residues that may remain years after the carcasses have been buried. Incineration is a biologically safe method of disposal, although it tends to be slow and expensive even when highly efficient incinerators are used (Blake and Donald 1992a). Methods for composting poultry carcasses were introduced in the late 1980s, and because composting yields a disease-free product that can be used as a *soil amendment*, it has gained favor in areas where burial has been discontinued (Cawthon 2000).

Removing poultry carcasses from the farm for rendering is environmentally acceptable and results in a valuable feed ingredient; however, spread of pathogenic microorganisms during routine pickup and transport presents a substantial threat. Currently, on-farm refrigeration is used for storage. Other methods, such as lactic acid or yeast fermentation and acid or base preservation, have been proposed but not adopted widely in commercial operations (Blake 2004). Methods that permit the accumulation of normal on-farm mortality losses during a typical *grow-out cycle* before rendering will lower transportation costs, stabilize carcass deterioration, and minimize pathogen threats. Methods for poultry mortality disposal have been reviewed (Blake 1998, 2004; Blake and Donald 1992a; Cawthon 2000); a more comprehensive evaluation of carcass disposal methods for both poultry and livestock was compiled by the National Agricultural Biosecurity Center (NABC 2004).

Catastrophic losses of poultry also are a concern and have brought about the need to redefine and discover new approaches to carcass disposal. Effective means of carcass disposal are essential regardless of the cause of mortality, but methods that can deal effectively and efficiently with large-scale depopulation are most crucial because rapid slaughter and disposal are integral parts of effective disease-eradication strategies. For maximum response efficiency, strategies for large-scale carcass disposal require preparation well in advance of an emergency.

The large volume and concentration of on-farm-generated wastes, coupled with intensification of environmental awareness, means that producers, scientists, and regulators alike are examining closely the acceptable methods of handling carcass disposal. The most effective disposal strategies will use every available, suitable disposal option to the fullest extent possible; therefore, it is beneficial to obtain a comprehensive understanding of the array of carcass disposal technologies. Such awareness implies a broad understanding of numerous factors for each technology, including principles and logistics of operation, personnel requirements, estimated costs, environmental and disease agent considerations, advantages and disadvantages, and past lessons learned.

Poultry producers recognize that mortality disposal is a continuous and growing challenge. Economics and resource factors should be considered key variables in the determination of which method is best suited for an individual producer in normal and "not-so-normal" conditions. Therefore, all methods that allow for the biologically and environmentally safe disposal of poultry carcasses should be considered, because no single method will solve the problem completely.

The primary purpose of this Issue Paper is to present information concerning current and future technologies for the disposal of normal poultry mortality. In addition, the authors have supplied information on depopulation and disposal of large populations of poultry resulting from a catastrophic loss or as part of an implemented disease-eradication strategy. This information will help increase understanding and appreciation for available disposal methods that may meet the needs of poultry producers.

Practices for the Routine Disposal of Poultry Carcasses

Burial

Burial has long served as a method for the disposal of flesh and bones and has been a feasible method for the disposal of poultry carcasses. In the past, a trench or open hole was dug somewhere on the farm, and as sections were filled with mortalities, the hole was back-filled with soil; an open ditch or poorly covered hole is hazardous for many reasons. A properly constructed *burial pit* is fabricated from concrete block, monolithic concrete, or treated lumber (Collins and Weaver 1974; Sweeten and Thornberry 1984). Precast, open-bottom septic tanks can be delivered to the site and offer the best alternative at a relatively low cost. The reinforced concrete cover can be fitted with a polyvinyl chloride pipe drop chute at the center with a tight-fitting cover.

Most decomposition is caused

[1] Italicized terms (except genus and species names) are defined in the Glossary.

by an array of *anaerobic* processes that create the objectionable odor normally associated with burial pits. *Aerobic* fermentations, by contrast, occur on the top layer, do not produce strong odors, and are more effective and desirable than anaerobic activities in degrading carcass solids (Lomax and Malone 1988). Despite the fact that disposal pits have been found to cause no more groundwater contamination than an individual septic tank and *soil adsorption bed* (Ritter and Chirnside 1990), the decline in groundwater quality in the area of an open-bottom pit and the fact that residue remains after years of use have been cited as reasons for discontinuation of burial pits.

On July 1, 1994, Arkansas became the first U.S. state to enact legislation prohibiting the use of burial pits as a method for poultry carcass disposal. Alabama was the second state to pass legislation, mandating that burial pits could not be used for poultry carcass disposal after July 1, 2000. Other states have passed, or are considering passage of, regulations to limit the further use of burial as a method for poultry carcass disposal. In certain situations, burial may be permitted where there is a catastrophic loss of birds.

Digesters

As an alternative to burial, *dead-bird digesters* were introduced as a totally enclosed system using a precast septic tank or large-capacity plastic tank. The tank is designed to contain poultry carcasses while promoting microbial breakdown of organic material and eliminating harmful bacteria. Typically, a bacterial culture with enzymes is added to the dead-bird digester to facilitate organic decomposition. Digesters are designed so that once they are full, resulting fluids can be pumped out and sprayed onto crop or pasture land. In a long-term (15 month [mo]) study of six units, Macklin, Norton, and Blake (1997, 1998, 2000) found that high levels of *enteric bacteria* and potentially *pathogenic bacteria* were isolated continuously from the dead-bird digesters throughout the study period. Because of the presence of pathogenic microorganisms, the use of dead-bird digesters has been prohibited in some major poultry-producing states. Carpenter and Carter (1996) indicated similar problems concerning the operation and biosecurity of digester units in North Carolina.

Controlled temperature digestion uses the application of heat to the storage tank and is a modification to the basic digester system surveyed by Macklin, Norton, and Blake (1997, 1998, 2000). *Thermophilic bacteria* introduced into a controlled-temperature dead-bird digester readily adapt to high temperatures (50°C [122°F]) and proliferate and digest organic matter in a complementary manner. It has been shown that species of thermophilic bacteria can be isolated and are effective in the *biodegradation* of poultry carcasses (Carey, Coufal, and Reynolds 2002). Characterization and development of suitable thermophilic cultures could lead to an alternative system that does not attract flies or produce offensive odors while maintaining consistency and viability in commercial conditions.

Incineration

Incineration is recognized as one of the biologically safest methods of disposal, eliminating the threat of disease. Normal mortality can be processed and the resulting residue easily disposed of without water quality problems. Proper, acceptable cremation of carcasses is not accomplished simply by drenching carcasses with a flammable fluid and igniting them, as is done in pyre construction. Such an approach usually is incomplete, and the resulting smoke and odors may prompt nuisance complaints. Other homemade incinerators constructed from drums or barrels are unsatisfactory because they fail to meet temperature and air emission requirements that would support complete combustion under environmental compliance regulations for carcass incineration.

Commercial units are available with oil or gas burners and usually are equipped with automatic timers to ensure proper burn. Smoke discharge stacks for such equipment also may be fitted with *after-burning devices* that recycle fumes to complete gas combustion and diminish odors. Regardless of whether these features are present, incinerators must be tested, approved, and rated for carcass disposal in accordance with federal or state air quality regulatory agencies. In some instances, a permit may be required to install and operate an incinerator.

After initially purchasing an incinerator, the average poultry grower will spend approximately $7.72 above installation to incinerate 100 kg of carcasses ($3.50/100 lb), based on a propane cost of $0.16/liter (l) ($0.61/gallon [gal]) (Donald and Blake 1992). A more comprehensive study was conducted to measure the efficiency and operational costs of three commercial incinerators on Alabama poultry farms (Blake et al. 2002; Simpson et al. 2002). Farm #1, a breeder flock, averaged 2.38 kg mortality/l of propane (19.86 lb/gal), with propane costing $0.22/l ($0.83/gal), for a cost of $0.0939/kg ($.0426/lb) during a four-quarter test period. Farm #2, a broiler farm, averaged 2.99 kg mortality/l (24.96 lb/gal) of diesel fuel ($0.26/l or $0.98.gal) for a cost of $0.0792/kg ($0.359/lb). Farm #3, also a broiler farm, averaged 5.98 kg mortality/l (49.91 lb/gal) of diesel fuel at a cost of $0.0439/kg ($0.0199/lb) during a six-flock test period. Fixed costs, which amount to an additional $0.02/kg ($0.01/lb), may include grate replacement every 2 to 3 years or, in some instances, the entire unit may require refurbishment or replacement every 5 to 7 years. Although these differences in efficiency and cost represent wide variability in specific model design and operation, it is apparent that recent technological advances in incinerator design result in lowered costs, regardless of past or current fuel costs.

Composting

Composting is a controlled, natural process in which beneficial microorganisms (bacteria and fungi) reduce and transform organic wastes into a useful end product called compost. Composting provides an economically and biologically safe means of converting carcasses resulting from daily mortality into an odorless, *humus-like material* useful as a soil amendment (Kalbasi et al. 2005).

On-farm composting of poultry carcasses requires two types of composting bins: a primary or first-stage bin and a secondary bin (Donald and Blake 1990; Murphy and Handwerker 1988). Required bin capacity and number will depend on the size of the poultry facility and the final bird weight to be achieved, as well as on the type of co-composting material to be used. In general, approximately 10 cubic meters (m) of bin capacity is required for every 1,000 kg of mortality (160 cubic feet (ft)/1,000 lb). Other adaptations of bin composting have included the construction of elongated alleyways to facilitate the daily layering process, and freestanding piles or windrows. Technical standards for the design and construction of a poultry composting facility are available from the Natural Resources and Conservation Service and numerous university agricultural biosystems engineering departments.

Daily, carcasses are sequentially layered into the primary bin with used or caked poultry litter and water at a ratio of 1:2:0.25 by weight, respectively (Blake, Conner, and Donald 1991). Caked or used bedding (usually pine shavings, sawdust, peanut hulls, or rice hulls) with manure is the primary compost medium, which supplies ammonia nitrogen (N) for bacterial growth. In certain situations, a carbon (C) source such as straw may be used to supply additional C to provide an acceptable C:N ratio between 15:1 and 35:1 with moisture content between 40 and 50% (Blake, Conner, and Donald 1991). Combinations of layer hens, solid manure, and straw also have been composted successfully in a two-stage static pile arrangement that yielded C:N ratios less than 15:1 (Gonzalez and Sanchez 2005).

Compost temperatures increase rapidly as bacterial action progresses, rising above 54°C (130°F) within 5 to 10 d. Increasing temperature has two important effects: (1) it hastens decomposition and (2) it kills pathogenic microorganisms, weed seeds, and fly larvae. Once primary bin temperatures begin to decrease 14 to 21 d later, material is moved to the second-stage area for aeration, mixing, and a secondary heating cycle. Temperatures in excess of 54°C (130°F) must be achieved and maintained for approximately 14 to 21 d during two composting cycles. Large turkey carcasses also have been composted successfully, but they may require an additional 14-d heating cycle to complete decomposition (Glanville 1999). The final step is to store the compost in a shed or pile it outside and cover it until land application.

Composters are intended to handle normal farm mortality. To be a viable method for poultry carcass disposal, the compost process must inactivate pathogenic microorganisms (avian and human) completely before land application. Studies by Conner, Blake, and Donald (1991a, b), Conner and colleagues (1991), and Murphy (1990) indicated that two-stage composting effectively inactivates poultry-associated bacterial pathogens. Viruses associated with highly pathogenic avian influenza (HPAI) and the *adenovirus* that causes egg drop syndrome (EDS-76) were inactivated completely after the second stage of the composting process (Senne, Panigrahy, and Morgan 1994). Such results support the effectiveness of composting for the inactivation of bacterial, fungal, and viral pathogens.

Researchers at the University of Delaware also tested simple, single-stage composters located within the poultry house (Scarborough, Palmer, and Williams 1992). Other researchers have proposed locating minicomposters outside the poultry house (Blake, Donald, and Conner 1994) or in the manure pit of high-rise layer houses (Mounce 1996). The most simply designed minicomposter consists of a portable wooden bin approximately 1.22 m (4 ft) by 1.22 m (4 ft) and 1.22 m (4 ft) in height with removable side panels. The side panels are constructed from pressure-treated boards (1.9 x 15.4 centimeter [cm]; 3/4 x 6 inch [in]) with 2.54-cm (1 in) air spaces between boards (Donald et al. 1994). The composter bin is loaded with carcasses, litter, and water similar to its larger counterpart, except that the complete cycle is attained within the bin and no turning of the material is required. Kotrola and colleagues (1993) microbiologically evaluated minicomposting during several growing cycles of broiler chickens and concluded that this method is a biosecure means of carcass disposal.

Composting technologies that have been used for the management of poultry mortality include windrow, static bin (most widely adopted), and in-vessel techniques. The use of a rotating drum composter also has been demonstrated to be successful when adapted for poultry carcass composting (Cawthon 1998, 2000). Aerated synthetic tubes known as EcoPOD (Preferred Organic Digester) or Ag-Bags (NABC 2004) also have been used.

Crews, Blake, and Donald (1994) presented a complex analysis of disposal methods currently in use (burial, incineration, and composting) and evaluated the net annualized cost per unit of carcass disposed. Their approach took into account initial investment costs, annual operating costs, and annual fixed costs as well as flock size (40,000, 100,000, and 200,000 birds) to measure sensitivity of economies of size among systems. In their final analysis, Crews, Blake, and Donald (1994) indicated that with current technologies, burial, composting, and incineration ranked from lowest to highest cost: $0.081, $0.108, and $0.197/kg carcass ($0.037, $0.049, and $0.089/lb), respectively. An economic analysis summarized by Clark in 1996 supports many of the analyses presented by Crews, Blake, and Donald (1994). Wineland, Carter, and Anderson (1998) indicated that composting costs were 2% higher than incineration costs for the disposal of broiler carcasses. Higher costs were calculated for commercial layer and broiler breeder disposal for composting compared with incineration (29% and 22%, respectively). In the Wineland, Carter, and Anderson (1998) study, labor and machinery costs (front-end loader) accounted for a large expense for composting compared with incineration.

Composting of poultry carcasses was introduced as a new idea in the late 1980s and has been accepted and implemented rapidly by poultry producers nationwide. Numerous universities have developed printed and audiovisual educational materials for distribution. Estimates indicate that approximately 30 to 40% of poultry producers may use composting as the method for mortality disposal (Cawthon 2000). The process transforms death and disease into an environmentally safe and nutrient-rich compost, which can be land applied in a timely manner. Options for poultry carcass disposal are limited; when properly managed, composting is a desirable environmental and economic alternative that the industry has adopted readily.

Rendering

Rendering is one of the best means for recycling poultry carcasses from the farm, and converting carcasses into a *protein by-product meal* is environmentally acceptable. Rendering of poultry mortalities involves conversion of carcasses into various products: *hydrolyzed whole poultry meal*, fat, and water. Hydrolyzed whole poultry meal results from modern processing methods that use hydrolysis with high temperature and pressure. These methods break down whole carcasses of dead, undecomposed poultry including feathers, heads, feet, entrails, undeveloped eggs, blood, and other specific portions of the carcass. The poultry carcasses may be fermented, or acid or alkaline treated, as part of the manufacturing process (AAFCO 2006).

The main carcass rendering processes include size reduction followed by cooking and separation of fat, water, and protein materials. The techniques used include mechanical (e.g., grinding, mixing, pressing, *decanting*, *sequential centrifugation*, and separating); thermal (e.g., cooking, evaporating, and drying); and, in some instances, chemical processes (e.g., *solvent extraction*). The resulting meal and fat obtained from hydrolyzed whole poultry are suitable as animal feed ingredients and are approved for use by the Food and Drug Administration (NRA 2006).

Because raw materials in an advanced stage of decay result in poor-quality end products, carcasses should be processed as soon as possible or stored appropriately to preserve them and retard decay. The cooking step in the rendering process kills most bacteria but does not eliminate endotoxins produced by some bacteria during the decay of carcass tissue; these endotoxins may induce disease (NABC 2004).

Most rendering plants are adjacent to slaughter facilities to process *offal*. These plants can sometimes accommodate normal mortality, but generally are not designed to handle feathers; therefore, whole carcasses present a challenge. Although rendering plants can be designed to process carcasses with feathers, investment costs are higher, and a plant will require a long-term commitment from the poultry industry to provide a constant supply of carcasses. With proper restrictions and sanitary precautions, whole-carcass rendering can be done with minimal risk.

Removing poultry carcasses from the farm is the most environmentally acceptable procedure, and a valued feed ingredient results. Rendering is only feasible, however, if there is a local rendering plant close enough for convenient pickup. Unfortunately, the spread of pathogenic microorganisms during routine pickup and transportation to a rendering facility presents a substantial risk. For this reason the practice has been abandoned in some regions of the United States.

The current focus definitely should be to develop innovative methods that support the long-term, on-farm stabilization of poultry carcasses, thus providing biosecure transport of carcasses for rendering. This approach is logical and economically feasible in places where rendering facilities are available and willing to process the stabilized material in a timely, efficient manner. Additional research and development on this approach will benefit the producer and consumer in resolving issues on an international scale. Two techniques—daily pickup and refrigeration—currently are in use. Other methods—acid/base preservation, lactic acid fermentation, and yeast fermentation—are in the experimental stage as means for providing on-farm storage of poultry carcasses before transport for rendering.

Daily Pickup

One of the major concerns with scheduled daily pickup of poultry carcasses destined for rendering is the possibility of disease transmission. Sound biosecurity procedures must be practiced before and after leaving the disposal site to prevent disease transmission. Central carcass disposal sites that offer daily pickup of poultry mortality have been evaluated using commercial conditions. Daily transportation costs were found to be prohibitively expensive, and poor biosecurity created a scenario for the spread of disease-causing microorganisms (Parsons and Ferket 1990; Poss 1990). Pickup of large animal carcasses on an as-needed basis is a common practice; however, the daily pickup of poultry mortalities from individual farms is neither economical nor logistically practical because of the small size of the carcass and the total weight produced daily.

Refrigeration

Commercial refrigeration units are available for carcass storage until a viable economic load accumulates and can be transported to a rendering facility. Refrigeration, principally freezing, has potential for short-term storage before rendering, but costs of operation and transportation need careful consideration. Costs associated with the on-farm refrigeration of broiler carcasses have been estimated at $0.60/d for each house using electrical energy at $0.08/kilowatt (Blake, Tucker, and Donald 1998). One problem encountered in this study was the capacity of the refrigeration unit to cool heavy loading of carcasses (45 kg [100 lb] daily) during periods of high environmental temperature (>24°C [75°F]), resulting in the inability of the lower layers to freeze thoroughly before the addition of more carcasses.

In their complex analysis, Crews, Blake, and Donald (1994) reported that refrigeration was much more costly than burial, incineration, or composting: $0.252 vs. $0.081, $0.197, and $0.108/kg ($0.114 vs. $0.037, $0.089, and $0.049/lb), respectively. The primary costs of refrigeration were related to electrical and equipment costs. Although costly, on-farm refrigeration with latent transport to a rendering facility has been implemented on a limited basis where transport is in close proximity to a rendering facility.

Acid/Base Preservation

The acid/base preservation method uses mineral acids or organic acids as a preservative until the mixture is transported to a rendering facility. Malone and colleagues (1988) placed punctured carcasses in a 3% solution of sulfuric acid and found that nutrients were preserved readily and pathogenic microorganisms were inactivated effectively. Processing and feeding of the resulting by-product meal indicated no detrimental effects when compared with conventional by-product meal (Lomax, Malone, and Saylor 1991). Because of concern for safety when mineral acids are transported and used on the farm, acid preservation has not been adopted readily. Organic acids such as acetic, propionic, and formic show promise, but may be prohibitively expensive.

Phosphoric acid also has been tested as a preservative for long-term storage of poultry carcasses (Middleton and Ferket 1998). In this study, the preservation of poultry carcasses with phosphoric acid to $pH < 3.0$ produced a biologically secure silage—without putrefactive by-products of protein degradation—that proved suitable for recycling into a valued feed ingredient. Neither *Salmonella* spp. nor fecal coliform bacteria survived the acidification process.

Fully feathered broiler carcasses can be preserved in a 2-molar (M) concentration of sodium hydroxide ($NaOH$) at a solution:carcass ratio of 1:1 (Carey, Shafer, and Smith 1997). The stabilized carcasses have been shown to retain nutritional value and inhibit the growth of *Salmonella* spp. when held within a pH range of 13.1 to 14.0. The process of alkaline hydrolysis effectively reduces poultry carcasses to a sterile solution of amino acids, peptides, nucleic acids, and soaps that can be used as a fertilizer, C and N soil supplement, or feedstock for anaerobic fermenters. Preserved carcasses exhibited no putrefaction, microbial growth, or odor development in trials lasting up to 6 m.

The stabilization of carcasses in alkaline hydroxide solutions, a method reported by Shafer and colleagues (2000), makes it possible to preserve carcasses on the farm during a typical grow-out period for later transport to a rendering facility. These researchers demonstrated successful on-farm preservation of broiler carcasses for 60 d without putrefaction or recoverable pathogenic microorganisms. Using a 2.0-M $NaOH$ solution at a 1:1 ratio with carcass weight, Shafer and colleagues (2001) produced a dry alkaline *poultry by-product meal* that showed no deleterious effects when fed for 24 d at 10% of the diet.

Niemeyer (2002) fed a potassium hydroxide (KOH) alkaline-based poultry by-product meal at 5% of the diet to broilers for 6 wk and reported no negative effects. Use of KOH resulted in a more usable liquid phase, and the resulting solution was evaluated as a soil amendment during two growing seasons (Niemeyer 2002). Plots were equalized in N; thus any differences in yield could be attributed primarily to differences in potassium (K). There were no deleterious effects of the treatments, and dry matter yield of bermudagrass was improved in the first year. Also, K uptake was increased in both years as the application rate increased. The author demonstrated a means to preserve carcasses for rendering and used the liquid phase of the treatment as a soil amendment. Primary concerns that limit the use and adoption of acid or base preservation include the safety of farm workers who handle dangerous chemicals, the cost and safety of transportation, and the corrosiveness of stored materials on rendering plant and farm application/spreader equipment.

Sodium hydroxide preservation

has been combined with lactic acid fermentation, in which whole hen carcasses were agitated with a 0.4-M concentration of NaOH (approximately a 1:6 ratio of solution:carcasses by weight) for 2 hours (hr) and then ground and mixed with 10% sucrose and allowed to ferment (Kim and Patterson 1998). Results from a chick assay indicated that the resulting feed ingredient from this treatment had no negative impact on chick growth rate. This type of approach may lower the risk associated with transport of concentrated alkaline solutions and also decrease the impact of corrosion on rendering plant and farm application/spreader equipment.

Lactic Acid Fermentation

Controlled natural fermentation has been used successfully for millennia as a preservation method for foods and feeds. Dobbins (1988) described methods for preserving poultry carcasses by lactic acid fermentation. Conner, Blake, and Donald (1991c) and Murphy and Silbert (1990) obtained similar results. Carcasses can be stored for a period of time before transport by using lactic acid fermentation, which stabilizes carcass deterioration but minimizes pathogen threat. Successful fermentation is enabled by the combination of prescribed amounts of farm carcasses with a fermentable carbohydrate source such as sucrose, molasses, whey, or ground corn (Cai and Sander 1995; Cai et al. 1994a; Conner, Blake, and Donald 1991c). For effective fermentation to occur, carcasses must be ground. Bacteria that produce lactic acid ferment the carbohydrate source, resulting in the production of volatile fatty acids and a subsequent decline in pH to below 4.5, which preserves the nutrients in the broiler carcasses.

Pathogenic microorganisms associated with the carcasses are inactivated effectively during the fermentation process (Conner, Blake, and Donald 1991c; Dobbins 1988; Murphy and Silbert 1990). Other researchers have confirmed that the fermentation of dead birds with lactic-acid-producing bacteria is very effective in inactivating pathogenic viruses (Wooley et al. 1981) and bacteria (Cai et al. 1994b; Talkington et al. 1981a, b). Presumably, fermented material can be stored and will remain in a stable state for several months. Therefore, fermentation could be initiated and continue on the farm until carcass amounts are sufficient to warrant the cost of transportation. Unlike routine pickup of "fresh" carcasses, the convenience of fermented carcasses will lower transportation costs and, when coupled with rendering, can result in an excellent feed ingredient.

The feasibility and economics of on-farm endogenous microbial fermentation for stabilizing poultry carcasses have been demonstrated under commercial conditions for broiler and broiler breeder mortality (Blake and Donald 1992b; Blake, Roden, and Scott 1998). Net disposal costs averaged \$0.10/kg (\$0.045/lb). Fermentation represents an economical, feasible, and environmentally safe method for on-farm storage of carcasses before transport to a rendering facility.

Yeast Fermentation

The Bertullo process for mortality fermentation using a proteolytic yeast was described by Malone (1990). Similar to the process of lactic acid fermentation, the carcasses require grinding, the addition of a fermentable carbohydrate, and a yeast starter culture (*Hansenula montevideo*). Carcasses are added repeatedly to a tank with constant agitation (aerobic process), maintained at 26.7 to 29.4°C (80.0 to 84.9°F). Within the first 48 hr, pH is reduced to 4.4. No *Escherichia coli*, *Salmonella typhimurium*, Newcastle disease, or infectious bursal disease viruses have been recovered 12 hr postinoculation. Both *Bacillus subtillis* and *Staphylococcus aureus* survived 48 hr postinoculation. Results indicated that the yeast process has limitations for inactivating pathogenic microorganisms.

Extrusion

Extrusion is a nontraditional rendering method that uses a high-temperature, short-time treatment that cooks, sterilizes, dehydrates, and stabilizes by-products into a high-quality, highly digestible feed ingredient. Extrusion technology uses the principle of friction as a means of creating heat, shear, and pressure. The material to be extruded is fed into a barrel and forced by means of a screw against a series of baffle-like restrictions, causing the material to flow back against itself. Because of the forces of friction and pressure within the barrel, the product is cooked to a preselected temperature of 115 to 155°C (239 to 311°F) in less than 30 seconds. As the product leaves the extruder, a rapid drop in pressure allows 12 to 15% of the moisture to evaporate. Excess moisture is removed by thermal drying to less than 15% before cooling and storing the final product.

In most cases, poultry by-products contain high initial moisture (>65%) and cannot be dried or dehydrated effectively without affecting nutritional value. Dilution of the by-product with an ingredient such as soybean meal, corn, or wheat middlings will help decrease the moisture for the extruder to process. Full extrusion can be achieved with a mixture of 50 to 60% by-product with the dry ingredient of choice.

Before extrusion, carcasses are ground and blended with other ingredients (i.e., in a complete diet) or with a single ingredient (i.e., soybean meal, corn, wheat). Haque, Lyons, and Vandepopuliere (1987) successfully incorporated whole ground hens into an extruded broiler diet. Other researchers have shown that feathers (Tadtiyanant, Lyons, and Vandepopuliere 1989), whole carcasses (Blake et al. 1990; Miller, Cook, and Blake 1990; Tadtiyanant, Lyons, and Vandepopuliere 1989), processing plant wastes (Blake et al. 1990; Tadtiyanant, Lyons, and Vandepopuliere 1991), and hatchery wastes (Tadtiyanant, Lyons, and Vandepopuliere 1991) have been extruded into acceptable feed ingredients. Mixtures of offal and condemned birds also have been extruded successfully in combination with wheat middlings, barley, and cassava (Patterson, Acar, and Coleman 1994).

In poultry feeding trials, researchers have shown that extrusion of poultry carcasses is a viable alternative to conventional by-product rendering. The process does not replace conventional rendering but rather complements it, producing high-quality, microbiologically safe feed ingredients. Microbiological studies also have been conducted to determine the ability of bacteria, molds, and viruses to survive the extrusion process (Blake et al. 1990; Tadtiyanant, Lyons, and Vandepopuliere 1993). In all instances, extrusion effectively inactivated these microorganisms, and the extruded products did not pose a potential disease transmission problem. The use of extrusion as an alternative to conventional rendering has been reviewed (Said 1996).

Alkaline Hydrolysis

The use of alkaline hydrolysis for treatment of animal carcasses was first reported in the treatment of radioactive animal carcasses from medical research laboratories. This process was expanded to encompass treatment of regulated medical waste primarily contaminated with pathogens (Kaye et al. 1998). A patent for the use of this technology was awarded (Kaye and Weber 1994), and the process has been commercialized (WR^2 2003); systems of varying size and use currently are marketed throughout the world.

Kaye and colleagues (1998) described the process as using 0.02 kg of a 50% NaOH solution for every 1 kg of carcass weight. Water is added to the appropriate volume of the system, and the solution is circulated within the closed container of carcasses for 16 to 18 hr at 110 to 120°C (230 to 248°F) and 12 to 15 lb/square in (2.68 kg/square cm). The process completely degrades the carcasses, and the remaining solids are composed of insoluble bones and teeth. This undigested residue typically accounts for approximately 2% of the original weight and volume of carcass material and can be ground into a powder and land applied.

The liquefied end product is a sterile, coffee-colored, alkaline solution with a soap-like consistency that may be released to sanitary sewer treatment systems (Kaye et al. 1998). This treatment system has been reported to kill a wide variety of pathogens and has been accepted by numerous state agencies as an alternative treatment system for animal and poultry carcass disposal (Weber, Thompson, and Kaye 2002). Taylor, Fernie, and McConnell (1997) reported the process inactivates the 22A strain of scrapie agent.

In summary, the reasons for choosing alkaline hydrolysis in which a weak alkaline solution (2 M) is used in a simple tanking system are twofold: (1) The method can be adapted to stabilize on-farm mortality for rendering, and (2) it yields a liquid fraction that can be used as a soil amendment. Methods for this procedure were presented previously in the section on "Acid/Base Preservation." The current discussion describes a relatively elaborate system that uses heat and pressure in addition to a highly concentrated alkaline (hydroxide) solution (50%) that yields a stable effluent and a small amount of insoluble material. This material is not appropriate for rendering, but rather for discharge into a sanitary sewer. This system is well adapted for the treatment and elimination of highly infective wastes in situations that need pathogenic microorganism destruction, rather than preservation of carcass materials destined for rendering. Alkaline hydrolysis offers a premier method for the disposal of highly infective carcasses; however, the capital and operational costs for disposal of animal carcasses by alkaline hydrolysis have been estimated at $352/tonne ($320/ton), including labor and sanitary sewer costs (NABC 2004).

The commercial providers of these systems offer them to the agricultural community as a means to treat highly infected carcasses for biosecure mortality management. There are no known peer-reviewed data published concerning the operational requirements and economics of the procedure in the context of on-farm mortality management. It can be assumed, however, that this method would offer a means of treating carcasses and potentially could control the spread of highly infectious agents. On-farm concerns range from the safety of workers who handle potentially dangerous chemicals to the possible need for effluent-discharge permits. Given these circumstances, daily on-farm use of alkaline hydrolysis for mortality disposal currently is not practical.

Strategies for the Disposal of Catastrophic Poultry Losses

Catastrophic loss is defined as any mortality that exceeds the normal mortality capacity of a poultry farm to accommodate losses within 24 hr. A catastrophic mortality event in poultry may be caused by mechanical failure in the facilities, a natural disaster, or an infectious disease outbreak that yields increased mortality or mandated depopulation. Catastrophic poultry mortality loss can be a few thousand birds at a single farm or millions of birds within an area that require prompt mortality disposal. Regardless of the cause of high mortality, every poultry farm or operation must have a comprehensive carcass disposal plan to deal with a catastrophic mortality event. This plan should include mass disposal options and procedures as well as a list of required materials, equipment, and personnel. Basic knowledge of the necessary procedure(s) and of all approvals required for a swift response is essential. Local, state, and federal regulations will dictate disposal option(s); furthermore, the method must be economical, biosecure, and environmentally and socially acceptable.

Although the poultry industry makes every effort to circumvent catastrophic losses, there are numerous situations that pose risks, many of which are unavoidable. The large number of carcasses resulting from a catastrophic event requires effective methods of mass disposal. There have been several recent examples in which there was uncertainty and a lack of knowledge on methods for mass disposal, a lack of preparation to deal with a catastrophic event, and—perhaps most importantly—a failure to have procedures preapproved by local and state regulatory authorities. The consequences of these situations included conflict, delays in responding to the emergency at the most critical time, and added overall costs to deal with the crises.

Causes of Catastrophic Mortality

Situations leading to catastrophic mortality in poultry are numerous but relatively infrequent. With a shift toward windowless housing and greater dependency on electronics and power ventilation, electrical outages of less than 30 minutes can result in partial or whole-house death losses. Although backup generators are required for most farms to deal with power outages, past experience has shown that generators are not fail-proof. In addition, generators and their fuel supply may not be workable until power is restored. To complicate mortality disposal issues further, natural disasters can cause structural damage to the houses. For example, wind from hurricanes and tornadoes can cause structural damage, and heavy loads of snow or ice can collapse roofs. Flooding is yet another natural disaster that can pose a significant disposal challenge.

Epizootic diseases are a continuous threat to the poultry industry. Catastrophic poultry mortalities caused by an infectious disease, or resulting from mandated depopulation after exposure to a highly infectious disease, must be disposed of using approved methods. Recent avian influenza (AI) outbreaks suggest that every effort should be made to inactivate the virus before carcass (and litter) removal from the house. When the decision is made to depopulate a farm for disease control purposes, selection of the disposal method should focus on minimizing disease spread. Flocks identified with, and depopulated by, chemical contamination must be handled by a disposal method that avoids further environmental consequences.

Choosing a Carcass Disposal Method

Current mass disposal methods include burial, landfills, incineration, composting, and rendering. These mass methods differ from routine, daily on-farm practices because mass methods deal with large volumes of carcasses that are encountered in an "immediate needs" situation. The unpredictability and lack of practical ways to reproduce the various types of catastrophic mortality events have limited the ability to conduct scientific studies on large-scale disposal methods.

Each catastrophic on-farm loss needs to be addressed individually and appropriate disposal methods considered. Any delay in responding to a catastrophic poultry mortality loss will add more cost and create an environmental problem. Poultry producers should be ready with state-approved disposal methods for catastrophic mortality losses. In assessing and choosing an appropriate carcass disposal method, the following questions need to be asked:

- What caused the catastrophic event?
- How many and what size of birds are involved?
- Is it a partial, whole-house, or entire farm loss, and are these losses widespread in the region?
- What resources and disposal options are available on the farm and from the poultry company or agency(s) overseeing the situation?
- What is the state of carcass decomposition?
- What is the proximity of the affected farm to other farms and to potential options for disposal?
- What local, state, and/or federal regulations apply to the situation?
- Will site conditions and weather restrict the chosen disposal method?
- How will the public perceive the recommended disposal option?
- What are the disposal costs, and who will pay for such costs?
- Is the method used for mass depopulation compatible and complementary to the disposal option?
- Will farms be accessible during or immediately after the mortality-causing event?

Unfortunately, the emergence of new practices has been limited to refinements or improvements imposed on current practices. Concern about the spread of zoonotic diseases such as the AI virus—especially the highly pathogenic H5N1 subtype—represents a serious issue for the poultry industry and public health authorities. It is imperative to address the matter objectively and scientifically (Smith

2007). The most important tools for emergency response are an early detection and warning system, contingency plans, and a plan of action during the catastrophic events.

Burial

Burial of mortalities is a natural process that has been used for hundreds of years, and for many catastrophic mortality events, on-farm burial historically has been the predominant disposal option. For catastrophic poultry mortality, this practice is the simplest and most cost-effective way to deal with various high mortality losses. If this method seems to be the best option, a site should be selected in advance based on soil type and drainage characteristics; site preselection avoids conflict when an emergency arises. Methods for burial are as simple as excavation of a trench, although more complex burial may include the use of a plastic liner placed under the birds, or the placement of birds in a cardboard tote that holds approximately 909 kg (2,000 lb).

When poultry houses are damaged beyond repair because of natural disasters, separation of house debris from carcasses and litter is challenging, and burial of the entire mass may be the only viable option. Although some states relax environmental standards for burial when dealing with an emergency, this situation is changing because of increasing concerns about water quality and public perception.

In locations having a high seasonal water table, such as the Delmarva Peninsula, burial is not an option. Finding an elevated site that is not in close proximity to the water table can be a major challenge after a flooding catastrophe. For example, after intact 15-yr-old carcasses from an AI event were unearthed at a trench burial site in Virginia in the late 1990s, environmental standards there became so stringent that requirements essentially eliminated on-farm burial as a mass disposal option. Furthermore, burial may not be an option for certain types of chemical residue depopulation situations, or when the ground is frozen. For disease outbreaks such as AI, burial of infected poultry carcasses does not necessarily destroy the AI virus and other pathogens that may infect animals and humans (NABC 2004). In these situations, burial may require long-term groundwater monitoring and may affect real estate values.

In the European Union, the practice of burying dead animals and all raw animal by-products has been prohibited by the advent of an animal by-products regulation. This regulation is based on concerns surrounding the transmission of *bovine spongiform encephalopathy* (BSE) and its residual infectivity after burial of infective carcasses was reported (Brown and Gajdusek 1991). In global terms, however, burial still is used as a means of dealing with dead animals safely when mass disease outbreaks, such as AI, occur.

Landfills

Municipal landfills sometimes are an option for handling catastrophic poultry mortalities. Each landfill operates by its own approved process; therefore, it is advisable to have preapproval from the landfill operator before considering this option. Dumping fees vary but normally are about \$77/tonne (\$70 per ton). Decomposition proceeds slowly and at a relatively low temperature (54 to 65°C [130 to 149°F]) in landfills, limiting pathogen inactivation (NRA 2006).

Landfills have been used extensively for mass disposal of AI-infected flocks in the last few decades. During a 2002 AI outbreak in Virginia, 65.5% of the total tonnage of carcasses was disposed of by landfilling (Flory, Bendfeldt, and Peer 2006). Such vast waste disposal sites also may be one of few options for disposal of some types of chemical residue contamination in poultry carcasses. Because not all landfills accept carcasses, preapproval may be required, and there can be logistical challenges when coordinating transportation and deposition of large volumes of carcasses to these sites. Costs associated with transportation and tipping fees can be significant. Flory, Bendfeldt, and Peer (2006) reported that costs associated with loading, transport, and disposal of flocks in the 2002 Virginia AI event were \$134/tonne (\$122 per ton).

During several other recent AI outbreaks, there were indications that any disposal option that removes infected carcasses from farms poses a potential biosecurity risk of spreading the virus to other farms. All off-site disposal methods, particularly for diseased flocks, require transport in sealed, leak-proof trailers or dumpsters. These containers often are double-lined with a waterproof material (e.g., polyethylene sheeting) and also may contain an absorbent material to retain body fluids. Coordination of on-farm loading equipment, transport vendors, and landfill receiving schedules as well as potential sanitation of equipment at both the farm and landfill site can pose a logistical challenge.

Using landfill to dispose of poultry mortalities may introduce a risk to biosecurity, posing a potential hazard to animal, poultry, and human health. When properly managed under mandate during a disease outbreak, landfilling is a proven, viable option for disposal of diseased carcasses. Supervised transport, internment, and immediate covering of carcasses at the landfill site are required. In some instances, bagging infected carcasses before transport may be required to control further the risks associated with highly pathogenic microorganisms.

Incineration

Catastrophic poultry mortalities can be processed using a large-scale incinerator. This practice meets emission standards for many states and is an efficacious means of minimizing human exposure to pathogenic microorganisms. Incineration is limited to the disposal of materials without any recovery of heat or other residues such as ash. Most incinerators are designed to operate at a high temperature and achieve aerobic combustion for a sufficient length of time that results in the conversion of all organic materials back to constituent molecules such as carbon monoxide, carbon dioxide, nitrous oxide, calcium oxide, and water. With special permits, collapsed or severely damaged poultry houses resulting from a natural disaster have been subjected to on-site incineration along with the litter and birds.

Incineration techniques include open-air burning, *fixed-facility incineration*, and *air curtain incineration* (NABC 2004). All methods require permits and are subject to local environmental regulations. Open-air burning (the burning of carcasses on combustible heaps known as pyres) dates back to biblical times but has been used as recently as 2001 in the foot-and-mouth disease outbreak in the United Kingdom. Fixed-facility incinerators include small on-farm incinerators, small and large incineration facilities, crematoria, and cement manufacturing and power plant incinerators (NABC 2004).

For catastrophic mortalities, larger incineration units, commonly referred to as air curtain incinerators, must be brought to the region having the catastrophic losses. Carcasses are then transported to a central, preferably remote, receiving and incineration site. Air curtain incineration involves a unit that fan-forces a mass of air through a manifold, thereby accelerating combustion (NABC 2004). Air curtain incinerators were used during recent AI outbreaks in Virginia and British Columbia, and similar processes have been used for large-animal depopulation (elk and deer) resulting from chronic wasting disease. Although the end product is very biosecure, there are some logistical and environmental issues associated with this procedure.

The incineration process is usually slow, costly, and requires disposal of 0.33 tonnes of ash per tonne of carcass (0.3 tons/ton) (Malone 2006). Loading decomposed carcasses also poses a problem, and temporary refrigeration of carcasses to prevent spoilage may be required. Without the proper fuel source and volume (typically a 1:1 weight:weight ratio of fuel to mortality for an air curtain incinerator) and without supervision of the process, smoke and odor can create nuisance complaints. Based on the 2002 Virginia experience, Flory, Bendfeldt, and Peer (2006) concluded that incineration was the most costly (~$551/tonne [~$500/ton]) and least publicly accepted method for mass disposal of AI-infected poultry flocks.

Composting

Composting methodology and procedures, discussed earlier in this paper, can be adapted easily to a catastrophic mortality loss. On-farm mass mortality composting avoids many of the water and air quality issues that may be associated with burial and incineration, respectively. This process also eliminates costs related to transportation (landfill, rendering, incineration) and tipping fees (landfill). Case studies presented in Textboxes 1 through 4 provide practical information concerning the composting of catastrophic numbers of mortalities encountered because of flooding (Textbox 1), chemical residues, disease outbreaks, and elevated environmental temperatures.

Depending on the cause and extent of the catastrophic loss, resources available (personnel, equipment, and materials), production schedule, and applicable regulations, *windrow composting* can be implemented inside the poultry house (Textbox 2), in a manure storage structure, or outside the poultry house on the same farm (Malone 2006). A larger composting facility provides the opportunity for disposal of catastrophic mortality losses but may be limited because large amounts of carbonaceous materials are needed to balance the high N and moisture content in mortalities.

Sites selected for composting must not pose public health risks to

Textbox 1. Flood loss case study

Carcass disposal in a flooded house is a very unpleasant task; decomposition of carcasses and litter often are advanced because days, even weeks, may pass before personnel can gain access to a poultry house. A number of procedures have been used to compost carcasses from flooded houses (Malone 2006; Malone et al. 2004). In some situations if decomposition is not advanced, carcasses can be skimmed off the litter surface and layered in outside windrows—as described previously—or placed in layers inside manure sheds. Most situations, however, have required blending large amounts of dry carbon or litter in these flooded houses to facilitate material handling and removal of the "soupy" litter/carcass mixture. This blended mixture is placed on a sawdust base in outside windrows or in manure sheds using a layering method with dry C materials or using the mix and pile procedure. After capping to cover exposed carcasses (both inside and outside windrows), outside windrows either are covered with tarpaulin or compost fleece or left uncovered to facilitate water evaporation. One state requires a 0.9-m (3-ft) berm of dry shavings around these uncovered windrows to contain runoff.

Additional requirements and considerations for composting flooded houses include using track-type skid loaders, having an all-weather roadway to an approved windrow site, providing an adequate quantity of trucks and equipment to load and transport the C materials and compost mixtures, increasing the frequency of turning piles to facilitate drying, and using chemicals for odor and fly control. Because downtime was not an issue but environmental impact and neighbor relations were concerns, the in-house mix and pile composting procedure with added C recently was used with success on the Delmarva Peninsula.

air or water. In addition, composting sites must prevent direct contact if the infectious agents being composted can pose a direct threat to humans and other animals (Textbox 3) (DeRouchey, Harner, and Murphy 2005).

Crushing or shredding carcasses before forming windrows decreases the additional C requirement for composting large carcasses such as roasters and turkeys (Bendfeldt et al. 2005). Although whole market-age tom turkey carcasses (up to 18 kg [40 lb]) were composted in the demonstration by Bendfeldt and colleagues (2005), shredding carcasses speeds up the composting process because there is an earlier and quicker increase in temperature. Both mixing or shredding and piling procedures tend to work best when the mass depopulation method distributes the mortality evenly over the floor of the house. If carcasses are concentrated in a small portion of the house, a layering procedure as discussed for *bin composting* may be more appropriate.

In recent years, when on-farm litter was used as the C source, windrows have been covered with polyethylene, tarpaulin, or compost fleece. These covered piles have been allowed to "age" for various lengths of time before turning (Textbox 4). Although the tarpaulin and compost fleece are more expensive, they are reusable, allowing moisture and gases to escape from the pile, while shedding rainfall. A wet condensate layer often will form under windrows covered with polyethylene or other impervious vapor barriers.

As an alternative to windrowing, the Ag-Bag composting system has been used to dispose of catastrophic poultry mortalities, but this system requires specialized equipment to mix carcasses with the C source, to load the mixture into bags, and to maintain proper aeration (Malone 2006). Ag-Bag composting was used during AI outbreaks in Virginia in 2002 and British Columbia in 2004, in which more than 1 million birds were composted successfully.

For a disease outbreak such as AI, in-house composting of meat-type birds may be one of the most biosecure methods, because the heat generated by the composting process (56 to 60°C [122 to 140°F]) is sufficient to inactivate the virus in the carcass and litter (Lu et al. 2003). Composting must be implemented correctly, however, and knowledge of the procedures is essential. Although heat produced during composting will inactivate pathogenic bacteria,

Textbox 2. Chemical residues case study

Occasionally, flocks have required depopulation and disposal because of chemical residues (e.g., pesticides, herbicides, polychlorinated biphenyls). Composting the carcasses and litter may be a choice if there are environmentally safe, approved options for disposal of the compost. One of the first documented applications of in-house composting was reported by Murphy (1992). A four-house farm with 86,000, 2-kg (4.4-lb) broilers contaminated with an herbicide was windrow composted in-house. After 10 d, the compost containing only a few bony carcass residues was removed from the house, land applied, and incorporated as a fertilizer.

Textbox 3. Disease outbreak case study

During the low pathogenic H7N2 AI outbreak on the Delmarva Peninsula in 2004, in-house composting was used successfully to contain and inactivate the virus in carcasses and litter (Malone et al. 2004). A procedure requiring the mixing of litter and carcasses uniformly into a windrow (mix and pile procedure) and covering all exposed carcasses with litter or C materials (e.g., sawdust) was used on three infected farms with a total of nine houses. A single windrow (3.0–3.6 m wide [9.8–11.8 ft wide] and 0.9–1.5 m high [2.9–4.9 ft high]) was formed in the center of the house. This procedure required a minimum of 2 cm (approximately 0.8 in) of litter or C material per 0.4 kg (0.9 lb) of carcass per 0.09 square m (1.0 square ft) of floor space. Temperatures during the 1-mo, in-house composting procedure averaged 56°C (133°F), enough to inactivate this heat-sensitive virus. Virus isolation tests of the compost at approximately 14 and 21 d were negative on all farms. After approximately 2 wk, the windrows were turned inside the house, capped to cover any exposed tissue, and allowed to continue composting for an additional 2 wk before removal. To avoid taking a house out of production for a prolonged period of time, the compost can be removed from the house at the first turn (approximately 2 wk); Tablante and Malone (2005) described procedures for in-house composting. In-house composting followed by outside windrow composting are the current preferred methods recommended by the U.S. Department of Agriculture–Animal and Plant Health Inspection Service–Veterinary Services (USDA–APHIS–VS 2006) for disposal of flocks infected with highly pathogenic AI.

Textbox 4. Elevated temperature case study

After a major heat loss event resulting from elevated environmental temperature on the Delmarva Peninsula in 1995, local universities conducted a demonstration and developed guidelines (Carr et al. 1996) for outside windrow composting of catastrophic mortalities. This procedure involved placing a 30-cm (12-in) layer of C material (e.g., sawdust, wood chips, litter) on a well-drained site. Starting with a 3.6-m- (11.8-ft-) wide base, the windrow was constructed in alternate layers of carcass (three to six layers of carcass, each layer not exceeding 25-cm [10-in] deep) and C material (38–50 cm [15–20 in]). The final windrow was capped with C material to cover exposed carcasses not to exceed 2.1 m (6.9 ft) in height. Windrows constructed in this manner will accommodate approximately 400 kg (882 lb) of mortality per linear meter (39.37 in). Ideally, the windrow should be turned to aerate the mixture when the temperature falls below 46°C (115°F), or about 2 wk after windrow formation.

viruses, fungi, and parasites, heat is not the only mechanism involved in the destruction of pathogens during the composting process. Microbial products also are likely to play a role in eliminating pathogens in compost (McCaskey 2006). Educational materials have been developed to assist the poultry producer with composting catastrophic losses (Carr et al. 1996; Malone 2008; Tablante and Malone 2005).

Rendering

Rendering of animal mortalities involves conversion of carcasses into three potentially marketable end products: carcass meal (proteinaceous solids), melted fat or tallow, and water (NABC 2004). For some geographic regions that have plants capable of processing mortalities, rendering may be a viable, cost-effective option for nondiseased and residue-free carcasses. Knowing the tonnage of nondeteriorated carcasses is a requirement and can be a logistical challenge. This option may not be suitable for carcasses infected with disease-causing organisms such as AI virus because of the risk of spreading the disease to other farms and the contamination of the rendering plant.

Rendering of poultry mortalities destroys pathogenic microorganisms, produces a feed ingredient, and is suitable for some types of catastrophic mortality events. The rendering industry is uniquely structured to provide the critical components necessary to handle catastrophic poultry events safely and responsively, including the disposal of carcasses that are considered, by science or perception, to be unsuitable for processing into an animal feed. Carcasses contaminated with chemical residues as well as those contaminated with HPAI cannot be rendered into a feed ingredient. On a global scale, modern, efficient rendering facilities are concentrated in countries and regions that have strong, well-established animal production industries. This is especially true in the United States, where the rendering industry is integrated closely with animal and meat production.

Pyrolysis

Pyrolysis, or thermal depolymerization, is a nontraditional, novel technology similar to *gasification* that can be adapted for disposal of catastrophic poultry mortalities. Pyrolysis occurs in the absence of air, and the product is a liquid biofuel rather than a gas. The major potential of pyrolysis is the production of a liquid fuel suitable for storage and transport. An advantage of this technology compared with other methods of energy extraction from a waste stream is the milder operating conditions, typically around 500°C (932°F) compared with 800 to 900°C (1,472 to 1,652°F) for gasification, and the very short processing times for anaerobic digestion (NRA 2006). The capital investment required for this technology would be similar to that of gasification, inasmuch as they both require a *fluidized-bed combustor*. The materials of construction may be cheaper for pyrolysis given the lower operating temperature, but a higher capital cost is incurred if drying or size reduction of the combustion residue is necessary.

Combustion-based technologies also can provide additional returns if the technologies are designed to recover energy in the form of heat, electricity, or both. Energy can be recovered from the combustion of animal by-products. Several *co-combustion* systems developed in the European Union after the BSE crisis in 1998 can be used to dispose of catastrophic poultry mortalities by producing renewable heat and electricity.

Summary

Methods for the routine and catastrophic disposal of poultry mortalities currently in use include burial, incineration, composting, and rendering. Concerns associated with burial include the in-ground residue remaining after years of use and potential effects on groundwater. Both concerns have prompted the prohibition of burial as a method for disposal in some states, but it may be used under limited conditions of catastrophic loss when approved sites are identified and located on the farm. Landfills offer an opportunity for off-site disposal of catastrophic mortality losses; however, local, state, and federal regulations dictate that certain criteria must be met for carcass disposal at these locations. Transportation of carcasses to a landfill site and tipping fees are additional cost considerations. Burial and landfills offer an immediate solution, but may be limited to certain types of mortality events. With these concerns in mind, there are opportunities to consider viable, environmentally friendly practices that may be used to benefit poultry carcass disposal in the future.

Recent improvements in incinerator technology have contributed to the development of more economical units that offer improved ease and efficiency of on-farm operation. Large portable incineration units may provide a suitable method for processing large volumes of birds in a biologically safe and equitable manner. But the costs of operation, turnaround time, and ash disposal remain challenges to consider. Emerging methods such as pyrolysis and co-combustion are other alternatives that exhibit potential for development, but the facilities necessary for these methods must be highly adaptive to deal with the flux in material availability and proximity to their supply source.

Experience with composting poultry carcasses is well documented, and composting has proved very effective in dealing with carcasses that harbor infectious bacteria, viruses, and fungi. As an innovative method that can be managed appropriately with proper assessment and planning, composting is becoming one of the more accepted methods for disposal of catastrophic poultry mortalities. Compared with alternative disposal methods, composting often is the more environmentally and socially acceptable, biosecure, cost-effective, and flexible implementation option. For composting to be a successful mass mortality disposal option, however, it is essential that workers have the knowledge and skills to execute the fundamental procedures properly. Highly infectious diseases such as HPAI subtype H5N1 must be disposed of using an appropriately selected method, under the direction of well-trained professionals with regulated supervision.

Rendering is a logical approach when rendering facilities are available and willing to process the stabilized material in a timely, efficient manner. The logistics of storage and transport to a rendering facility, however, offer challenges. Daily amounts of poultry mortality do not reach the level of volume that justifies pickup on a daily basis; therefore, long-term on-farm storage during a typical grow-out cycle offers a sensible approach. Some innovative methods may support long-term storage of poultry carcasses at the farm level, thereby lowering transportation costs to rendering and producing a usable protein by-product meal. Additional research and development in these areas will benefit producers and consumers in resolving issues on an international level.

Alkaline hydrolysis is not adaptable to rendering or catastrophic mortality events, but serves well as a method for disposal of limited quantities of highly infectious carcasses. Because of its highly specialized and costly nature, its use currently is limited to diagnostic laboratories and other medical facilities. This method easily could replace incineration under most circumstances for the biologically safe eradication of pathogenically infected carcasses.

Methods, strategies, and practical applications presented in this paper summarize acceptable means for disposal of poultry mortality. Each method has its advantages and disadvantages, as well as costs and benefits. The actual decision on which method is best should be based on individual farm circumstances and the restrictions that apply. It is crucial for emergency responders to develop a response plan based on the nature of the catastrophic event, the individual farm situation, local conditions, and regulations, because these factors will determine the applicability and feasibility of the carcass disposal method. All methods that allow for the environmentally safe disposal of poultry carcasses should be considered, because no single method will solve all problems.

Glossary

Adenovirus. Common infectious agents in poultry that do not grow to any extent in human cells and do not pose a public health hazard.

Aerobic. An adjective describing a microorganism or process that requires oxygen.

After-burning device. A fueled burner fitted to the smoke stack of an incinerator used to further combust emissions from the burn chamber.

Air curtain incineration. Incineration technology based on the use of a forced air system that greatly enhances operational efficiency, with greater throughput and improved performance.

Anaerobic. A term describing a microorganism or process that does not require air or free oxygen.

Bin composting. A composting technique in which mixtures of materials are composted in simple structures (bins) rather than in free-standing piles or windrows. Bins are considered a form of in-vessel composting, but usually are covered or totally enclosed.

Biodegradation. The process by which a substance is broken down into innocuous products through the action of living microorganisms.

Bovine spongiform encephalopathy (BSE). A fatal, non degenerative disease in cattle that causes a spongy degeneration in the brain and spinal cord; also called "mad cow disease" or transmissible spongiform encephalopathy.

Burial pit. Fabricated structure placed or built into the ground and used for the burial of a designated object.

Co-combustion. Combining or mixing a product to be combusted with another product so that a more complete and efficient combustion will be achieved.

Composting. A natural biological decomposition process that occurs in the presence of oxygen (air).

Controlled temperature digestion. A totally enclosed system similar to the "dead-bird digester," with the exception that it is maintained under a controlled temperature environment and agitated to accelerate microorganism growth and biodegradation.

Dead-bird digester. A totally enclosed system for the decomposition of poultry carcasses in which iving microorganisms are used to break down the contained substance.

Decanting. The process of removing the liquid portion and separating it from the solids portion.

Dry matter. The portion of a substance not composed of water. The dry matter content of a substance is equal to 100% minus the percentage of moisture content.

Endotoxin. A poison produced by the growth of certain microorganisms under specific conditions.

Enteric bacteria. Microorganisms common to the intestinal tract.

Epizootic disease. Disease that appears as new cases in a given animal population, during a given period, at a rate that substantially exceeds the level of recent experience.

Extrusion. A process in which by-products or feed has been pressed, pushed, or protruded through a die orifice under pressure.

Fixed-facility incineration. Permanently installed, nonportable incinerators.

Fluidized-bed combustor. Combustion technology that suspends solid fuels on upward-blowing air jets during the combustion process. The result is a turbulent mixing of gas and solids. The tumbling action, much like a bubbling fluid, provides more effective chemical reactions and heat transfer.

Gasification. A process that converts carbonaceous materials, such as coal, petroleum, or biomass, into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen.

Grow-out cycle. A period of time in days or weeks for which a species of poultry is reared before slaughtering. For example, on average the broiler chicken may have a grow-out cycle of 49 days.

Humus-like material. The dark or black, carbon-rich, relatively stable residue resulting from the decomposition of organic matter.

Hydrolyzed whole poultry meal. The result of rendering whole carcasses of culled or dead, undecomposed poultry including feathers, heads, feet, entrails, undeveloped eggs, blood, and any other specific portions of the carcass.

Offal. All material from an animal's body subject to processing in a rendering facility.

Pathogenic bacteria. Specific microorganisms associated with a diseased state.

Poultry by-product meal. A dry protein by-product meal prepared from the rendering of material obtained during poultry processing.

Protein by-product meal. A dry rendered protein product prepared from the rendering of dead animals or waste materials associated with slaughtering operations (carcass trimmings condemned carcasses, livers, inedible offal [lungs], and bones).

Pyrolysis. Chemical change brought about by the action of heat.

Rendering. A process of using high temperature and pressure to convert whole animal and poultry carcasses or their by-products with little or no value to a safe, nutritional, economically valuable feed ingredient. A combination of blending, cooking, pressurizing, fat melting, water evaporation, and microbial inactivation.

Sequential centrifugation. A process that uses centrifugation to separate substances of different densities and remove moisture.

Soil adsorption bed. The leach bed commonly associated with the installation of an in-ground home septic system.

Soil amendment. Any substance applied and incorporated into the soil that contributes to soil fertility and viability in support of plant growth.

Solvent extraction. Use of an organic solvent for the extraction of oil from seeds or animal by-products.

Thermophilic bacteria. Heat-loving microorganisms that thrive in, and generate, temperatures above 40°C (105°F). Microorganisms that grow well in a thermophilic environment in which temperatures are between 45 and 70°C (113 and 158°F).

Windrow composting. A method that involves placing the feedstock in long, relatively narrow, low piles called windrows. The large exposed surface area encourages passive aeration and drying. Aeration is achieved by convective airflow as well as by turning. The windrow piles act like a chimney in which the center gets hot and air is drawn through the sides.

Literature Cited

Association of American Feed Control Officials (AAFCO). 2006. Official Publication. Association of American Feed Control Officials, Oxford, Indiana.

Bendfeldt, E., R. Peer, G. Flory, G. Evanylo, L. Carr, and G. Malone. 2005. In-house composting of poultry mortalities as a rapid response to catastrophic losses. Pp. 44–50. In *Proceedings of the Symposium on Composting Mortalities and Slaughterhouse Residuals. Portland, Maine, 24–25 May 2005*, University of Maine Cooperative Extension, Waldoboro, Maine.

Blake, J. P. 1998. Upgrading the value of mortality residues. Pp. 50–60. In *Proceedings of the 1998 National Poultry Waste Management Symposium. Springdale, Arkansas, 19–21 October 1998*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Blake, J. P. 2004. Methods and technologies for handling mortality losses. *World Poult Sci J* 60:489–499.

Blake, J. P. and J. O. Donald. 1992a. Alternatives for the disposal of poultry carcasses. *Poult Sci* 71:1130–1135.

Blake, J. P. and J. O. Donald. 1992b. An on-farm fermentation system for dead poultry disposal. *Poult Sci* 71(1):51.

Blake, J. P., D. E. Conner, and J. O. Donald. 1991. Wheat straw and peanut hulls are useful bulking agents in composting poultry carcasses. *Poult Sci* 70(1):14.

Blake, J. P., J. O. Donald, and D. E. Conner. 1994. Small-scale composting of poultry carcasses. Pp. 261–266. In *Proceedings of the 1994 National Poultry Waste Management Symposium, Athens, Georgia, 31 October–2 November 1994*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Blake, J .P., R. M. Roden, and J. T. Scott. 1998. Feasibility and economics of on-farm poultry carcass fermentation. *Poult Sci* 77(1):97.

Blake, J. P., J. K. Tucker, and J. O. Donald. 1998. Operating costs associated with on-farm refrigeration of poultry carcasses. *Poult Sci* 77(1):97.

Blake, J. P., M. E. Cook, C. C. Miller, and D. Reynolds. 1990. Dry extrusion of poultry processing plant wastes and poultry farm mortalities. Pp. 319–327. In *Proceedings of the 6th International Symposium* *on Agricultural and Food Processing Wastes, Chicago, Illinois, 17–18 December 1990*. American Society of Agricultural Engineers, St. Joseph, Michigan.

Blake, J. P., E. H. Simpson, J. O. Donald, and R. A. Norton. 2002. Economic evaluation of incineration as a method for dead bird disposal. Pp. 281–287. In *Proceedings of the 2002 National Poultry Waste Management Symposium, Birmingham, Alabama, 28–30 October 2002*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Brown, P. and D. C. Gajdusek. 1991. Survival of scrapie virus after three years internment. *Lancet* 337(8736):269–270.

Cai, T. and J. E. Sander. 1995. Fermentation mixture formulation and the preservation of poultry carcasses. *J Appl Poult Res* 4:88–93.

Cai, T., O. C. Pancorbo, J. E. Sander, W. C. Merka, and H. M. Barnhart. 1994a. Stabilization of poultry processing by-products and waste, and poultry carcasses through lactic acid fermentation. *J Appl Poult Res* 3:17–25.

Cai, T., O. C. Pancorbo, J. E. Sander, W. C. Merka, and H. M. Barnhart. 1994b. Chemical and microbiological characteristics of poultry processing by-products and waste, and poultry carcasses during lactic acid fermentation. *J Appl Poult Res* 3:49–60.

Carey, J. B., C. D. Coufal, and P. I. Reynolds. 2002. Utilization of thermophilic microbes for digestion of poultry carcasses. Pp. 295–300. In *Proceedings of the 2002 National Poultry Waste Management Symposium, Birmingham, Alabama, 28–30 October 2002*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Carey, J. B., D. J. Shafer, and D. G. Smith, 1997. Field testing of sodium hydroxide preservation of on-farm broiler mortalities. *Poult Sci* 76(1):13.

Carpenter, G. and T. Carter. 1996. Poultry mortality digesters-Field observations. Pp. 309–312. In *Proceedings of the 1996 National Poultry Waste Management Symposium, Harrisburg, Pennsylvania, 21–23 October 1996*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Carr, L., H. Brodie, J. Martin, Jr., G. Malone, D. Palmer, and N. Zimmermann. 1996. Composting catastrophic event poultry mortalities. Fact Sheet #732. University of Maryland Cooperative Extension, College Park, Maryland.

Cawthon, D. 1998. Rapid composting of poultry mortality using in-vessel technology. Pp. 432–433. In *Proceedings of the 1998 National Poultry Waste Management Symposium, Springdale, Arkansas, 19–21 October 1998*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Cawthon, D. 2000. Evaluation of mortality processing alternatives. Pp. 249–254. *In Proceedings of the 2000 National Poultry Waste Management Symposium, Ocean City, Maryland, 16–18 October 2000*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Clark, R. A. 1996. Options for poultry mortality disposal. Pp. 313–319. In *Proceedings of the 1996 National Poultry Waste Management Symposium, Harrisburg, Pennsylvania, 21–23 October 1996*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Collins, E. R. and W. D. Weaver. 1974. Disposal of dead poultry and other farm animals. Publication 638. Virginia Cooperative Extension Service, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Conner, D. E., J. P. Blake, and J. O. Donald. 1991a. Microbiological evaluation of poultry farm mortality composting. *Poult Sci* 70(1):154.

Conner, D. E., J. P. Blake, and J. O. Donald. 1991b. Microbiological safety of composted poultry farm mortalities. Paper #91-4053. 1991 International Summer Meeting of the American Society of Agricultural Engineers, Albuquerque, New Mexico, 23–26 June 1991.

Conner, D .E., J. P. Blake, and J. O. Donald. 1991c. Fermentative stabilization of poultry farm mortalities. *Poult Sci* 70(1):28.

Conner, D. E., J. P. Blake, J. O. Donald, and J. S. Kotrola. 1991. Microbiological safety and quality of poultry mortality composting. *Poult Sci* 70(1):29.

Crews, J. R., J. P. Blake, and J. O. Donald. 1994. An economic evaluation of dead-bird disposal systems. Pp. 304–309. In *Proceedings of the 1994 National Poultry Waste Management Symposium, Athens, Georgia, 31 October–2 November 1994*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

DeRouchey, J. M., J. P. Harner, and J. P. Murphy. 2005. Catastrophic mortality composting: Is it safe and effective? *J Appl Poult Res* 14:414–416.

Dobbins, C. N. 1988. Lactobacillus fermentation: A method of disposal/utilization of carcasses contaminated by pathogenic organisms or toxic chemicals. Pp. 76–80. In *Proceedings of the 1988 National Poultry Waste Management Symposium, Columbus, Ohio, 18–19 April 1988*. Ohio State University, Columbus, Ohio.

Donald, J. O. and J. P. Blake. 1990. Dead poultry composter construction. Pp. 38–44. In *Proceedings of the 1990 National Poultry Waste Management Symposium, Raleigh, North Carolina, 3–4 October 1990*. National Poultry Waste Management Symposium Committee. Auburn University, Auburn, Alabama.

Donald, J. O. and J. P. Blake. 1992. Comparison of mortality disposal systems. Pp. 56–63. In *Proceedings of the 1992 National Poultry Waste Management Symposium, Birmingham, Alabama, 28–30 October 1992*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Donald, J. O., J. P. Blake, K. Tucker, and D. Harkins. 1994. Mini-composters in poultry production. Circular ANR-804. Alabama Cooperative Extension Service, Auburn University, Alabama.

Flory, G., E. Bendfeldt, and R. Peer.

2006. Landfilling of poultry carcasses: Lessons learned from the Virginia avian influenza outbreak of 2002. In *Proceedings of the National Carcass Disposal Symposium. Beltsville, Maryland, 5–7 December 2006* (CD-ROM; no page numbers).

Glanville, T. D. 1999. Composting dead livestock: A new solution to an old problem. Bulletin SA 8. Iowa State University Extension, Ames, Iowa. 8 pp.

Gonzalez, J. L. and M. Sanchez. 2005. Treatment of poultry mortalities on poultry farms. *Compost Sci and Utiliz* 13:136–140.

Haque, A. K. M., J. J. Lyons, and J. M. Vandepopuliere. 1987. Utilization of ground whole hens in broiler diets. *Poult Sci* 66(1):110.

Kalbasi, A., S. Mukhtar, S. E. Hawkins, and B. W. Auvermann. 2005. Carcass composting for management of farm mortalities: A review. *Compost Sci and Utiliz* 13:180–193.

Kaye, G. I. and P. B. Weber. 1994. U. S. Patent 5,332,532. A method for disposing of radioactively labeled animal carcasses. U.S. Patent Office, Washington, D.C.

Kaye, G. I., P. B. Weber, A. Evans, and R. A. Venezia. 1998. Efficacy of alkaline hydrolysis as an alternative method for treatment and disposal of infectious animal waste. *Contemp Topics Lab Anim Sci* 37(3):43–46.

Kim, W. K. and P. H. Patterson. 1998. Recycling hen mortalities by using a feather digesting enzyme or sodium hydroxide treatment and fermentation. Pp. 394–400. In *Proceedings of the 1998 National Poultry Waste Management Symposium. Springdale, Arkansas, 19–21 October 1998*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Kotrola, J. S., D. E. Conner, J. P. Blake, and J. P. Donald. 1993. Microbiological evaluation of small-scale in-house composting of poultry carcasses. *Poult Sci* 72(1):78.

Lomax, K. M. and G. W. Malone. 1988. On farm digestion system for dead poultry. Paper #88-4075. 1988 International Summer Meeting, 21–24 June 1988. American Society of Agricultural Engineers, Rapid City, South Dakota.

Lomax, K. M., G. W. Malone, and W. W. Saylor. 1991. Acid preservation for poultry carcass disposal. Paper #91-4051. 1991 International Summer Meeting. 23–26 June 1991. American Society of Agricultural Engineers, Albuquerque, New Mexico.

Lu, H., A. E. Castro, K. Pennick, K. Liu, Q. Yang, P. Dunn, D. Weinstock, and D. Henzler. 2003. Survival of avian influenza virus H7N2 in SPF chickens and their environments. *Avian Dis* 47:1015–1021.

Macklin, K. S., R. A. Norton, and J. P. Blake. 1997. Preliminary results of long term monitoring of pathogenic bacteria recovery from experimental bird digesters in the state of Alabama. *Poult Sci* 76(1):137.

Macklin, K. S., R. A. Norton, and J. P. Blake. 1998. Current status of dead bird digesters in Alabama. *Poult Sci* 77(1):123.

Macklin, K. S., R. A. Norton, and J. P. Blake. 2000. Surveillance of dead bird digesters in Alabama. Pp. 204–212. In *Proceedings of the Alliance for Environmental Stewardship: A Comprehensive Approach, St. Louis, Missouri, 27–29 September 2000*. Western Coordinating Committee-059 (WCC-059), Auburn University Printing Services, Auburn, Alabama.

Malone, B. 2006. Mass mortality composting programs. Pp. 29–34. In *Proceedings of the 2006 National Poultry Waste Management Symposium, Springdale, Arkansas, 23–25 October 2006*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Malone, G. 2008. Mass mortality composting [Narrated presentation] http://www.poultryextension.udel.edu/Dead%20Bird%20Disposal/Chapter%201.htm. (29 September 2008)

Malone, G., S. Cloud, R. Alphin, L. Carr, and N. Tablante. 2004. Delmarva in-house carcass composting experiences. Pp. 27–29. In *Proceedings of the 39th National Meeting on Poultry Health and Processing, Ocean City, Maryland, 6–8 October 2004*.

Malone, G. W. 1990. Carcass preservation systems-Acid preservation and proteolytic yeast. Pp. 49–55. In *Proceedings of the 1990 National Poultry Waste Management Symposium, Raleigh, North Carolina, 3–4 October 1990*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Malone, G. W., W. W. Saylor, M. G. Ariza, K. M. Lomax, and C. R. Kaifer. 1987. Acid preservation and utilization of poultry carcasses resulting from mortality losses. Pp. 13–16. In *Progress through Research and Extension 1987*. Report 11. University of Delaware, College of Agricultural Sciences, Newark, Delaware.

Malone, G. W., C. W. Kaifer, W. W. Saylor, and K. M. Lomax. 1988. Preservation of broiler mortality losses using various acids. *Poult Sci* 67(1):113.

McCaskey, T. A. 2006. Bacterial pathogen die-off in poultry mortality compost. Pp. 141–145. In *Proceedings of the 2006 National Poultry Waste Management Symposium, Springdale, Arkansas, 23–25 October 2006*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Middleton, T. F. and P. R. Ferket. 1998. The effect of incubation temperature and level of acidification with phosphoric acid on quality parameters of poultry mortality silage. *Poult Sci* 77(1):110.

Miller, C. C., M. E. Cook, and J. P. Blake. 1990. Performance of male turkeys fed a diet containing an extruded blend of soybean meal and whole turkeys. *Poult Sci* 69(1):93.

Mounce, D. 1996. High rise mortality composting. Pp. 133–134. In *Proceedings of the 1996 National Poultry Waste Management Symposium, Harrisburg Pennsylvania. 21-23 October 1996*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Murphy, D. W. 1990. Disease transfer studies in a dead bird composter. Pp. 25–30. In *Proceedings of the 1990 National Poultry Waste Management Symposium, Raleigh, North Carolina, 3–4 October 1990*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Murphy, D. 1992. Massive depopulation

and disposal by composting. Pp. 342–347. In *Proceedings of the 96th Annual Meeting of the United States Animal Health Association. Louisville, Kentucky, 4 November 1992.*

Murphy, D. W. and T. S. Handwerker. 1988. Preliminary investigations of composting as a method of dead bird disposal. Pp. 65–72. In *Proceedings of the 1988 National Poultry Waste Management Symposium, Columbus, Ohio, 18–19 April 1988*. Ohio State University, Columbus, Ohio.

Murphy, D. W. and S. A. Silbert. 1990. Carcass preservation systems-lactic fermentation. Pp. 56–63. In *Proceedings of the 1990 National Poultry Waste Management Symposium, Raleigh, North Carolina, 3–4 October 1990*. National Poultry Waste Management Symposium Committee, Auburn University, Alabama.

National Agricultural Biosecurity Center (NABC). 2004. *Carcass Disposal: A Comprehensive Review*. National Agricultural Biosecurity Center Consortium, Carcass Disposal Working Group, Kansas State University, Manhattan, Kansas.

National Renderers Association (NRA). 2006. *Essential Rendering: All about the Animal By-Products Industry*. D. L. Meeker (ed.). National Renderers Association, Arlington, Virginia.

Niemeyer, T. P. 2002. Utilization of by-products from alkaline hydroxide preservation of whole broiler carcasses. MS Thesis, Texas A&M University, College Station, Texas.

Parsons, J. and P. R. Ferket. 1990. Alternative dead bird disposal methods central pickup and fermentation. Pp. 7–20. In *Proceedings of the North Carolina State University Poultry Supervisors Short Course, Raleigh, North Carolina*.

Patterson, P. H., N. Acar, and W. C. Coleman. 1994. Feeding value of poultry by-products extruded with cassava, barley, and wheat middlings for broiler chicks: The effect of ensiling poultry by-products as a preservation method prior to extrusion. *Poult Sci* 73:1107–1115.

Poss, P. E. 1990. Central pickup of farm dead poultry. Pp. 75–76. In *Proceedings of the 1990 National Poultry Waste Management Symposium, Raleigh, North Carolina, 3–4 October 1990*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Ritter, W. F. and A. E. M. Chirnside. 1990. Dead bird disposal and ground-water quality. Agricultural and food processing waste. Pp. 414–423. In *Proceedings of the 6th International Symposium on Agricultural and Food Processing Wastes, Chicago, Illinois, 17-18 December 1990*. American Soc. of Agricultural Engineers, St. Joseph, Michigan.

Said, N. W. 1996. Extrusion of alternative ingredients: An environmental and a nutritional solution. *J Appl Poult Res* 5:395–407.

Scarborough, J. N., D. H. Palmer, and T. H. Williams. 1992. Composting structures for dead poultry disposal. Circular EQ-4. University of Delaware Cooperative Extension, Newark, Delaware.

Senne, D. A., B. Panigrahy, and R. L. Morgan. 1994. Effect of composting poultry carcasses on survival of exotic avian viruses: Highly pathogenic avian influenza (HPAI) virus and adenovirus of egg drop syndrome-76. *Avian Dis* 38:733–737.

Shafer, D. J., J. B. Carey, R. P. Burgess, K. A. Conrad, and J. F. Prochaska, 2000. Chemical preservation of whole broiler carcasses utilizing alkaline hydroxides. *Poult Sci* 79:1517–1523.

Shafer, D. J., R. P. Burgess, K. A. Conrad, J. F. Prochaska and J. B. Carey. 2001. Characterization of alkaline hydroxide-preserved whole poultry as a dry byproduct meal. *Poult Sci* 80:1543–1548.

Simpson, E. H., J. P. Blake, J. O. Donald, and R. A. Norton. 2002. Evaluation of incineration for disposal of poultry mortalities. *Poult Sci* 80(1):6.

Smith, R. 2007. Avian flu message seems odd. *Feedstuffs* 79(5):8.

Sweeten, J. M. and F. D. Thornberry. 1984. Construction and use of on-site disposal pits for dead poultry. Pp. 34–52. In *Proceedings of the 16th Annual Texas Broiler Symposium. Center, Texas*.

Tablante, N. and G. Malone. 2005. Guidelines for in-house composting of poultry mortalities due to catastrophic disease. Compact disk available from University of Maryland or University of Delaware and at http://www.rec.udel.edu/poultry/2005%20In-House%20Composting%20of%20Poultry%20Mortalities.pdf (27 September 2008)

Tadtiyanant, C., J. J. Lyons, and J. M. Vandepopuliere. 1989 Utilization of extruded poultry mortalities and feathers in broiler starter diets. *Poult Sci* 68(1):145.

Tadtiyanant, C., J. J. Lyons, and J. M. Vandepopuliere. 1991. Extrusion processing used to convert egg shells, hatchery waste and deboning residuals into feedstuffs for laying hens. *Poult Sci* 70(1):188.

Tadtiyanant, C., J. J. Lyons, and J. M. Vandepopuliere. 1993. Extrusion processing used to convert dead poultry, feathers, egg shells, hatchery waste and mechanically deboned residue into feedstuffs for poultry. *Poult Sci* 72:1515–1527.

Talkington, F. D., E. B. Shotts, Jr., R. E. Wooley, W. K. Whitehead, and C. N. Dobbins. 1981a. Introduction and reisolation of select gram-negative bacteria from fermented edible wastes. *Am J Vet Res* 42:1298–1301.

Talkington, F. D., E. B. Shotts, Jr., R. E. Wooley, W. K. Whitehead, and C. N. Dobbins. 1981b. Introduction and reisolation of select gram-positive bacteria from fermented edible wastes. *Am J Vet Res* 42:1302–1305.

Taylor, D. M., K. Fernie, and I. McConnell, 1997. Inactivation of the 22A strain of scrapie agent by autoclaving in sodium hydroxide. *Vet Microbiol* 58:87–91.

U.S. Department of Agriculture (USDA). 2008. *Poultry—Production and Value*. 2007 Summary, April 2008, Publication POU 3-1(08)a. USDA-National Agricultural Statistics Service, Washington, D.C.

U.S. Department of Agriculture–Animal and Plant Health Inspection Service–Veterinary Services (USDA–APHIS–VS). 2006. *National Highly Pathogenic Avian Influenza Response Plan*, http://www.aphis.usda.gov/newsroom/hot_issues/avian_influenza/contents/printable_version/DraftSummaryNationalHPAIresponseplan08-31-06.pdf (August 2006).

Waste Reduction by Waste Reduction (WR^2). 2003. Company website, www.biosafeengineering.com (21 July 2008)

Weber, P., K. Thompson, and G. Kaye. 2002. The use of alkaline hydrolysis for the processing and disposal of poultry carcasses. Pp. 375–380. In *Proceedings of the 2002 National Poultry Waste Management Symposium, Birmingham, Alabama, 28–30 October 2002*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Wineland, M. J., T. A. Carter, and K. E. Anderson. 1998. A cost comparison of composting and incineration as methods for mortality disposal. Pp. 312–319. In *Proceedings of the 1998 National Poultry Waste Management Symposium. Springdale, Arkansas, 19–21 October 1998*. National Poultry Waste Management Symposium Committee, Auburn University, Auburn, Alabama.

Wooley, R. E., J. P. Gilbert, W. K. Whitehead, E. B. Shotts, Jr., and C. N. Dobbins. 1981. Survival of viruses in fermented edible waste material. *Am J Vet Res* 42:87–90.

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