

Effectiveness of Composting as a Means of Emergency Disposal: A Literature Review

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Abstract. *There has been a multitude of research conducted on different aspects of passively aerated windrow systems (PAWS) composting of mortality in the past several years. Early on, the research was concentrated on whether or not (PAWS) composting could actually dispose of animal tissue. Once that was determined, researchers began looking at optimization of the process (bulking material, type of system, etc.), destruction of pathogens and disease control, environmental impacts, and economics. Evaluation of the effectiveness of static pile composting to inactivate disease causing organisms in carcasses requires identification of those organisms and analysis of their sensitivity to inactivation by heating or composting's athermic properties. Pathogen and disease control are essential during emergency disposal, but it is impossible to test for all pathogens/diseases that may occur. This literature review discusses composting process, feedstocks pathogens/diseases and environmental effects that have been studied. Research indicates that the use of composting as one means of disposal during emergencies is not only effective in deactivating pathogens, but also limits the risk of groundwater and air pollution contamination. On-farm composting also reduces the potential for farm-to farm-disease transmission and decreases transportation costs and tipping fees associated with off-site disposal. There is also the added benefit of producing a usable product.*

Keywords. Animal mortality, disease control, mortality composting, pathogen inactivation, passively aerated windrow system (PAWS)

Introduction

Composting of mortalities started in the late 1980s when Dr. Dennis Murphy at the University of Maryland designed a successful poultry composting facility using a series of bins. Other methods of composting dead birds, including passively aerated windrows were quickly adopted. Passively aerated windrow systems (PAWS) is a composting method where the windrow or pile is built with enough natural aeration that the composting process can progress without regular turning to incorporate air (Wilson et al., 1992), killing viruses, pathogens and possibly even prions. The importance of this method's effectiveness is the basis for all of the research that has been conducted and reviewed in this paper. Conventional turned windrow composting would have the potential to liberate odor, spread disease and place mortality on the outside of the carbon envelope. All of these results would be problematic. The Natural Resource Conservation Service (NRCS) developed mortality disposal standards in the 1980s to guide farmers through the process and updated these standards in the 1990s to address disposal of larger livestock. Using these same principles from the success with poultry, composting of larger animals was explored and it was found to be effective and economical for all animal mortalities, even large whales. However, to be economical for livestock producers, it must not be labor intensive and should be able to use equipment and carbon feedstocks that are readily available on-farm. With that in mind, there has been a considerable amount of mortality research on process and feedstocks as well as pathogen control and livestock, human and environmental health.

Process and Feedstocks

Bedding from animal pens – carbon material mixed with livestock manure – is the cheapest and most available feedstock on a livestock farm. Successful composting of dead swine (Fonstad et al., 2003), sheep (Stanford et al., 2000), and calves (Stanford et al., 2009) has been accomplished with straw/manure mixes and turkey carcasses (Rahman, 2012) with sunflower-hulls-based turkey litter. Feasibility of year-round composting of lamb and mature sheep mortalities within the arid climate of the Canadian prairies was also looked at in terms of feedstock. In the winter, when manure was wetter and more dense, decomposition slowed down with less air flow and became anaerobic indicating a need to add more carbon material for better aeration. Too much aeration from the carbon source can also reduce temperatures and slow down decomposition as was observed over the winter in road-killed carcass piles in NY where wind was high and snow cover was minimal (Schwarz et al., 2010). In addition, the amount of carbon required, especially the amount used for the base material, is important. Rozeboom et al., 2009, suggest that the most important factor in determining compost volume is the target animal tissue density. This density has been determined through experimentation where animal tissue composting has been successfully accomplished using densities varying from one-half to 15 pounds of animal tissue (mortality) per cubic foot of bulking material (carbon). This has been further demonstrated by Tablante and Malone, 2005, who found that with the mix-and-pile method, a minimum of 2.1 cm of base litter material was required for each 5 kg of meat per square meter (target animal tissue density of 14) of floor space for in-house composting. With larger birds or with the layering method of composting, the factor increased to 2.6 cm of base litter for each 5 kg of meat per square meter (target animal tissue density of 12) of floor space.

Comparison of pine shavings, a 50:50 mixture of pine shavings and poultry litter, and hay as the carbon source for composting large animal carcasses showed that shavings and the 50:50 mixture maintained higher temperatures and were more effective at decomposing bones when compared to hay (Payne and Pugh, 2009). A comparison of biodegradability of swine carcasses

in passively aerated composting systems using corn silage, ground cornstalks, and ground oat straw as the envelope material showed that after 16 weeks of composting only 66% of the initial carcass mass had decomposed in corn silage as compared to 86 and 79% in ground cornstalks and oat straw, respectively (Ahn et al., 2007). Further research using these same materials was conducted over three different seasons to assess time/temperature criteria for pathogen reduction (Glanville et al., 2013). Internal temperatures met USEPA Class A time/temperature criteria for pathogen reduction in 89, 67, and 22%, respectively of seasonal test units constructed with corn silage, straw/manure, or ground cornstalks.

Pathogen Inactivation

As temperature is related to pathogen kill, research has been conducted on composting as a means of emergency management and disease control. Although time/temperature criteria was not met consistently in the aforementioned study (Glanville et al., 2013), survival times of vaccine strains of avian encephalomyelitis and Newcastle disease virus in cornstalk and straw/manure test were similar to those in test units constructed with silage during summer trials, but noticeably longer during winter trials. Pathogen reduction in road-killed deer composting piles took up to 12 months in piles where the highest temperatures reached were 40°C compared to 3 months in piles reaching 55°C, suggesting that the athermic properties of composting are also at work in pathogen and disease control (Schwarz et al., 2010).

The inactivation of viruses during composting is determined by a combination of chemical, physical and biological factors. The most important is the heat generated during the thermophilic phase, but pathogens are also inactivated by microbial degradation and ammonia. According to Winchuk and McCartney, 2007, pathogen reduction during composting is accomplished to some degree by several processes, including competition between indigenous microorganisms and pathogens, antagonistic relationships between organisms, the action of antibiotics produced by certain fungi and actinomycetes, natural die-off in the compost environment and production of toxic by-products such as gaseous ammonia, nutrient depletion, and thermal destruction. As these mechanisms work together during composting, viral inactivation should be attributed to a synergistic interaction between them, rather than to each mechanism taken individually. In general, the temperature increase seen during the first phase of an optimal compost process (thermophilic composting) exceeds the temperature levels needed for viral inactivation. For catastrophic carcass composting, the Canadian Food Inspection Agency has suggested using the term “bio-heat treatment” to clarify that the composting process produces heat, NH₃ and other products that can kill viruses (Spencer et al., 2004).

According to Guardabassi et al., 2003, bacteria and protozoa are important to virus removal. Many bacteria produce proteolytic enzymes inactivating enteric viruses, including certain bacterial species that are prevalent in the mesophilic flora during maturation of compost, for example *B. subtilis*. It also appears that viruses may serve as a nutrient source for bacteria, as indicated by the recovery in bacterial cells of labelled viral capsid proteins. In two different studies where viruses (Poliovirus I and HAV) were composted in mixed waste that included animal manure versus autoclaved waste or septic tank effluent alone, viral destruction was quicker. Many researchers have shown that composting inactivates pathogens such as *E. coli* O157:H7 (Xu et al., 2009), and *Salmonella* (Collar et al., 2009), and viruses such as Newcastle disease (ND) virus (Benson et al., 2008) Avian Influenza (AI) virus (Senne et al., 1994; Flory and Peer, 2009), and adenovirus that causes egg drop syndrome-76 (Senne et al., 1994) and have attributed this inactivation to high temperatures. However, Senne’s work showed that despite differences in temperature between lower and upper levels of carcasses, two-stage composting (2 cycles of 7 days separated by turning) was found to destroy various avian pathogenic viruses in infected carcasses. The peak temperatures reached during composting

were 58.3° C in the upper level and 42.8° C in the lower level. In addition, using real-time reverse transcriptase polymerase chain reaction (PCR), Guan et al., 2009, provided evidence that in addition to temperature, microbial activity during composting contributed to the rapid killing of AI and ND viruses and to the degradation of their viral RNA. Viruses in mesh bags were inactivated by day 21 in compost held at ambient temperatures of 13 to 28° C while those in sealed vials survived to day 21 and the time required for a 1 log₁₀ reduction of viruses was significantly shorter in water extracts made from compost than in phosphate buffers at temperatures of 25 to 45° C. Elving et al., 2012, showed that acceptable inactivation of H7N1 Highly Pathogenic Avian Influenza (HPAI) virus can be achieved rapidly within the compost material even at mesophilic temperatures of 35° C and Guan et al., 2012, report that compost temperatures of 35° C for a day should be sufficient to kill Bovine Viral Diarrhea (BVD) virus and support the claim that similar composting conditions should be sufficient to destroy the closely related Classical Swine Fever (CSF) virus.

Lu et al., 2003, studied AIV resistance to different environmental factors. AIV was mixed with different types of chicken manure and incubated at several different temperatures. Controls of AI virus alone were also incubated at the same temperatures. The manure was from field chickens, and also from specific pathogen free (SPF) chickens. These particular SPF chickens, as their name indicates, are guaranteed to be free of the AIV being used. The field manure/AIV mixture lost its infectivity after 15 minutes at 56°C, 24 hours at 30-37°C, and 2 days at 15-20°C. The SPF chicken manure/AIV mixture lost its infectivity after 20 minutes, 36 hours and 6 days, while AIV alone (no manure) took 90 minutes, 12 days and 32 days, respectively. AIV mixed with field chicken manure lost its infectivity about 5 to 10 times faster than unmixed AIV control. In comparison of chicken manure source on AIV inactivation, it can be concluded that field chicken manure had a quicker inactivating effect over the SPF chicken manure. Field chicken manure that naturally contains microorganisms or their digestive enzymes or by-products has the ability to destroy AIV in less than a week under field conditions at ambient or higher temperatures. Glanville et al., 2006, conducted a three-year study to examine the feasibility, performance, environmental impact and biosecurity of composting as a disposal method should a livestock or poultry disease outbreak occur in Iowa. They ran 6 seasonal field trials in which they looked at several different cover materials for composting cows. Among other parameters, they implanted and retrieved samples of vaccine strains of 2 common avian viruses (avian encephalomyelitis [AE] and Newcastle disease virus [NDV], both of which are highly representative of other viruses, such as influenza viruses) to evaluate the potential of emergency composting procedures to inactivate viral pathogens, and did blood sampling and serum testing of SPF poultry housed in cages near selected composting test units to assess the potential of the composting operations to retain live viruses. Both AE and NDV were inactivated during the composting process. When just subjected to heat, survival time ranged from 2 days to 4 weeks for NDV and 1 to 7 weeks for AE. When subjected to heat plus other stress factors in the composting pile, both types were inactivated within one week regardless of the season or type of cover material. This implies that other factors, besides heat alone, play important roles in pathogen reduction during composting. Negative serum antibody test results for 71 of 72 SPF poultry housed in cages located within a few feet of the composting test units indicate that the birds were not exposed to the live AE and NDV viruses applied to the carcass surfaces when the piles were constructed. This suggests that the composting process deactivated the viruses. When the virus was applied to the external surface of the windrows, there were 6 of 22 positives, indicating that contaminated material should not be used in the outer envelope of the compost pile.

Viruses such as picornavirus (responsible for Foot and Mouth disease), Infectious Bursal Disease virus (IBDV), and pseudorabies virus (responsible for Aujeszky's disease) pass into the environment from clinically ill or carrier hosts, and although they do not replicate outside living

animals or people, they are resistant to many environmental stresses and thus can be maintained and transported to susceptible hosts. Guan et al., 2010b, investigated the inactivation and degradation of foot-and-mouth disease (FMD) virus during composting of infected pig carcasses as measured by virus isolation in tissue culture and by PCR. FMD was inactivated in specimens in compost by day 10 and the viral RNA was degraded in skin and internal organ tissues by day 21. In another study, by day 7 in compost, IBDV had been inactivated in specimens that had been inoculated with virus and was inactivated in tissues taken from infected chickens by day 14 (Guan et al., 2010a). Survival of pseudorabies virus (PRV) was studied by Garcia-Siera et al., 2001. Pigs infected with PRV were composted for 35 days. Tissue samples collected on days 7 and 14 were culture negative for PRV. Paluszak et al., 2012, observed survival rate of Suid Herpesvirus (Aujeszky's disease virus) under the influence of temperature alone (water bath) compared to composting in sewage sludge. The viruses survived considerably longer under laboratory conditions: as long as 21 days at 30° C, 93 hours at 40° C and less than an hour at 50° C in comparison to survival time in sewage sludge, even though the highest temperature was 48° C, survival time of viruses ranged from 34 to 44.5 hours indicating that other physicochemical factors, apart from temperature, contribute to virus inactivation.

Does that then translate to composting having an effect on spore-formers, hardy viruses and other disease causing organisms, such as prions, that are more resistant to environmental stresses? Reuter et al., 2012, has performed compost studies that investigate microbial communities linked to biodegradation. *Bacillus* spp. spores (related to anthrax outbreaks) carry exceptional resistance to heat, but spore survival times were magnitudes lower when exposed to wet-heat in compost as compared to dry-heat. Their data revealed that under composting conditions, a million-fold inactivation of *Bacillus* spores occurred and residual spores within compost bio-containment are unlikely to remain at an infectious concentration due to dilution. In addition, the use of molecular biology and microbiological assays revealed biodegradation of specified risk materials and a wide range of pathogens in combination with physiochemical compost conditions. Hongsheng et al., 2007, investigated whether the abnormal prion protein (PrP^{Sc}) in tissues from sheep with Scrapie would be destroyed by composting. Before composting, PrP^{Sc} was detected in all the tissues by Western blotting, but not detected in the first experiment after composting. It was detected in the 2nd experiment but analysis showed there were more diverse microbes involved in experiment 1 than in experiment 2. It was suggested that the greater dominance of thermophilic microbes in experiment 1 may have value as a means for degrading PrP^{Sc} in carcasses and other wastes. In another experiment using PrP^{Sc} over 28 days in laboratory-scale composters, Xu et al., 2013, showed that prior to composting, PrP^{Sc} was detectable in manure with 1-2 log₁₀ sensitivity, but was not observable after 14 or 28 days of composting. The authors state that this may have been due to either biological degradation of PrP^{Sc} or the formation of complexes with compost components that precluded its detection.

According to Xu et al., 2012, recent evidence has indicated that some bacterial proteinases exhibit the ability to degrade bovine spongiform encephalopathy (BSE) prions, (PrP^{TSE}). The bacterial species capable of this activity have been shown to be associated with compost. Also, their research group previously isolated a novel keratinolytic actinobacteria involved in the degradation of hoof keratin during composting. The microbial consortia in compost could carry out the biodegradation of recalcitrant proteins such as keratin or possibly PrP^{TSE}, owing to the wide range of proteolytic enzymes produced by these complex microbial communities. Poultry feathers added to compost produced effective non-specific proteolytic activity early in the composting process and promoted the growth of specialized keratinolytic fungi that degraded keratin in feathers during the latter stages of composting. Inclusion of feathers altered the composition of microbial community within the compost matrix, resulting in the establishment of

communities that were more adept at degrading keratin and specified risk material (SRM). In 2014, Xu et al., further investigated degradation of prions associated with scrapie, chronic wasting disease (CWD) and BSE in lab-scale composters and scrapie in field-scale compost piles. Western blotting (WB) indicated that the prions for scrapie, CWD and BSE were reduced by at least 2 log₁₀, 1-2 log₁₀ and 1 log₁₀ after 28 days of lab-scale composting, respectively. Further analysis by protein misfolding cyclic amplification (PMCA) confirmed a reduction of 2 log₁₀ in scrapie prions and 3 log₁₀ in CWD. Addition of feather keratin (for proteolytic microorganisms) enhanced degradation of both scrapie and CWD prions. In field-scale composting scrapie prions were removed periodically for bioassays in Syrian hamsters. After 230 days of composting, only one in five hamsters succumbed to transmissible spongiform encephalopathy (TSE) disease, suggesting at least a 4.8 log₁₀ reduction in scrapie prion infectivity. Their research findings show that composting reduces TSE prion resulting in one 50% infectious dose (ID50) remaining in every 5600 kg of final compost for land application. Microbial activity is likely part of the destruction of TSE prions (greater reduction in field scale which had longer periods of temperature above 55° C, than lab scale where it was only 1 or 2 days of > 55° C – temp indicating greater microbial activity). Addition of chicken feathers (composed of β-keratin) enhanced protease activity in compost and promoted the growth of specialized keratinolytic fungi with the capacity to degrade feathers. As TSE prions share some structural similarities with feathers (both are rich in β-sheets), this may have helped in the destruction of prions.

Environment

Disease issues are not the only concern in mortality composting. Concentration of nutrients in leachate from composting are a concern for the environment, as well as in the use of the compost product. Hutchinson, et al., 2012, found that carcass compost piles develop an identifiable structure with zones that can be distinguished based on color, texture, moisture and chemical composition. This structure appears to help minimize nitrogen losses by intercepting both soluble nitrogen in fluids and gaseous ammonia and concentrating them in the organic material. Compost leachate is variable in terms of its chemistry and is influenced by feedstock, process, maturity, cover and weather. Generally, the higher the carbon to nitrogen ratio, the less leachate will be formed. Woodchips as a base will absorb leachate, and lower turning frequency will decrease leachate production. Donaldson et al., 2013, demonstrated this in a study that analyzed leachate constituents in deer mortality static windrow composting. They concluded that soil filtration of leachate was effective in reducing concentrations of ammonia, chloride, and total organic carbon, and the low volume of leachate (i.e. two percent of the precipitation that fell on windrows) results in nominal losses of nitrate and other contaminants. Schwarz, et al., 2013, also showed that very little leachate is produced during carcass composting as approximately 1.7% of total fluids from a horse carcass were collected, with the rest being absorbed by the woodchips in the compost pile. However, if composting is performed using too dense material that is not able to reach temperature, more leachate is generated and can become problematic in terms of nutrient loading as well as resulting in higher pathogen levels in the end product (Bonhotal and Schwarz, 2009).

Conclusion

During composting, pathogen reduction is achieved primarily through thermal destruction, but also through competitive interactions between microorganisms, nutrient depletion, by-product toxicity and natural die-off. Microbial activity during composting contributes to the rapid killing of bacteria, viruses and even to the inactivation of hardier pathogens and prions. Greater microbial activity results in faster degradation. Proteolytic enzymes produced by bacteria and/or

temperature and pH changes caused by microbial metabolism may contribute to virus and other pathogen inactivation. High pH, low moisture, microbial activity, free ammonia and high temperature are among the most unfavorable conditions for pathogen survival. Mortality composting not only has been proven effective in deactivating pathogens, but also limits the risk of groundwater contamination and air pollution. On-site composting reduces the potential for farm to farm disease transmission and decreases transportation costs and tipping fees associated with off-site disposal. There is also the added benefit of producing a usable product. Composting should be considered as one of the first disposal methods in any emergency situation.

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