Final Project Report

Environmental Impacts and Biosecurity of Composting for Emergency Disposal of Livestock Mortalities

by

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PREFACE

This report presents key results of a three-year study sponsored primarily by the Iowa Department of Natural Resources. Biosecurity studies included in this project were partially funded through a USDA-National Research Initiative grant.

Primary objectives of the study were to evaluate the effectiveness, environmental impacts, and biosecurity of using composting for emergency disposal of cattle mortalities, and to recommend materials and composting practices that could be used in the event of a livestock or poultry disease outbreak or agro-terrorism in Iowa.

To meet the information needs of a variety of potentially interested readers, the report is organized in four main sections.

- The executive summary summarizes the purpose and key results for general interest readers.
- The main body of the report describes study objectives, methods, and findings in detail for scientists, engineers, regulatory officials, and others who may be interested in incorporating aspects of this study into new environmental policies, or in conducting similar research.
- The recommended practices section is written for producers, veterinarians, and others in the livestock industry who may be involved in implementing an emergency disposal operation.
- For readers interested in composting theory or in additional details regarding methods used in this research, Appendix H lists project-related conference papers presented at various professional meetings. Readers are cautioned that project results reported in these papers were based on preliminary data available at the time they were written, and these results may not reflect the final data interpretations presented in this report.

The project website, which is located at http://www.abe.iastate.edu/cattlecomposting/ also provides detailed information and many photographs documenting project methods and results.

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Disclaimer

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EXECUTIVE SUMMARY

Following the foot-and-mouth disease epidemic in Great Britain in 2001, the Iowa Department of Natural Resources (IDNR) commissioned Iowa State University to conduct a three-year study to evaluate the practical feasibility, performance, environmental impacts, and biosecurity of using composting for emergency disposal of cattle — or large quantities of smaller species — should a livestock or poultry disease outbreak (or agro-terrorism) occur in Iowa.

During the three year study approximately 49,000 kg (54 tons) of 450 kg (1,000 lb) cattle carcasses were composted in 27 full-scale test units, each containing 1800 kg (2 tons) of cattle carcasses. Since composting operations can be adversely affected by seasonal weather conditions, the study included six seasonal field trials — each lasting approximately 12 months — that were begun during times of the year that can pose challenging conditions for composting (spring – cool/wet, summer – hot/dry, winter- cold/dry).

During the seasonal field trials, test units were extensively monitored to evaluate composting performance, environmental impacts, and process biosecurity. Three emergency carcass cover materials — corn silage, ground cornstalks, and straw/manure — were evaluated in replicated field tests, and these and 10 other potential cover materials were also extensively tested in the lab and mathematically modeled to characterize and predict their performance potential for use in both routine and emergency mortality composting operations.

Field monitoring included:

- continuous logging of internal operating temperatures in three zones (core, carcass surface, and outer envelope) to assess general composting performance and the ability to meet pathogen reduction criteria developed and used in the biosolids composting industry;
- periodic measurement of internal oxygen concentrations in three zones (core, carcass surface, and outer envelope) to assess evaluate the ability of the cover materials to transport oxygen to the carcass decay zone, and to transport excess water vapor and composting gases out of the pile;
- periodic excavation of selected test units to observe and photograph carcass decay and to estimate the time necessary for completion of soft-tissue decomposition;
- leachate capture, quantification, and chemical testing to evaluate soil and water pollution potential;
- soil testing to a depth of 4 feet — before and after composting — to assess actual pollution impacts on soil and shallow groundwater;
- collection of odor samples from the outer surface of the composting test units to evaluate air pollution potential;

- implantation and retrieval of samples of vaccine strains of two common avian viruses to evaluate the potential of emergency composting procedures to inactivate viral pathogens; and
- blood sampling and serum testing of specific-pathogen-free poultry housed in cages near selected composting test units to assess the potential of the composting operations to retain live viruses.

Laboratory testing and modeling included:

- comprehensive testing of 5 cover materials used in field trials — and 9 alternative organic cover materials — for bulk density, porosity, free air space, initial moisture content, water holding capacity, volatile solids, pH, electrical conductivity, mechanical strength, biodegradability, respiratory quotient, gas permeability, thermal conductivity, and specific heat capacity;
- assessment of the practical value of the laboratory tests listed above in terms of their relationship to composting theory, reliability, ease of completion, and relevance to observed field performance;
- identification of four key laboratory tests that appear to be most useful in predicting cover material performance;
- ranking of the 13 potential cover materials — based on both field and key test parameter performance — with regard to their suitability for use in routine mortality composting, non-disease-related emergency composting, and disease-related composting; and
- mathematical modeling of the 13 cover materials to determine maximum windrow heights that permit maintenance of sufficient free air space for gas transport and good composting.

Key findings and recommendations of the study are as follows:

Carcass degradation - periodic excavation and observation of small sections of selected windrows showed that all soft tissues associated with the 450 kg carcasses were fully decomposed within 4-6 months in unturned emergency composting windrows constructed during warm weather, and in 8-10 months in unturned windrows constructed during cold-weather.

Internal temperatures – continuous temperature monitoring showed that test units constructed with corn silage reached temperatures in excess of 55 °C in only one or two days regardless of external temperatures, produced the highest core and carcass surface zone temperatures (usually 60-70 °C), and sustained high temperatures the longest of any of the materials tested. Test units constructed with ground cornstalks or straw and manure were generally 10-20°C cooler than those constructed with corn silage, and sometimes took a week or more to reach peak temperatures if their initial moisture content was low.

Pathogen reduction potential - test units constructed with corn silage met USEPA Class A time/temperature criteria for pathogen destruction in biosolids in 89% of the seasonal units tested. Class A requirements in the carcass surface zones of straw/manure test units were achieved in 67% of test units, and in 22% of the cornstalk units. Less stringent USEPA Class B requirements for significant reduction of pathogens were attained in the carcass surface zones of 100%, 67%, and 22% of the silage, straw/manure, and ground cornstalk test units respectively.

Internal oxygen concentrations - reflecting the high gas permeability characteristic of ground cornstalks, mean O_2 concentrations within the core, carcass surface, and outer envelope zones of test units constructed with this material exceeded 15%, and minimum values never dropped below 11%. Mean O_2 concentrations in the core zone of corn silage and straw/manure test units, however, were in the 5-10% range during the initial weeks of the trials and minimum values dropped below 5%. In the carcass surface and outer envelope zones, mean O_2 concentrations for silage and straw/manure units exceeded 10% at all times, and minimum values were above 5%.

Impact of temperature and O_2 on carcass degradation - despite substantially higher internal temperatures in silage test units, soft tissue degradation times of carcasses in silage test units appeared to be essentially the same as for those in test units constructed with ground cornstalks or straw/manure. This emphasizes several important points regarding temperature and microbial activity. First, while high temperatures are sometimes indicative of higher microbial activity, they also can occur when microbial activity is moderate but heat retention is high due to use of cover materials with good insulating characteristics. Furthermore, as temperatures rise above 60°C, microorganisms begin to die or go dormant, thereby slowing the rate of decay. Considering the higher O_2 concentrations within the cornstalk test units — indicative of higher gas permeability and intrusion of cool external air — it is believed that lower temperatures within cornstalk and straw/manure test units are due mainly to heat loss — not low microbial activity — and that the similarity in carcass decay times reflects similar biodegradation rates in the interior of the piles.

Odor release and air pollution potential – 30-45 cm of ground cornstalks, ground straw, or silage were effective at containing, breaking down, and masking odorous gases released during carcass decay. The 75th percentile of odor threshold data for air samples collected from the surfaces of mortality compost piles and cover material stockpiles (during the first 4 weeks following construction) were similar to those reported for pond water (200 - 300 ODT) for cornstalk and straw/manure piles, and less than 1400 for silage. Theses odor detection levels are considered to be quite low for manure-related facilities and, due to the low ODT, small pile area, and naturally-occurring dilution between the pile and a neighboring residence, it is concluded that properly managed emergency mortality composting piles would not present an odor nuisance problem.

Leachate release & soil/water pollution potential - evidence of runoff from the emergency composting windrows was rarely noted. Leachate volumes captured beneath the test units were less than 5% of the precipitation (500-600 mm) that fell during the year. The high water holding capacity and gas permeability of the cover materials, resulting in temporary absorption and subsequent evaporation of excess water, are believed to account for their relatively low leachate release. Peak concentrations of selected contaminants (total organic carbon, total solids, and ammonia-nitrogen) in the leachate were high, but the total mass of contaminants calculated to have leached into the soil beneath the windrows was relatively low. Organic carbon loadings, for example, were calculated to be less than 8% of the estimated total carbon in the top 15 cm of soil, and NH_3-N loadings were generally less than 40 kg/ha (35 lb/acre).

Soil contamination – Statistically significant increases in chloride concentrations were noted in all depth increments of soil cores collected beneath the composting test units indicating that leachate had penetrated to depths of 120 cm (4 ft) or more. Significant increases in % total carbon, and % total nitrogen were limited to the top 15 cm (6 in) of soil, occurring only beneath silage test units for total carbon, and beneath silage, cornstalk, and straw/manure test for total N. The increases in these pollutants were moderate, amounting to less than 20% of pre-composting concentrations of % total carbon, and 10-40% of % total N concentrations prior to composting.

Large and statistically significant increases in ammonia-nitrogen were found at depths of up to 90 cm (3 ft) beneath test units constructed with silage or leaves, and at 30 cm (1 ft) and 15 cm (6 in) depths respectively beneath test units constructed with straw/manure and cornstalks. These increases were 40-160 times pre-composting levels of ammonia-nitrogen in the topsoil, and are roughly equivalent to fertilizer or manure nitrogen applications of 360 – 1440 kg/ha (325-1300 lb/acre). High residual concentrations of ammonia-nitrogen in the topsoil following composting are expected to nitrify following removal of the finished compost from the disposal site. This may lead to subsequent nitrate pollution of the subsoil or shallow groundwater. Further monitoring of soil N at the composting research site is recommended to better understand the dynamics of ammonia dissipation in the soil, and to evaluate mitigation measures that can help to minimize groundwater pollution risks.

Despite the large increases in ammonia-nitrogen concentrations in the topsoil, when compared with the groundwater pollution potential of carcass burial — the most common on-farm method for emergency disposal of livestock carcasses — the nitrogen-related groundwater pollution risks associated with composting appear to be much lower. The total mass of N contained in the composted cattle carcasses was 4–10 times greater than the increases in N that were measured in the soil beneath composting test units. Furthermore, burial would have placed the carcass N much closer to the groundwater, further increasing the risks of groundwater pollution.

Soil pollutant loading rates predicted from measurements of leachate volume and pollutant concentrations are considerably lower than the loadings indicated by pollutant concentrations measured in the soil cores. This may have resulted from inaccurate measurement of leachate volumes, loss of chemical pollutants from the leachate, or a combination of these mechanisms. Loss of volatile compounds, such as ammonia, from the collection vessels is believed to be the most likely source of this discrepancy.

Pathogen reduction - vaccine strains of avian encephalomyelitis and Newcastle Disease virus were reliably inactivated during emergency composting of large animal carcasses in unsheltered windrows. When the test viruses were contained in sealed vials that protected them from stress factors other than heat, survival times ranged from 2 days - 4 weeks for NDV, and 1-7 weeks for AE. When the test viruses were contained in dialysis cassettes which exposed them to heat plus other stress factors, both types were inactivated within 1 week regardless of the season when the trial was begun, or of the type of cover material used. This does not imply that time/temperature criteria are not important factors in virus inactivation, but it suggests that other factors also play important roles in pathogen reduction.

Pathogen containment – Negative serum antibody test results for 71 of 72 pathogen-free sentinel poultry housed in cages located within a few feet of the composting test units indicate that the vast majority of the sentinel birds were not exposed to live AE and NDV viruses (vaccine strains) that had been applied to carcass surfaces when the test units were constructed. This further suggests that 45-60 cm (18-24 inches) of clean cover material placed over the contaminated carcasses were reasonably successful at retaining viruses until they were inactivated. Positive serum antibody test results (6 of 22 birds tested positive for NDV) in sentinel poultry exposed to test units whose external surfaces had been contaminated with vaccine strains of AE and NDV, confirm that live viruses do not reliably adhere to the external surfaces of emergency composting piles, and that use of pathogen contaminated materials in the outer envelope of emergency composting windrows can expose nearby birds or animals to disease. This further emphasizes the importance of using a sufficiently thick layer of uncontaminated materials over the emergency composting piles to help insure pathogen retention.

Consistently negative serum antibody results during supplemental tests in which poultry were exposed to dust from finished compost (0 of 23 birds tested positive), and to soil beneath composting test units (0 of 6 birds tested positive), provide further evidence that emergency composting procedures are reasonably bio-secure and that the composted material is safe to handle and spread.

Predicting cover material performance - comprehensive physical and biological testing of 13 potential cover materials — combined with field performance data for 5 of those materials — suggest that water-holding capacity, gas permeability, mechanical strength, and biodegradability are the most useful variables for predicting cover material performance.

Cover material ranking and recommendations - Based on laboratory testing and field observations, turkey litter, corn silage, oat straw, and alfalfa hay are top ranked for use in disease-related carcass disposal scenarios where production and retention of heat, and ability to retain liquid, are critical in reducing pathogens and retaining leachate in un-turned windrows. These materials, and four others — ground cornstalks, wood shavings, sawdust and soybean straw — are also considered suitable for composting routine or emergency mortalities that have not been caused by disease.

Guidelines for emergency composting – The following general guidelines are based on results of the comprehensive 3-year emergency cattle mortality composting research, as well as on practical experience with non-emergency composting practices used in the swine and poultry industries. These general guidelines are based on performance observations made under Iowa environmental conditions (temperature, wind, precipitation, soil type) and using specific types of cover materials produced in Iowa. They may not be appropriate for locations having significantly different climatic or environmental conditions, or when using cover materials whose physical, chemical, or biological characteristics differ substantially from the cover materials tested during this study.

Composting System & Configuration

- Narrow-based windrow composting systems are recommended for emergency mortality disposal — they are practical to construct with on-farm equipment and materials, and do not require construction of special facilities (base pad, walls, cover) if the proper types and thickness of organic base/cover material are used.
- To promote oxygen penetration, release of excess heat, and evaporation of excess water, a long and narrow windrow configuration is preferable to a wide-based system. For full-sized (1,000 lb) cattle, a maximum base width of 16-18 ft is recommended (this is sufficient for two full-sized cattle laid side-by-side).
- Properly constructed and operated emergency cattle mortality composting operations do not pose unusual pollution threats to soil, water, or air quality but should be sited observing

recommended setbacks from roadways, public land, private dwellings, wells, streams, and active poultry and livestock operations, that are typically used for other animal waste facilities. To the extent possible, select a reasonably level location that will not be subject to overland flow of runoff during rainfall or snowmelt.

Base/Cover Material Selection and Thickness

- If livestock death is caused by disease, use of moderately moist corn silage or a similar material that quickly produces and sustains high internal temperatures, is recommended as it offers the best potential for quick pathogen inactivation. Laboratory testing suggests that materials that are likely to have heating and heat retention characteristics similar to corn silage include alfalfa hay, turkey litter, and oat straw.
- Ground cornstalks, ground soybean straw, wood shavings, sawdust, leaves, ground wheat straw, and dry bedded beef manure will sustain carcass decay and retain excess water, and are suitable for routine or non-disease-related carcass disposal. These materials have low potential for rapid development of sustained high temperatures, however, and are not the cover material of choice for situations where rapid pathogen reduction is desired. Dense, soil-like, or fine-textured materials similar to the soil/compost blend tested during this study should not be used for emergency carcass composting. Such materials tend to lack sufficient free air space, and are prone to compaction and moisture retention leading to further loss of free air space. This can lead to low O_2 concentrations in the core and carcass surface zones of the composting pile, and very slow carcass decay.
- Avoid using any base/cover materials that are too wet. To test wetness, squeeze a handful tightly. If any water drips out, the material is too wet and may perform poorly due to reduced water absorption, low oxygen transmitting capacity, and high leachate production.
- Long and fibrous agricultural residues must be ground (2-inch maximum length recommended) prior to use as carcass composting cover material to enhance their water absorbing capacity and to minimize formation of large voids in the outer envelope that could lead to carcass exposure, excessive heat loss, and leachate release.
- To minimize the risks of excessive leachate release a 24-inch deep base layer beneath the carcasses is recommended.
- To minimize the risks of both odor and leachate release, a 24-inch thick envelope of cover material over the carcasses is recommended.
- To avoid excessive compaction and subsequent loss of free air space in the base layers of the windrow, pile heights should be limited to a maximum of 2m for turkey litter, 1m for dry bedded beef manure, and 0.5m for dense soil-like materials (not recommended for emergency

composting) such as the soil/compost blend. For the remaining 10 materials tested, compost modeling indicates that pile heights of up to 3m can be used without serious compaction.

Organic Loading Rates

- Every 1,000 lbs of carcasses contains approximately 650 lbs of water, so stacking of large carcasses greatly increases the likelihood of leachate production, excessive compaction of base layers, severe pile settling, and development of anaerobic conditions beneath the carcasses.
- To avoid the problems listed above, it is recommended that large (> 750 lb) carcasses be composted in single layers (no stacking).
- Smaller carcasses may be stacked if at least 12-inches of absorptive material are placed between layers.
- Windrow mass loading rates of one ton (2,000 lbs) of carcasses for every 8 feet of windrow length proved successful during the study. Higher mass loading rates will increase the quantity of water in the pile and may lead to low internal O_2 concentrations, reduced decay rates, and release of leachate from the sides of the windrow.

Operation

- Windrows constructed with cover materials that are sufficiently permeable (see material recommendations) to air flow need not, and should not, be turned if mortalities were caused by disease, until soft tissues are fully decayed.
- Non-disease-related mortalities may be turned to improve oxygen transfer and moisture distribution, but turning of large carcasses too early in the decay process can release odors or cause undue cooling during cold weather. It is recommended to wait at least 90 days before turning heavily loaded emergency composting windrows, and extra cover material should be kept on hand to control odor releases if they occur following turning.

Amount of Base/Cover Materials Needed

- Using the recommended narrow-based windrow geometry (16-18 ft base width with pile height ~ ½ of base width) and 24-inch base and outer envelope layer thicknesses, approximately 12 cubic yards of base/cover material will be needed for every 1,000 lbs of large cattle carcasses composted in an emergency windrow system. At typical cover material densities in newly-constructed windrows, this is equivalent to 1.0 ton of ground hay or straw, 1.4 tons of ground cornstalks, or 3.2 tons of corn silage.
- Due to the large volume of cover material required, livestock operations planning to use composting for emergency mortality disposal should plan on stockpiling sufficient quantities of cover material, or develop a plan for quickly locating and hauling sufficient material to meet emergency needs.

Site Cleanup and Remediation

- Finished cattle mortality compost may include large bones that can interfere with tillage and planting, or offend nearby residential property owners. Additional tillage operations may be needed to break up or cover the bones. Use of a manure spreader equipped with a hammer-mill type discharge can help to reduce the size of large bones. Screening and burial of the large bones is another option.
- The uppermost layers of topsoil located beneath carcass composting windrows may accumulate salts or other phytotoxic materials that suppress crop emergence and growth. Tillage of these soils may help to break up the affected layer and mix it with uncontaminated soil, thereby improving 1st year crop production.

PROJECT BACKGROUND

As one of the largest producers of meat and eggs in the United States, Iowa has extensive livestock and poultry populations including: 15,800,000 pigs [#1 in U.S.]; 3,400,000 cattle & calves [# 8 in U.S.]; and 50,000,000 laying hens [#1 in U.S.].

Because of these very large numbers, major herd or flock depopulation necessitated by a disease outbreak or agro-terrorism incident could pose serious logistical and environmental problems. As was the case during the 2001 foot-and-mouth disease outbreak in Great Britain, rendering plant capacity — and the trucking capacity needed to move huge numbers of carcasses to Iowa's five rendering plants —would most likely be overwhelmed. Furthermore, the increased biosecurity risks associated with transporting diseased carcasses large distances to central disposal facilities further complicates this option.

On-farm burial, the long considered the most cost efficient method for disposal of occasional poultry and livestock losses, could pose serious pollution threats to local groundwater and surface water resources if thousands of tons of carcasses needed to be disposed of at one time. Iowa Department of Natural Resources analysis of geographic data indicates that nearly 40% of Iowa is characterized by shallow groundwater resources, shallow fractured bedrock, or other environmentally sensitive conditions that would make burial of large quantities of carcasses undesirable. Furthermore, mass burial during the winter months when the ground is frozen, although not impossible, would require heavy duty soil ripping and earthmoving equipment that could take days or weeks to line up. Finally, it should also be recognized that every 450 kg (1,000 lbs) of animal carcasses contains about 10 kg (22 lbs) of organic nitrogen, and that high density emergency burial procedures, which can easily result in total carcass mass loading rates of more than 1,500,000 kg/ha (1,350,000 lb/acre) and organic nitrogen loading rates in excess of 33000 kg/ha (30,000 lbs/acre).

Burial in public landfills that are designed and constructed to minimize threats to groundwater, poses less of a threat to groundwater than on-farm burial. Like rendering, however, this disposal option would require massive transport of potentially infectious over public roads and past neighboring livestock operations.

Petroleum or wood fired incineration equipment of the type routinely used for on-farm disposal of small carcasses would be of little use during a large scale disposal emergency. Such equipment has relatively low capacity, and is used mainly for small carcasses. Open pyre incineration like that used during the early stages of the foot-and-mouth epidemic in Great Britain, require huge quantities of wood fuel that are not readily available in Iowa. This method also causes significant air pollution, a fact that quickly led to public outcry and a subsequent ban by the British government. High capacity trench- or box-type air curtain incinerators produce much less air pollution and have been used successfully for large scale disposal of carcasses following hurricanes and other natural disasters, but this type of equipment — and the large quantities of fuel it requires — is not commonly available in Iowa and could take days or weeks to acquire during a widespread emergency.

PROJECT OBJECTIVES

Following the foot-and-mouth disease epidemic in Great Britain, and anticipating many of the disposal constraints described above, the Iowa Department of Natural Resources (IDNR) commissioned a three-year study by Iowa State University (ISU) to evaluate the possibility of using composting for emergency disposal of large quantities of cattle and other large livestock carcasses. Interest in emergency use of composting stemmed from the fact that composting has been widely used for routine mortality disposal in the poultry industry since the late 1980s, and more recently has been adopted for routine mortality disposal by many in the swine industry.

Although it has not been used a great deal for emergency carcass disposal, composting was successfully used to dispose of large numbers of poultry in Missouri following severe flooding in 1993, and in Iowa following a period of severe heat stress in 1996. More recently, the Canadian Food Inspection Agency reported successful use of composting for carcass disposal during an outbreak of avian influenza in British Columbia in the spring of 2004.

No emergency carcass disposal option is likely to solve all potential problems, but composting offers several significant benefits that have brought it to the attention of environmental and animal health officials. If done properly, composting provides immediate carcass containment and produces temperatures in excess of 55 °C — sufficient to kill many types of pathogens found in carcasses and contaminated manure. Since composting is done above ground, it also poses fewer threats to shallow groundwater than burial.

Composting also has potential to solve certain emergency-related logistical problems. It can be done reasonably quickly on the farm or ranch using a typical farm tractor/loader and forest or agricultural by-products — sawdust, wood chips, and ground cornstalks or straw — thereby reducing biosecurity problems and time delays associated with options that require transport of carcasses to centralized disposal facilities. Furthermore, since no excavation is required, composting can be accomplished when the ground is frozen without need for high powered digging equipment.

With the previously mentioned potential benefits in mind, the IDNR/ISU emergency mortality composting project was begun in August of 2002 with these objectives:

- develop and field test a practical composting procedure suitable for large species such as cattle that can be rapidly implemented on Iowa livestock and poultry farms during an emergency;
- field test potential carcass cover materials and provide recommendations on preferable materials, quantities needed, and the thickness of material — beneath and over the carcasses — to successfully retain leachate, heat, odorous gases, and pathogens;

- evaluate the performance of the composting process with regard to acceptable organic loading rates and carcass decay times;
- assess environmental impacts of the proposed process on air and water quality; and
- evaluate the biosecurity of the process in terms of it's ability to both retain and kill pathogens.

STUDY DESIGN & PROCEDURES

After considering the practical constraints likely to be posed by various emergency scenarios, project investigators concluded that unturned windrows appeared to offer the simplicity and flexibility needed for successful emergency implementation by livestock producers. Windrow systems are easy to adapt to any size or quantity of carcasses, they are relatively easy to construct with on-farm equipment, and windrow maintenance is limited mainly to periodic repair of holes caused by settling or burrowing scavengers.

Those familiar with composting practices will recognize that the decision to use unturned windrows is unconventional. Most composting windrows are turned periodically to increase organics degradation rates, and to reduce pathogen survival by increasing exposure of all material to the core of the windrow where temperatures are typically highest. While turning of mortality composting piles generally reduces carcass decay time, in instances where death is caused by disease, turning could also increase biosecurity risks by releasing viable pathogens into the air. To fully assess the practical value of composting for emergency situations, therefore, it was decided that the benefits and drawbacks of not turning needed to be documented during this research.

EXPERIMENTAL DESIGN

Field trials were conducted using full-scale — 6 m (long) x 5.5 m (wide) x 2.1 m (high) — windrows constructed and instrumented as shown in Figure 1. Recognizing that type of cover material and seasonal weather conditions are critical factors in emergency composting, the experimental design was formulated to facilitate performance comparisons between three potential emergency cover materials operating under three potentially stressful seasonal weather conditions — hot/dry (summer), cold (winter), and cool/wet (spring). To improve the power of statistical analyses, all seasonal and cover material combinations were planned to be replicated three times resulting in a total of 27 field test units (3 cover materials x 3 seasons x 3 replications).

Each test unit contained four 450-kg cattle carcasses placed on a 60-cm thick absorptive base layer of material and subsequently covered with at least 30-45 cm of the same material. Corn silage, ground cornstalks, and yard waste compost were originally selected for testing. The first two are commonly available on cattle farms and would normally be available in an emergency.

Though not typically found on crop or livestock farms, yard waste compost was selected for testing because — due to a ban on land filling of yard wastes passed by the Iowa Legislature in the late 1980s —

this material is stockpiled by many community or county composting facilities. Two seasonal trials using compost from the ISU yard waste composting facility, however, showed that material from this particular facility was very dense and soil-like (subsequently referred to as “soil/compost blend”) and that it performed very poorly as a cover material for mortality composting. It is believed that coarser textured (more mulch-like) yard waste composts available from other composting facilities might function adequately as an emergency cover material but, since this kind of compost was not readily available to the research team, yard waste compost was dropped from the study.

During the third seasonal trial, yard waste compost was replaced with dry unprocessed leaves, a material that performed similarly to ground cornstalks. The research team concluded, however, that large quantities of leaves were unlikely to be available throughout the state during all seasons of the year, and that this limitation significantly reduced the reliability of leaves as a potential emergency composting material.

Ground oat straw, a material that would by likely be available to cattle farmers throughout much of the year, was finally selected as the third material for replicated testing. To evaluate the feasibility of simultaneous disposal of infected manure, a 15-cm layer of scraped feedlot manure also was placed over carcasses composted in test units that were constructed with ground straw. Since the straw/manure design was introduced after the first year of the study, only two replications were done using these materials while seasonal trials using ground cornstalks and corn silage were replicated three times. Table 1 summarizes starting dates, cover materials, and number of trial replications for each of the six seasonal trials conducted during the study.

Table 1. Trials conducted during emergency composting study.

Trial #	Starting Date	Initial Seasonal Conditions	Type and Number of Test Units
1	August, 2002	warm/dry	ground cornstalks (1), corn silage (1), yardwaste/soil mixture (1)
2	November, 2002	cold	ground cornstalks (1), corn silage (1), yardwaste/soil mixture (1)
3	April 2003	cool/wet	ground cornstalks (1), corn silage (1), leaves(1)
4	June 2003	warm/dry	ground cornstalks (2), corn silage (2), straw/cattlemanure (2)
5	November 2003	cold	ground cornstalks (2), corn silage (2), straw/cattlemanure (2)
6	April 2004	cool/wet	ground cornstalks (2), corn silage (2), straw/cattlemanure (2)

COMPOST SYSTEM OPERATION

Once the windrows were constructed, operating and maintenance procedures during the research were minimal. Since windrows were not turned, it was occasionally necessary to add cover material to prevent carcass exposures caused by pile settling or occasional burrowing animals.

All test units were allowed to compost for approximately one year. During this time, small portions of selected test units were temporarily excavated with a backhoe 3-6 months following construction to photograph and assess carcass degradation.

FIELD PERFORMANCE MONITORING

Corresponding to the project objectives, field trials were monitored to assess: overall performance of the composting process; environmental impacts on soil and air; and process biosecurity. Methods and indicators used for each type of assessment are described in the following sections.

Process Performance

Process performance was assessed through: continuous logging of internal temperatures; periodic measurement of internal oxygen concentrations; and by periodic excavation of selected test units to observe and photograph the extent of carcass degradation.

Internal Temperatures

Internal temperature data provide valuable insights into heat production and retention which are critical factors affecting organic matter degradation rates. The magnitude and duration of peak temperatures also are important in assessing the ability of the composting system to inactivate pathogens.

Temperatures within each test unit were measured using 20 type-T thermocouples (10 around each pair of carcasses). As shown in Figure 1, thermocouples were positioned in three conceptual zones — 4 in the "core" zone at the center of the test unit (between carcasses), 8 in the "carcass surface" zone immediately above and below and to the side of the carcasses, and 8 in the "outer envelope" of cover material.

Temperature measurements at each thermocouple were logged electronically every 2 minutes and subsequently averaged to obtain representative hourly and daily values for each thermocouple. Daily data from all thermocouples within a conceptual zone averaged to obtain representative zone temperatures, and these were subsequently charted to observe and compare the impacts of cover material type and season on performance.

In addition to visual comparisons of temperature trends within different types of test units, the likelihood of pathogen inactivation was assessed by comparing time/temperature data in the core and carcass-surface zones with time/temperature criteria outlined in USEPA Subpart D - Part 503 rules for pathogen reduction in composted biosolids. Part 503 rules recognize two classes of biosolids.

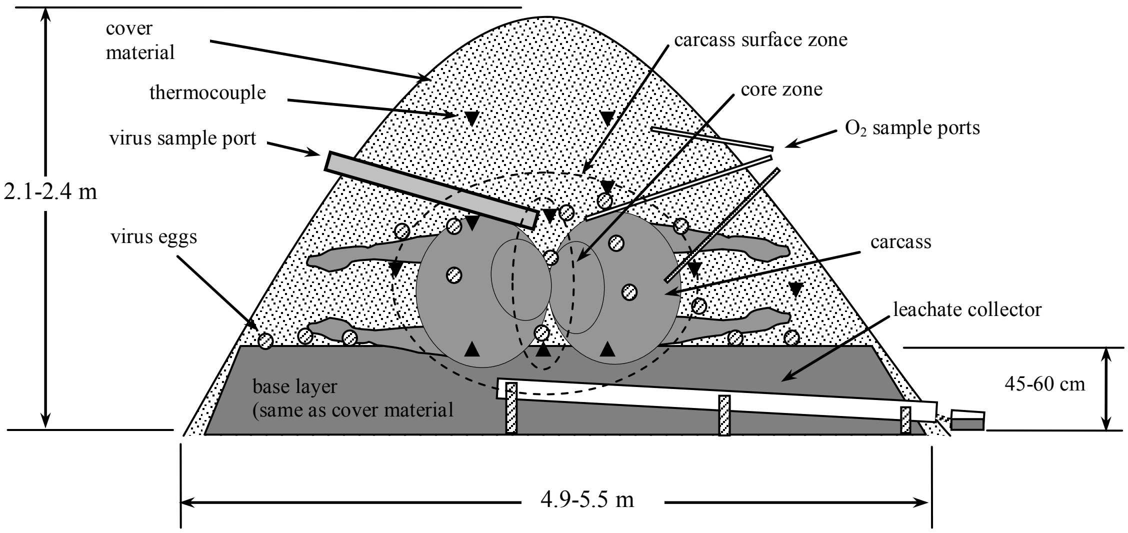


Figure 1. Cross section of emergency composting test unit showing material placement and instrumentation

Class A biosolids are treated to reduce pathogens below detectible levels, thereby enabling them to be safely applied to public or private land — such as parks or private lawns — where human contact is likely. Class B biosolids are treated to significantly reduce pathogens, but are not permitted to be applied to public access areas since disease-causing agents may still be detectible. Class B biosolids are approved for application to agricultural land and this use is believed to not pose a threat to public health or the environment.

To meet Class A requirements, Part 503 rules require that biosolids treated via static (unturned) aerated composting be exposed to temperatures of 55 °C or greater for at least 3 consecutive days. Class B composts must be exposed to temperatures of at least 40 °C for 5 or more consecutive days, and temperatures must exceed 55 °C for at least 4 hours during the 5-day period.

Internal Oxygen Concentrations

To provide an additional indicator of process performance, internal O_2 concentrations were measured every 10 days at three locations within the core, carcass surface, and outer envelope zones of the 12 test units included in trial #6. Measurements were made using an Oxy Guard portable O_2 meter equipped with an external O_2 sensor mounted within a flow-through sampling chamber (rated system accuracy = $\pm$ 1%) (Figure 2).

Attempts to measure internal O_2 concentrations during trials 1- 4 were unsuccessful due to use of a faulty O_2 meter, and to the use of an O_2 probe system that had to be inserted and withdrawn from the test unit at each location and time when measurements were made. The insertion procedure disturbed the composting matrix, making it difficult to obtain representative measures of internal O_2 that were not affected by external oxygen concentrations as well. The Oxy Guard meter was not purchased until January of 2004 and so its use was begun midway through trial 5. Three sets of readings were taken and these data and practical field experiences were used to develop reliable O_2 field measurement protocols that were applied during trial 6.

Consistent O_2 measurements during trial 6 were facilitated by permanently installing dedicated gas sampling ports consisting of small diameter polyethylene tubing at the time of test unit construction. These ports were connected to the flow-through chamber via surgical rubber tubing, thereby allowing collection of internal air with minimal disturbance of the compost matrix and minimizing introduction of air from the external environment. Sample tubes were purged prior to taking oxygen readings to minimize errors caused by introduction of external air when the O_2 meter was connected.

Figure 2. Meter, hand pump, flow-through sample cell, and dedicated gas sampling tubes used to monitor internal oxygen concentrations.

Observation of Carcass Degradation

One hundred to 180 days following test unit construction, small sections of selected units were excavated with a backhoe (Figure 3) to permit observation and photographic documentation of the extent of the cattle carcass degradation. Care was taken to disturb only as much material as necessary to obtain a clear view of the carcass. Following these observations excavated material was replaced so that decomposition could continue.

Figure 3. Temporary excavation of test unit to observe and photograph carcass decay.

Air Quality Impacts

The original research plan called for a general assessment of air quality impacts of emergency cattle mortality composting through periodic odor observations made with a scentometer at locations 30 and 150 m (100 and 500 ft) downwind from the test units. Using this approach, odor observations during year 1 were inconclusive. Compost-related odors were often difficult to detect and, when odors were detected, it was equally difficult to identify which of the adjacent test units was the source. The year 1 experience also suggested that some of the observed odors were attributable to the cover materials and that improved odor monitoring methods would be needed to distinguish these from odors attributable to mortality decomposition.

To obtain more specific and quantitative odor observations in years 2 and 3, downwind odor assessment using scentometers was replaced with weekly collection of odor samples (during 1st 4 weeks of the trial) directly from the external surfaces of each composting test unit. These were captured by placing an equilibrium chamber on the surface of each pile and using a vacuum pump to draw air from the chamber into Tedlar storage bags (Figure 4). Samples were immediately transported to the Agricultural & Biosystems Engineering olfactometry laboratory at Iowa State University where they were tested for threshold odor levels, and NH_3 and H_2S concentrations. Threshold odor levels were determined using trained odor panelists and following standard procedures in which the odor samples were diluted with successively smaller quantities of fresh air until panelists indicated that they could detect the presence of odor.

Figure 4. Collection of odor samples from surface of composting test units using equilibrium chamber, vacuum pump, and Tedlar storage bags (left), and determination of threshold odor level in ISU olfactometry laboratory (right).

To provide a basis for distinguishing between odors caused by the cover materials and those attributable to carcass decomposition, samples also were collected from the surfaces of cover materials (corn silage, ground cornstalks, ground straw) that were stockpiled at the research site. Threshold odor levels and descriptors from the stockpile samples were used as a benchmark for assessing the strength and offensiveness of mortality composting system odors relative to other odors that are common on cattle farms.

Soil & Water Quality Impacts

Leachate Quantity and Quality

During seasonal trials 1- 4, plywood leachate trays (four feet wide by 8 feet long) lined with plastic sheeting were placed beneath each pair of cattle carcasses in a test unit to capture a substantial fraction of the leachate that would be released into the soil. Trays were constructed so as to drain into shallow plastic pans that were intended to be emptied through suction lines leading to the outer edges of the piles. Despite repeated efforts to improve the design and reliability of the plywood collectors, they were plagued by operational problems. Continuous exposure to moist compost and the heavy weight of the carcasses warped and cracked the plywood resulting in loss of leachate. Furthermore, the high BOD and suspended solids content of the leachate led to serious plugging of the leachate drain tubing, making sample collection both messy and difficult. Finally, since the plastic leachate storage pans were hidden beneath carcasses and cover material, it was difficult to predict when they needed to be emptied, and this too contributed to leachate loss.

For the 12 test units included in trials 5 and 6, the large plywood collectors were abandoned and leachate was captured in U-shaped PVC plastic troughs constructed from half-sections of 6-inch diameter PVC water pipe. The troughs were mounted on 2x10 treated lumber beams that sloped from the center of the piles toward the outer edges thereby permitting gravity transfer of leachate into 1-liter polyethylene bottles at the edges of the windrow (Figure 5). Two collectors were installed in each test unit and each was positioned so as to capture an integrated sample of leachate contributed by the carcasses and the adjacent cover materials. Since the leachate collector bottles were translucent, this made it easy for researchers to tell when they were full and needed to be replaced. After transfer to the lab and storage in a freezer, total leachate sub volume was measured, and sub-samples were tested for total solids, total organic carbon (TOC), nitrate (NO_3), and ammonia-nitrogen (NH_4-N).

Figure 5. Gravity flow leachate collection troughs (left) and polyethylene leachate bottles (right) used to capture leachate samples during trials 5 and 6.

Soil Contamination

To evaluate the impacts of the carcass composting process on soil chemistry, four soil cores (3.1 cm diameter X 1.2 m long) were collected from the area beneath each test unit before and after carcass composting. Two of the four post-composting cores were collected near the center of the test units directly beneath the cattle carcasses, and two were collected from locations nearer to the edge of the test units where leachate would originate mainly from the cover material.

All cores were collected and stored in plastic zero-contamination core tube liners which were immediately transported to the lab and frozen. Prior to chemical analysis, the tubes were cut into 6 sub-samples (four 15-cm sections in the top 60 cm, and two 30-cm sections in the lower 60 cm). Sub-samples were tested for moisture content, total C and total N via combustion analysis, and for NH_4-N, NO_3-N, and Cl via standard wet chemistry procedures using KCl as the extractant for adsorbed species, and water for extraction of NO_3-N and Cl.

Biosecurity Assessment

Biosecurity evaluation procedures were designed to evaluate virus survival and the ability of composting units to retain live viruses. Survival time was assessed by placing vaccine strains of two poultry viruses (Newcastle Disease Virus - NDV, and avian encephalomyelitis - AE) into the composting piles at the time of construction and periodically withdrawing samples and testing them for viability. To help determine whether compost heating is the primary cause of virus inactivation, a portion of the virus samples was housed in sealed cryogenic vials that exposed the viruses to heat, but protected them from other environmental stresses associated with the internal composting environment. The remaining virus samples were housed in gas-permeable dialysis cassettes which exposed the viruses not only to heat produced by composting, but also to gaseous decomposition products, moisture fluctuations, and changes in pH.

NDV and AE vaccines were used to test the ability of the composting system to inactivate pathogenic viruses found within diseased animal carcasses. Cryogenic vials and dialysis cassettes were filled with media preparations containing each virus. Eight cryogenic vials and 4 dialysis cassettes (each containing 1 ml of vaccine) were inserted in each test section of the windrow. The dialysis cassettes and vials were retrieved at various time intervals throughout the trial.

Ten-day-old embryonated chicken eggs were inoculated with material from the recovered samples (10 eggs used for each sample), and the allantoic fluid was evaluated for NDV virus and brains were examined using the indirect fluorescent antibody (IFA) test for AE virus.

Viral containment (retention of viruses within a pile) was assessed by contaminating exterior surfaces of the cattle carcasses with vaccine viruses at the time of test unit construction, and by placing pathogen-free sentinel poultry in cages (warm weather trials only) at the edges of the test units. Weekly blood samples drawn from the birds during the first 2-3 months of the trial were tested for antibodies to determine if any of the sentinel birds had become exposed to the viruses. Newcastle disease virus (NDV) and avian encephalomyelitis virus (AEV) were used to evaluate the degree of bio-containment provided by composting. Twenty dozen 10-day-old embryonating chicken eggs were inoculated with NDV vaccine strain (NDV vaccine, B1 type, B1 strain, American Scientific Laboratories, Inc.) via allantoic sac as described in *A Laboratory Manual for the Isolation and Identification of Avian Pathogens*. Similarly, 20 dozen 6-day-old embryonating chicken eggs were inoculated with AE vaccine strain (Tremblex, 1143 Calnek strain, Vineland Laboratories) via yolk sac as described in *A Laboratory Manual for the Isolation and Identification of Avian Pathogens*. The NDV and AE infected eggs were incubated at 37C and at 60% humidity for 7 and 12 days respectively. After the incubation period, they were stored in the refrigerator until the starting day. As previously noted, the carcasses placed into the composting windrows were contaminated with liquid from these eggs prior to covering so as to simulate composting of diseased animals and contaminated bedding and feed.

Specific Pathogen Free (SPF) chickens were used as sentinels to evaluate the bio-containment provided by composting. These birds were housed under SPF conditions prior to the beginning of the study. Twenty-four of the 12-week-old chickens were wing banded, sampled (blood) and transferred to the project site one day after the construction of the windrows. Four chickens were placed in each of six cages surrounding the composting windrow. Blood samples were collected from each bird following transport to the field research site, at weekly or biweekly intervals. Serum samples were tested for specific NDV and AE antibodies. The hemagglutination-inhibition (HI) test was done for NDV. A typical β procedure (Diluted serum Constant-Virus) was performed as described in *A Laboratory Manual for the Isolation and Identification of Avian Pathogens*.

The Enzyme-Linked Immunosorbent Assay (ELISA) was used for AE. A commercially-available test kit (IDEXX Laboratories, Inc. One Idexx Drive Westbrook, ME) was purchased and used according to the manufacturer's directions.

To insure that the bio-containment test procedures were functioning as planned, two 12-week-old SPF chickens were spray-vaccinated with the NDV vaccine, and two 12-week-old SPF chickens were spray-vaccinated with the AE vaccine. These birds were placed in separate laboratory rooms to serve as positive controls for observation and testing. Blood samples confirmed that these birds seroconverted to NDV and AE as expected.

LABORATORY TESTING AND RANKING OF ALTERNATIVE COVER MATERIALS

Practical considerations (time, money, research space) limited replicated field testing to four cover materials (ground cornstalks, corn silage, straw/manure, and soil/compost blend). Other commonly available organic materials may perform equally well, however, and if large numbers of producers located in a particular region were forced to depopulate their herds or flocks simultaneously during an emergency — as was the case in Great Britain during the foot-and-mouth disease epidemic in 2001 — it may be necessary to rely on a wide range of cover materials. With this in mind, a comprehensive laboratory testing program was initiated to identify and predict the performance of alternative cover materials that could conceivably be obtained in large quantities and used in the event of a carcass disposal emergency.

Materials Tested & Tests Performed

In addition to the four materials tested in the field, nine additional potential cover materials — turkey litter, oat straw, alfalfa hay, soybean straw, wood shavings, sawdust, leaves, wheat straw, and beef feedlot manure — were tested in the lab.

Laboratory tests included bulk density, porosity, free air space, initial moisture content, water holding capacity, volatile solids, pH, electrical conductivity, mechanical strength, biodegradability, respiratory quotient, gas permeability, thermal conductivity, and specific heat capacity. Since several of these parameters change significantly as moisture content changes, tests for porosity, free air space, mechanical strength, and gas permeability were carried out at 20, 50, and 80% of water-holding capacity. Biodegradability, which is sensitive to high water content, was tested at 20, 50, 80, 90, and 100% of water-holding capacity. Similarly, thermal properties (conductivity and diffusivity) were measured at 0, 20, 50, and 80% of water-holding capacity and at saturation. A brief description of procedures for the less common tests is provided in Appendix E of this report.

Ranking Procedures

After the physical, chemical, and biological characteristics listed above were measured and tabulated for the 13 potential cover materials, laboratory values for the field-tested materials (ground cornstalks, leaves, silage, ground straw, soil/compost blend) were assessed by the research team — in light of composting theory and observed field performance —to identify a limited set of key parameters that could be used to predict and rank the field performance of all materials. Once the key parameters were identified, each of the 13 materials tested were then rated as "excellent," "acceptable,", or "unacceptable" with regard to each of the key parameters, and these ratings were then used to rank the suitability of each material for use in three mortality composting scenarios. These scenarios are:

1. composting of routine mortalities — where disease is not a serious concern, the number of carcasses to be dealt with at one time is small, and there is sufficient time and money to construct bins or use other methods to shelter the composting operation from excessive precipitation;
2. composting of non-disease-related emergency mortalities — caused by fire, flood, or ventilation failures, where the numbers of carcasses to be dealt with at one time may be large, and unsheltered emergency composting piles or windrows must be used due to time and money constrains; and
3. composting of mortalities caused by contagious disease where — in addition to the issues associated with scenario 2 — biosecurity is a major concern.

MODELING TO EVALUATE & RECOMMEND DESIGN HEIGHTS FOR COMPOSTING OPERATIONS

One of the most important factors in successful composting is maintenance of a moderately aerobic internal environment. Composting experts typically recommend that minimum O_2 concentrations of at least 5% be maintained within the pore spaces of a composting pile to promote rapid decomposition of organics and oxidation of malodorous byproducts (Rynk et. al., 1992), and concentrations of 10% or greater are preferred for good performance.

Forced aeration or frequent turning is often used to maintain O_2 concentrations in municipal or industrial composting operations, but on-farm mortality composting operations are typically turned infrequently, and may not be turned at all if carcasses are the result of death caused by disease and therefore pose biosecurity concerns. In such cases favorable O_2 levels can be sustained only if the outer envelope of the composting matrix has sufficient free air space to permit natural pile ventilation driven by external wind currents and thermal gradients. Based on previous research, minimum free air space (FAS) of at least 30% is recommended to help maintain internal O2 concentrations. While it is quite difficult to actually measure FAS within an active composting matrix, it is feasible to model and predict it based on laboratory measurements of moisture content, dry matter, and sample bulk density, and on the known densities of water (1000 kg/m3), organic matter(1600kg/m3) and ash(2500kg/m3). Results of such a physical modeling effort, described in the Results and Interpretations section, will be used to predict maximum pile depth recommendations for emergency windrows.

RESULTS AND INTERPRETATIONS

PROCESS PERFORMANCE

Internal Temperatures

Time/Temperature Trends and Effects of Cover Material Type

As illustrated by the sample time/temperature data in Figure 6 (see Appendix A for all time/temperature charts and tables), those constructed with corn silage generally exhibited the highest temperatures in all zones (core, carcass surface, outer envelope) and during all seasons, while test units constructed with ground cornstalks generally had the lowest. Temperatures within straw/manure generally were between the other two, but were more similar to cornstalks than silage. Within the important core and carcass surface zones where pathogen populations are likely to be the highest, peak temperatures for the duration of the trial were generally in the 60-70 ° C range for silage and in the 50-60 ° C range for cornstalk and straw/manure test units.

During cool or cold weather, silage units generally achieved temperatures of 55 °C or greater more quickly, and sustained these periods of relatively high temperature for longer periods, than the other two types of materials. This improved the odds of meeting time/temperature criteria for pathogen inactivation (see later section on pathogen inactivation potential) during the early stages of carcass degradation, thereby giving pathogen populations less time to adapt to high temperatures. The longer time needed to reach peak temperatures in cornstalk test units is thought to have been caused primarily by lower initial moisture content than in units where silage or manure were used to cover the carcasses.

During cool or warm season trials, temperatures within all test units tended to converge and to approach external air temperatures within 5-6 months. During cold season trials this process took 7-8 months.

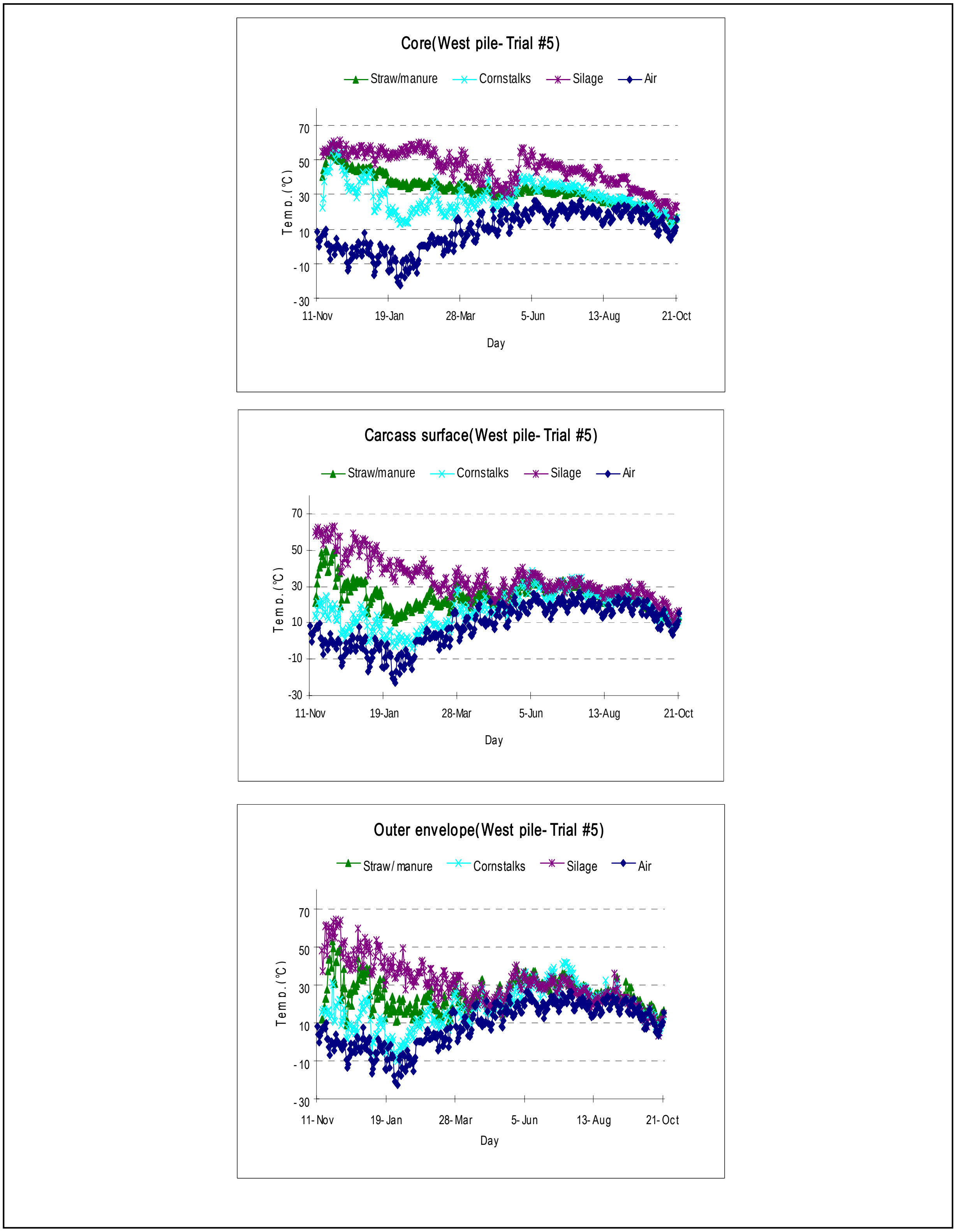


Figure 6. Daily average external (air) and internal temperatures for three test units constructed in November 2003 (Trial #5).

This convergence corresponded roughly with observed carcass degradation times, and is thought to signal conditions when readily degradable organics from the carcasses were no longer available to fuel microbial heat production.

Spatial Temperature Distribution

Spatial temperature distributions within the compost pile are affected by the ability of the composting system (carcasses and cover materials) to produce heat, the gas permeability and thermal properties of the cover materials — which affect their ability to retain heat — and by external temperatures and rainfall that contribute to heat loss. If adequately shielded from external factors, temperatures within core and carcass surface zones are often considerably higher and less variable than in the outer envelope as shown in Figure 6. This emphasizes the importance of maintaining a relatively thick outer envelope during the early phases of carcass decomposition, particularly in instances where animal death is caused by disease.

During cold weather, temperatures in all zones (core, carcass surface, and outer envelope) are suppressed to some extent. Silage test units, however, were generally affected the least by external temperatures as evidenced by the fact that outer envelope temperatures in nearly every silage test unit managed to exceed 50 °C for significant periods of time. This is believed to be due mainly to the relatively high biodegradability and low gas permeability of silage, factors that support production and retention of heat throughout the pile — not just in zones receiving moisture and nitrogen from the carcasses. As would be expected, temperatures were generally highest in the core zone during cold weather. During warmer weather, however, temperatures in the core and carcass surface zones were similar, and peak temperatures in the carcass surface zone during warm weather were often slightly higher than those in the core. Reduced oxygen concentrations — caused by the close proximity of carcasses on both sides of the core zone, and to supplemental moisture added by warm season rainfall — are thought to be the most likely cause of the peak temperature suppression within the core.

Potential to Inactivate Pathogens

While the zone temperature data discussed in the previous section provide a general indication of the potential to kill pathogens, documented success rates in meeting time/temperature criteria for Class A or Class B biosolids provide a more well-defined basis for assessing pathogen inactivation potential.

As shown in Table 2, silage test units were most likely to meet Class A time/temperature requirements (55 °C for at least 3 consecutive days). In 8 of the 9 silage test units (89%) Class A criteria were met in the core zone, and 8 of 9 units also met Class A criteria in the carcass surface zone. The two failures to meet Class A criteria did not occur in the same test unit — core zone failure occurred during a summer silage trial, and carcass surface zone failure occurred during a winter trial. As a result, simultaneous attainment of Class A criteria in both zones occurred in only 7 of 9 test units (78%).

Table 2. Zone success meeting Class A and Class B time/temperature requirements (Y=success, N=failure for the trials listed in the column heading).

Zone	Material	Spring (T3,T6N, T6S)[1]	Summer (T1, T4E,T4W)	Winter (T2, T5E, T5W)	Success rate (%) [4]
Class A Requirements					
Core	Cornstalks	Y, Y, Y	N, Y, N	N, N, Y	56
	Silage	Y, Y, Y	Y, N, Y	Y, Y, Y	89
	Straw/manure	-, N, Y	-, N, N,	-, Y, N	33
	Soil/compost blend	-, -, -	N, -, -	Y, -, -	50[2]
	Leaves	Y, -, -	-, -, -	-, -, -	-[3]
Carcass Surface	Cornstalks	N,N, N	N, Y, Y	N, N, N	22 [a]
	Silage	Y,Y, Y	Y, Y, Y	N, Y, Y	89 [b]
	Straw/manure	-, Y,Y	-, Y, Y	-, N, N	67 [a] [b]
	Soil/compost blend	-, -, -	N, -, -	Y, -, -	50[2]
	Leaves	N, -, -	-, -, -	-, -, -	-[3]
Core + Carcass Surface	Cornstalks	N,N,N	N,Y,N	N, N, N	11 [a]
	Silage	Y,Y, Y	Y, N, Y	N,Y,Y	78 [b]
	Straw/manure	-, N,Y	-, N, N	-, N, N	17 [a] [c]
	Soil/compost blend	-, -, -	N, -, -	Y, -, -	50[2]
	Leaves	N, -, -	-, -, -	-, -, -	-[3]
Class B Requirements					
Core	Cornstalks	Y, Y, Y	N, Y, N	N, Y, Y	67
	Silage	Y, Y, Y	Y, N, Y	Y, Y, Y	89
	Straw/manure	-, N, Y	-, N, N,	-, Y, Y	50
	Soil/compost blend	-, -, -	N, -, -	Y, -, -	50[2]
	Leaves	Y, -, -	-, -, -	-, -, -	-[3]
Carcass surface	Cornstalks	N,Y, N	N, Y, Y	N, N, N	22 [a]
	Silage	Y,Y, Y	Y, Y, Y	Y, Y, Y	100 [b]
	Straw/manure	-, Y,Y	-, Y, Y	-, N, N	67 [a] [b]
	Soil/compost blend	-, -, -	N, -, -	Y, -, -	50[2]
	Leaves	Y, -, -	-, -, -	-, -, -	-[3]
Core + Carcass Surface	Cornstalks	N,Y, N	N, Y, N	N, N, N	22 [a]
	Silage	Y,Y, Y	Y, N, Y	Y, Y, Y	89 [b]
	Straw/manure	-, N,Y	-, N, N	-, N, N	17 [a] [c]
	Soil/compost blend	-, -, -	N, -, -	Y, -, -	50[2]
	Leaves	Y, -, -	-, -, -	-, -, -	-[3]

[1] – values in parenthesis identify trial # and pile location e.g. T6N = trial # 6, north windrow

[2] – success rate for soil/compost blend based on only two trials, this material was dropped from the study due to very poor carcass degradation performance.

[3] – success rate not calculated for leaves since only one trial was conducted.

[4] – means (within the same zone) followed by different letters are significantly different ($p<0.05$).

Dual layer straw/manure test units had the second highest success rate for meeting Class A criteria (core 33%, carcass surface 67%, joint 17%), while those constructed with ground cornstalks had a slightly lower success rate (core 56%, carcass surface 22%, joint 11%). It is speculated that the low success rate in the core zone of straw/manure test units may have resulted from O_2 limitations (see Figure 7) caused by the layer of moist cattle manure placed over the carcasses. This material had low gas permeability when wet, and water released from the carcasses undoubtedly helped to sustain high moisture levels in the manure layer. In the carcass surface zone of straw/manure test units, where O_2 concentrations were higher, the success rate was twice that in the core. The low success rate in the carcass surface zone of the cornstalk test units is believed to have been caused by high gas permeability leading to increased movement of cool air through the outer envelope.

Although the much lower (40°C) temperatures associated with Class B pathogen reduction criteria might appear to be easier to achieve than the higher (55°C) Class A temperatures, the longer time requirement (5 consecutive days) and concurrent requirement to have at least 4 hours above 55 °C made these criteria almost as difficult to achieve as the Class A criteria. Consequently, Class B zone success rates for each of the cover materials were the same or only slightly higher than those for Class A (Table 2). This may be due, in part, to the way in which Class B conditions were defined for the purpose of this study. Due to the large amount of temperature data collected during the project, only daily average data were archived. Since hourly data were not available, it was necessary to use a proxy for Class B criteria — in this case 40 °C for at least 5 days and >55 °C for at least one day (rather than 4 hours) — was used. Since these modified criteria are somewhat harder to meet than the official Class B definition, it is possible that the materials tested have slightly higher Class B success rates than shown in Table 2.

Due to the design of the internal temperature monitoring system, carcass surface data, which are based on data from 12 thermocouples, are considered to be a more reliable indicator of carcass exposure to heat than the core data, which are derived from only 4 thermocouples. Not only are the carcass surface mean temperatures based on more information, and they also are less likely to be seriously affected by thermocouple malfunctions.

Internal Oxygen Concentrations

Typical O_2 concentrations within the core, carcass surface, and outer envelope zones of three selected test units are in trial 6 are charted in Figure 7 (all O_2 data are in Appendix B of this report), and summary statistics for all test units in trial 6 are given in Table 3. These data reflect the effects of oxygen consumption during aerobic decomposition of organic matter, and the ability of the cover materials to transport oxygen to interior zones to replace the consumed O_2.

Keeping the carcass composting environment moderately aerobic is important as this helps to ensure decomposition of malodorous compounds. Heat production — an important factor in pathogen control — also is higher when decay is aerobic rather than anaerobic. To achieve these benefits, composting experts typically recommend that minimum O_2 concentrations within the pore spaces of composting piles not be allowed to drop below 5% (by volume) for significant periods of time, and concentrations of 10% or greater are preferred for good composting.

During the first 25 days, minimum oxygen concentrations in the core zone of silage and straw/manure test units dropped below 5% , and average O_2 concentrations were less than 10% . Reflecting the results of

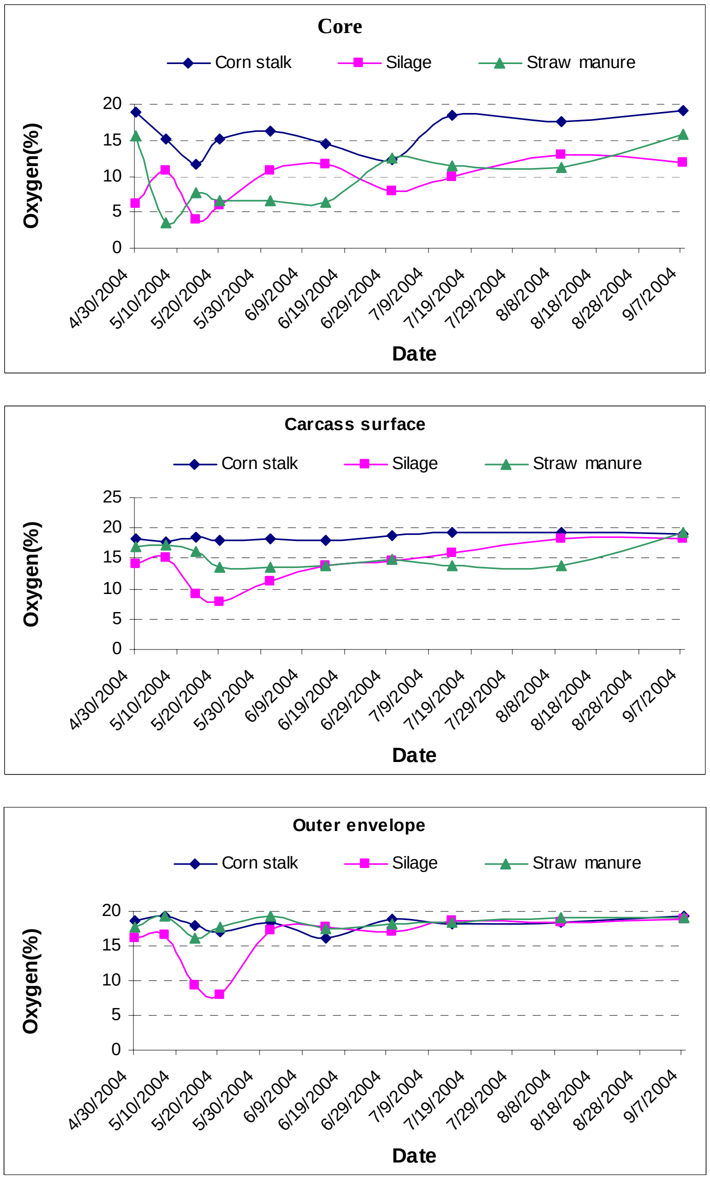


Figure 7. Zone O_2 concentrations in three test units during trial # 6.

inherently higher gas permeability, concurrent minimum O_2 levels in the core zone of cornstalk test units exceeded 10%, and the average concentrations exceeded 15%.

As time progressed beyond the initial month, mean O_2 levels exceeded 10% in all zones of all three test materials, and minimum concentrations exceeded 5%. Drying, settling, and cracking of the outer envelope are thought to be key factors leading to the increased O_2 levels. Reflecting the high gas permeability of ground cornstalks, and quite possibly a lower initial oxygen demand (due to dryness), mean O_2 levels within all zones of cornstalk test units exceeded 15% and minimum O_2 concentrations exceeded 11%.

Table 3. Mean, standard deviation, and minimum value of %O_2 during four consecutive time periods in first 10 weeks of trial # 6.

	Materials	$0 \le D^1 \le 25$		$26 \le D^1 \le 50$		$51 \le D^1 \le 80$		$81 \le D^1 \le 130$	
		Mean[2] ± s.d.	Min	Mean[3] ± s.d.	Min	Mean[3] ± s.d.	Min	Mean[3] ± s.d.	Min
Core	Corn stalk	15.7±2.7	11.6	15.8±0.9	14.5	15.6±2.6	12.4	18.0±0.7	17.6
	Silage	8.3±2.8	3.9	10.6±0.9	9.4	12.2±4.7	7.8	12.4±3.5	8.0
	Straw manure	9.4±4.6	3.6	10.3±4.5	6.4	14.3±3.1	11.3	14.1±2.3	11.1
Carcass surface	Corn stalk	17.0±1.7	13.8	15.9±2.8	12.4	15.8±3.7	11.9	18.8±0.4	18.2
	Silage	11.5±2.7	7.8	12.2±1.3	11.1	13.5±2.1	11.2	15.4±3.9	10.1
	Straw manure	15.7±1.7	13.6	15.9±2.8	13.4	15.5±2.3	13.8	17.9±2.7	13.9
Outer envelope	Corn stalk	18.6±0.9	17.0	17.6±1.1	16.1	18.5±0.3	18.1	19.1±0.4	18.5
	Silage	12.8±4.2	7.5	17.1±2.4	13.7	18.3±0.9	17.1	18.1±1.5	15.9
	Straw manure	18.2±1.2	16.2	18.7±0.9	17.5	18.6±0.5	18.1	19.3±0.2	19.1

[1] D = day number during trial, [2] Mean of 4 data points, [3] Mean of 2 data points

Carcass Decay Time

Approximately 49,000 kg (54 tons) of 450 kg (1,000 lb) cattle carcasses were composted in 27 full-scale test units that were monitored during six seasonal trials each lasting at approximately 12 months. Temporary excavation of small sections of selected test units showed that carcass decay was strongly influenced by seasonal weather conditions. Internal organs and soft tissues were generally fully decayed within 4-6 months in silage, straw/manure, ground cornstalk test units constructed during warm weather (April or June), and in 8-10 months within test units constructed during cold weather (November).

Two replicated trials during the early part of the project using a soil/compost blend failed to adequately decompose carcasses within a 12-month period. Although these test units exhibited moderately high internal temperatures, when they were removed from the study their internal contents had a very strong septic odor and contained much un-decomposed carcass material that had to be mixed with cornstalks and re-composted prior to final application on cropland. At the time these the soil/compost test trials were run, the equipment needed to obtain reliable internal O_2 measurements was not available, but subsequent laboratory testing of this material showed that it had a very low gas permeability and hence low ability to conduct O_2 into the carcass surface and core zones.

Periodic turning, particularly during warm weather, would be expected to reduce decay times for all cover materials but, as noted earlier, test units in this study were purposely not turned so as to permit observation of the performance and environmental impacts of emergency disposal procedures that minimize biosecurity risks.

Contrary to initial expectations, higher temperatures within the silage test units did not result in noticeably shorter carcass decay times than those observed in the much cooler cornstalks. It is speculated that the less favorable temperatures in the cornstalks may have been offset by significantly higher O_2 concentrations (than in silage test units) which tend to favor rapid aerobic decomposition of organic materials.

During the early weeks of the composting process considerable settling of the unturned windrows took place, particularly during warm and wet weather. Under such conditions it was not unusual for test units that were 2.1-2.4 m (7-8 ft) tall at the time of construction to settle to a depth of about 1.2 m in 45-60 days. This phenomenon was caused by rapid initial decomposition and release of liquid from the carcasses — each 450 kg (1,000 lb) of carcasses contains approximately 300 kg (650 lb) of water — and by subsequent moistening and compaction of cover and base materials. In some instances rapid pile settling necessitated addition of cover material to fill cracks and voids and maintain cover over the carcasses. Based on these experiences it is recommended that the carcasses of large animals such as cattle not be stacked during emergency carcass disposal composting in unturned windrows as this is likely to lead to severe pile settling and release of leachate caused by excessive carcass weight and release of liquid. Intermediate sized species such as swine, calves, and sheep weighing 115 kg (250 lbs) or less can be stacked, but it is recommended that this be limited to only two layers if carcasses are large, and at least 30 cm (1 ft) of absorptive material should be placed between the layers to help retain liquid and aid oxygen penetration into the pile.

After one year of composting, the resulting material included many large cattle bones and skulls that were relatively dry and free of soft tissues Figure 8. These large bones were quite strong, and many were not broken up significantly during land application using a normal manure spreader. Disking of the application area was not successful in breaking up or covering the large bones; moldboard plowing was generally successful in covering them, but subsequent tillage and planting operations are likely to bring them to the surface again so careful consideration should be given to how and where composted cattle mortalities will ultimately be disposed. Use of a Kuhn-Knight manure spreader equipped with a hammer-mill discharge was effective at reducing large bones to much smaller fragments.

Composite samples collected from finished test units were tested for total N and total P_2O_5. As summarized in Table 4, the nutrient content of most samples was low. With the exception of compost from the straw/manure test units (and a single leaf test unit), total N content was well below 1% (wet basis), and P_2O_5 was less than ½ % (wet basis). The relatively large component of un-decomposed nutrient-poor straw and cornstalks are believed to account for the generally low values. Beef manure used in the straw/manure test units undoubtedly contributed to the elevated nutrient levels in this compost. The cause of the relatively high level of total N in compost from the single test unit constructed with leaf mulch is unknown.

Figure 8. Large bones and skulls remaining following cattle carcass composting (top) were free of soft tissues, use of a Kuhn-Knight manure spreader with hammer-mill type discharge (lower left) significantly reduced the size of bones in field following compost spreading (lower right).

Table 4. Mean total Kjeldahl nitrogen (TKN) and P_2O_5 content of cattle mortality compost after approximately one year of composting.

	Number of samples	TKN(%, wet basis)	P_2O_5(%, wet basis)
Cornstalks	9	0.58±0.23	0.28±0.12
Silage	9	0.83±0.19	0.41±0.13
Straw/manure	6	0.97±0.46	0.89±0.62
Soil/compost blend	2	0.29±0.04	0.2±0.02
Leaves	1	1.01	0.41

Air Quality

Air quality samples were taken during three trials, June-July 2003, November-December 2003, and April-May 2004. The data set includes 161 usable samples for odor intensity measurements. There were 42, 43 and 43 from the cornstalk, straw/manure and silage treatment piles, respectively, and 11 from each of the stockpile treatments.

Two main questions were the focus of the statistics. First of all, did the compost piles have different characteristics than the corresponding co-compost stockpiles? It was felt a paired comparison was the most unbiased way to evaluate the characteristics because the stockpile and compost would be exposed to the same weather conditions and sampled at the same time. The other area of interest was comparison of compost materials to each other.

Elapsed time from the start of a trial and season of the year made the data set particularly complex. To eliminate the time and season influences and to isolate the treatment effect, a mean was calculated for each pile (a total six treatment piles and three stockpiles). Paired t tests and analysis of variance were then performed on these means.

Odor Detection Threshold (ODT)

Odor detection threshold (ODT) is defined as the volumetric ratio of fresh air to sample air at the lowest level that the olfactometry panelists could detect an odor; the greater the ODT, the more odorous the sample. In order to develop a frame of reference, other familiar levels of ODT were used for comparison. The ODT for pond water measured in a similar way can be 200-300 ODT while manure in the first cell of an anaerobic lagoon can be around 4000 ODT, Bundy (2004).

Table 5 contains the mean values of odor detection thresholds broken down by material, treatment and the length of time post-pile construction. The overall column is the mean of the pile means. It should be noted that no time dependency seems apparent. Figure 9 graphically illustrates the weekly data. Sample means for ODT do not appear to decline with time with occasional spikes appearing. These most likely are due to climatic effects due to rainfall, wind or other factors occurring between sampling events. This was somewhat expected because moisture level can have a direct bearing on composting activity level and on porosity of the compost piles.

Table 5 Mean values of Odor Detection Thresholds (ODT).

Material	Treatment	Week 0	Week 1	Week 2	Week 3	Week 4	Overall [1]
Cornstalks	Compost	665	666	314	362	607	519
	Stockpile	349	500	71	462	235	349
Straw/ Manure	Compost	509	582	325	551	3033	723
	Stockpile	273	150	179	351	1603	359
Silage	Compost	2669	869	423	1059	657	1230
	Stockpile	1558	583	222	571	601	704

Means with different superscripts were statistically different (P<0.05)

[1]Overall average refers to the averages of individual piles (two for treatment and one stockpile per replicate) averaged together.

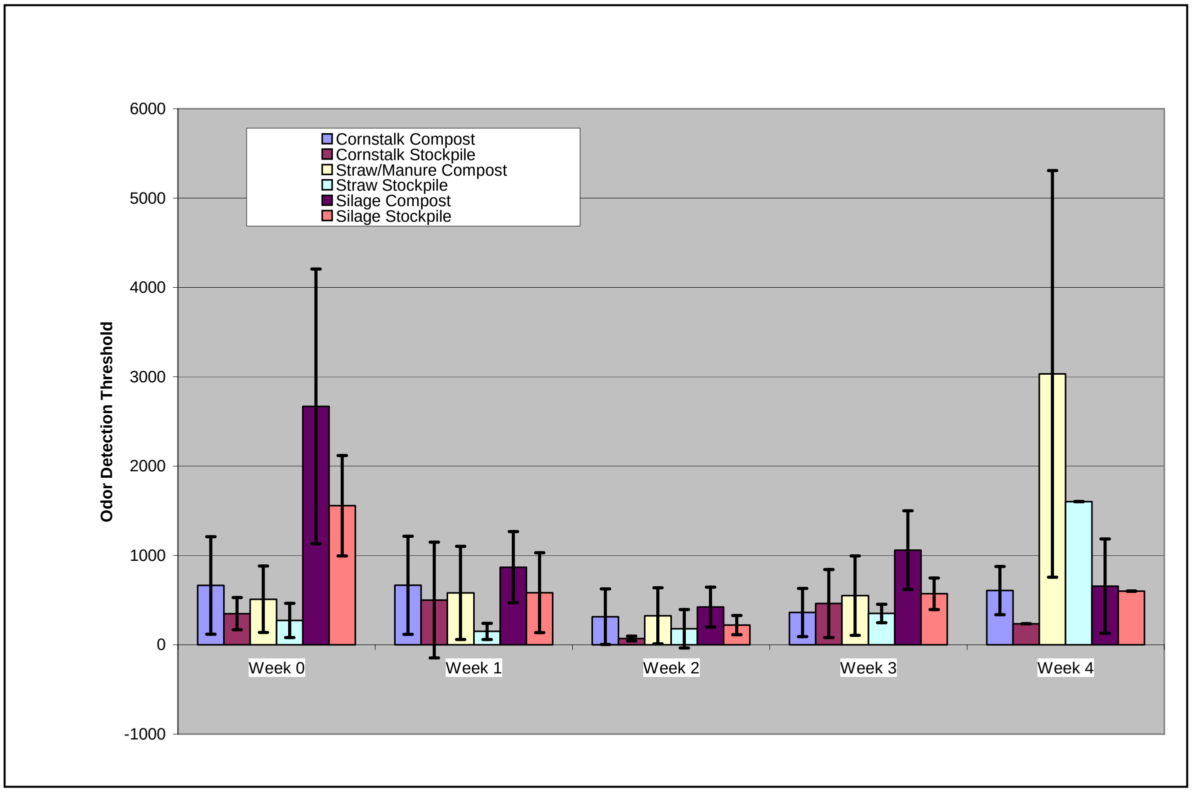


Figure 9. Composite weekly means for odor detection threshold along with error bars showing one standard deviation.

To compare the odor level of the compost piles to their respective co-compost material, a paired t test was performed on the difference between the pile ODTs for the treatment and the respective stockpile ODT. The null hypothesis for each test was that the difference between the mean ODT for the treatment and the stockpile was zero with the alternative hypothesis that the treatment mean was more odorous than the stockpile (one tail test).

Figure 10 shows the treatment and stockpile means along with the statistical significance. The straw/manure and silage compost piles and their respective stockpiles had unequal variances; therefore the appropriate t tests were performed to account for this factor. The t tests indicated that for cornstalks, the mean ODT for the carcass compost was significantly greater than the stockpile (P=0.0037). For silage and straw/manure treatments, the mean ODT for the carcass compost pile and the stockpiles were not significantly different (P=0.050 for silage, P=0.08 for straw/manure). A comparison of the overall mean of compost versus stockpile indicated that the means are significantly different (P=0.0086).

These results are somewhat influenced by the unusually high variances. The cornstalk treatment and stockpile had lower variances and statistical differences were easier to detect even though the actual difference in ODT is less than that for silage or straw/manure. Cornstalks tend to be more porous, exchanging air more freely. Silage has more of a tendency to crust over and the odor level may have been

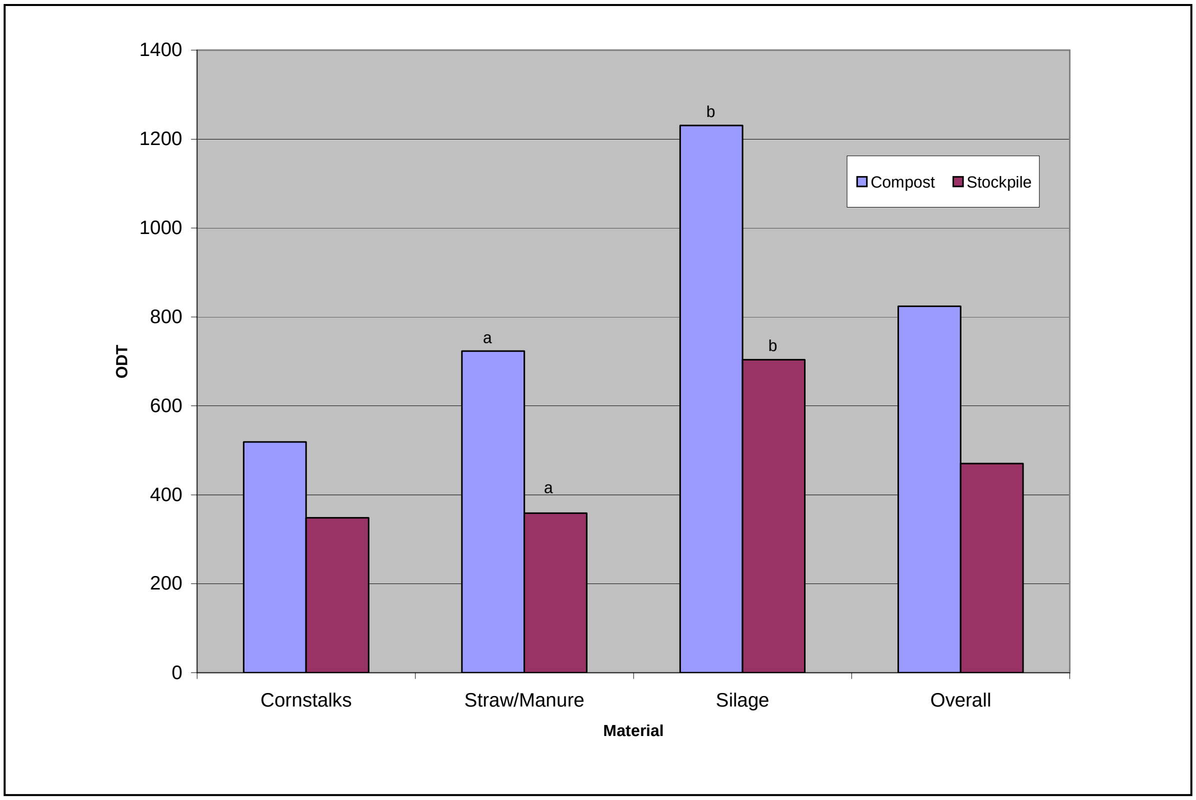


Figure 10. Paired odor comparisons (compost versus stockpile) of pooled data for each cover material.
Similar letters for a material indicate a lack of statistical differences (P>0.05)

more influenced by the presence or absence of macropores in the sampling area. The straw/manure treatment may have the same tendency in the manure interface below the straw.

Table 6 gives more of the characteristics for the ODT samples. It was theorized that perhaps the mean is not as pertinent as the peak in ODT level since the possibility of odor nuisance would likely be the major concern. There were few samples that were highly odorous so an examination of the 75th percentile or the median ODT readings would be more appropriate. In all cases the 75th percentile for the compost was higher than that for the stockpile but not more than double.

Table 6. Characteristics of Individual Samples: Odor Detection Thresholds (ODT).

Material	Treatment	Maximum	Minimum	75th Percentile	Median	Mean
Cornstalks	Compost	1946	92	765	391	521
	Stockpile	1248	52	445	221	360
Straw/ Manure	Compost	5007	29	835	436	741
	Stockpile	1603	27	430	248	365
Silage	Compost	5182	103	1338	944	1150
	Stockpile	1955	145	886	661	693

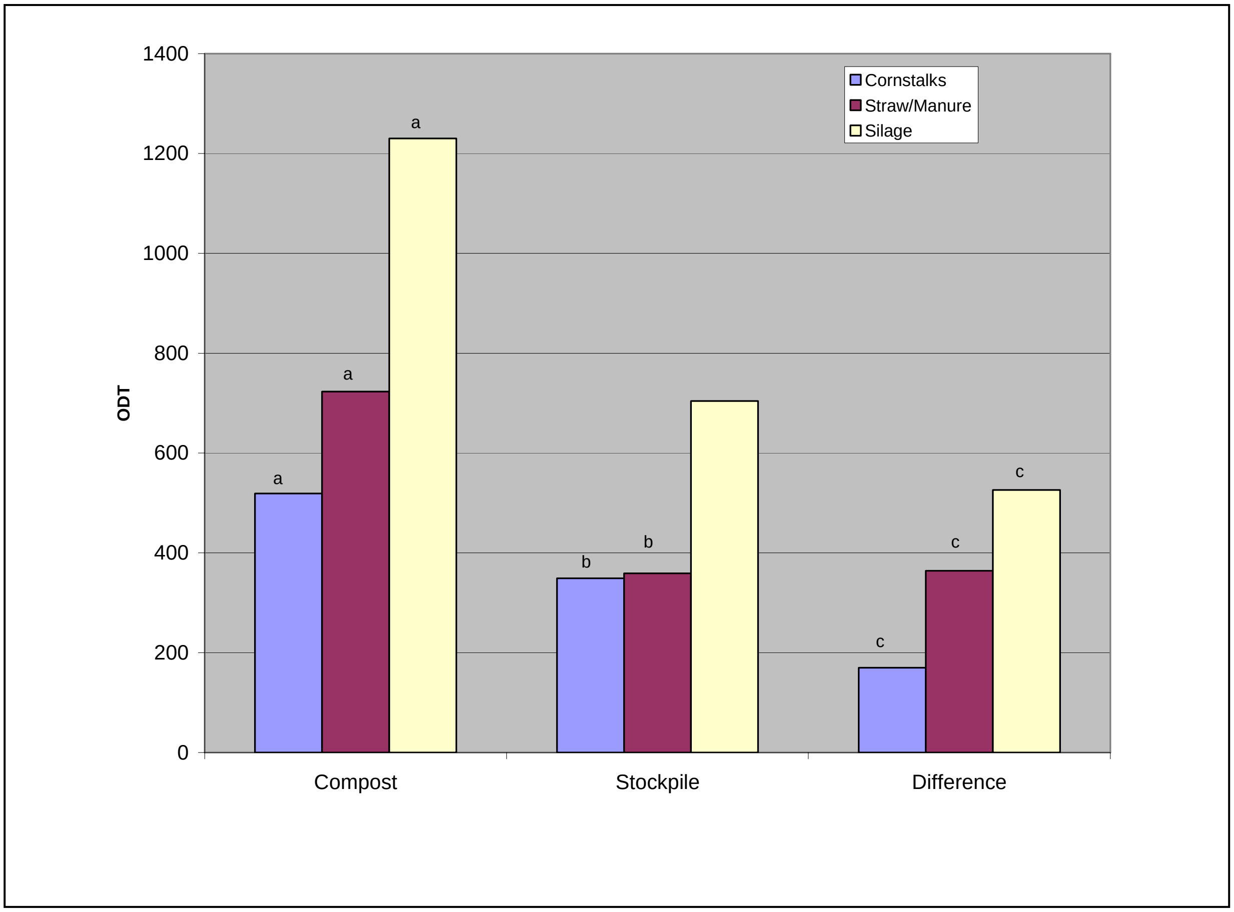


Figure 11. Comparisons of pooled odor data for composted and stockpiled materials.

Similar letters indicate a lack of statistical differences (p>0.05)

Difference = composted ODT minus stockpiled ODT

Figure 11 shows the ANOVA results of comparing the three materials as they resided in the compost pile, in the stockpile, and the difference between the two. The null hypothesis tested was that all the means for the materials were equal. For the compost piles, there was no significant difference in ODT (p=0.057). This indicates that no composting material performed better than the others from an odor standpoint. For the stockpiles it was found that at least one of the means was significantly different (p=0.0032). A least significant squares (LSD) test yielded that the mean for the silage stockpile was significantly different than those for the straw or cornstalk piles. This was expected because of the naturally more odorous nature of silage due to its higher moisture content. For the differences between compost and stockpiles, again, no significant difference was detected (p=0.286) indicating that the quantity of added odor due to composting is similar for all materials.

Based on the statistical evaluation and the general trends in the data, none of the compost materials appeared to be unduly odorous. Median ODT levels for cornstalks (391) and straw/manure (436) tended to be very close to the level of pond water (200-300 ODT, Bundy, 2004). Silage had a higher ODT in the stockpile and one could theorize that it would tend to have more odorous compost, even though there was no significance detected due to greater variances in ODT. The median ODT level for silage compost (944) was still far below that of the first cell of an anaerobic lagoon (4000 ODT) and the natural smell of the silage might actually act as a masking agent for the carcass compost. While peaks for straw/manure and silage compost exceeded the 4000 ODT plateau, it was not sustained at this level. It should also be noted that the source would generally have a much smaller surface area than that of a lagoon and would likely have very little impact on neighbors. Downwind concentrations would be much less due to dilution.

Hydrogen Sulfide Concentration

Hydrogen sulfide was measured for each olfactometry sample. The characteristics of the data set can be seen in Table 7. These values were pooled for each pile and analyzed using the same method as that used for analyzing the ODT. No significant differences were found between the means of the paired piles (compost versus stockpile) ($P>0.05$). It would appear that concentrations from the compost were generally greater than that from the stockpile but large variances made detection statistical difficult. An analysis of variance comparing the means of the three compost treatments indicated no significant difference between piles ($p=0.695$). Comparison of the three stockpile materials yielded no significant difference as well ($p=0.636$). This indicates that no material is superior in terms of the suppression hydrogen sulfide production.

In general, the readings tended to be highest one week after the piles were constructed; however, occasional spikes occurring after that point were likely due to rain events. These hydrogen sulfide levels are very low, come from a small source area and would be diluted before reaching any nearby residences.

Table 7. Characteristics of Individual Samples: Hydrogen Sulfide (ppb)

Material	Treatment	Maximum	Minimum [1]	75th Percentile	Median	Mean
Cornstalks	Compost	280	0.5	33.8	8.5	38.6
	Stockpile	32.0	0.5	10.0	5	8.6
Straw/ Manure	Compost	250	0.5	48.5	24	40.1
	Stockpile	19.0	0.5	9.8	0.75	5.4
Silage	Compost	230	0.5	57.8	24	52.8
	Stockpile	31.0	0.5	17.5	10	11.7

[1] The minimum reading for the instrument was "< 1 ppb". This was given a value of 0.5 ppb.

Ammonia Concentrations

Ammonia was measured for each olfactometry sample. The characteristics of the data set can be seen in Table 8. These values were pooled for each pile and analyzed using the same method as ODT. No significant differences were found between the means of the piles ($P>0.05$). It would appear that concentrations from the compost were generally greater than that from the stockpile but large variances made detection statistical difficult. An analysis of variance comparing the means of the three compost treatments indicated no significant difference between piles (p=0.975). Comparison of the three stockpile materials yielded no significant difference as well (p=0.116). This indicates that no material is superior in terms of the suppression of ammonia production.

Table 8. Characteristics of Individual Samples: Ammonia (ppm)

Material	Treatment	Maximum	Minimum [1]	75th Percentile	Median	Mean
Cornstalks	Compost	103	0.5	2.8	0.5	10.2
	Stockpile	0.5	0.5	0.5	0.5	0.5
Straw/ Manure	Compost	143	0.5	3.0	0.5	11.6
	Stockpile	0.5	0.5	0.5	0.5	0.5
Silage	Compost	133	0.5	2.0	0.5	13.3
	Stockpile	2.0	0.5	0.5	0.5	0.65

[1] The minimum reading for the instrument was "< 1 ppm". This was given a value of 0.5 ppm.

No time dependency characteristics seemed apparent. Occasional spikes occurred that were likely due to rain events. These ammonia levels are very low, come from a small source area and would be diluted before reaching any nearby residences.

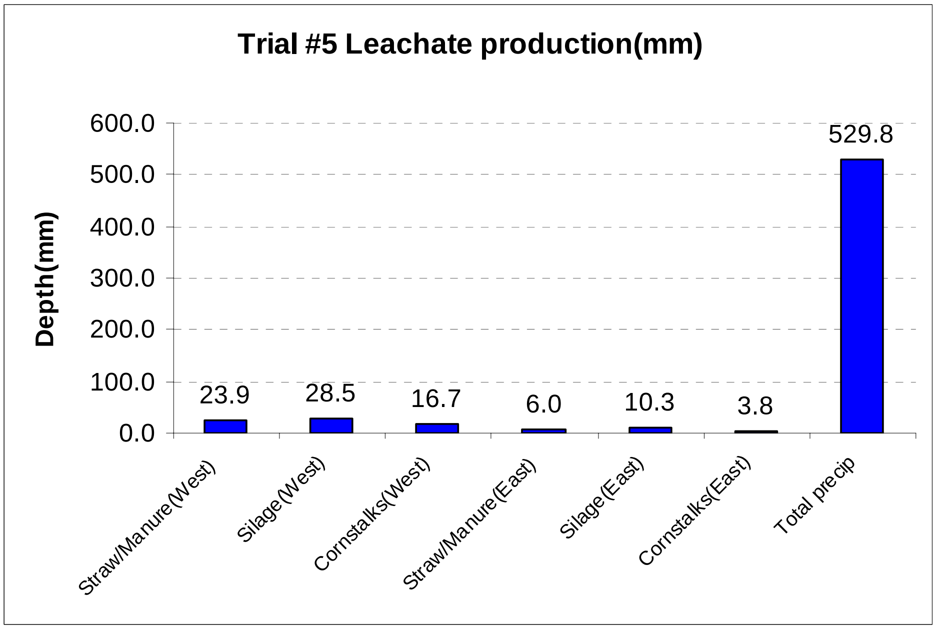
SOIL & WATER POLLUTION POTENTIAL

Leachate Quantity

The accumulated depths of leachate captured by collectors beneath each of the 12 test units in trials 5 and 6 are shown in Figure 12. These data indicate that leachate depths were only 1-5% of the accumulated precipitation that occurred during these trials. Considering that the 1.8 metric tons of cattle carcasses in each test unit contained roughly 1200 liters of water — the equivalent of about 90 mm of depth when spread over the area directly beneath the carcasses — and that an additional 500-600 mm of water was added by precipitation, this result is somewhat surprising, and it emphasizes the important liquid storage function of material that is placed over and beneath the carcasses. Not only do these materials temporarily absorb excess water, but they also provide a gas permeable matrix that facilitates evaporation of excess water from the piles. Evidence of this phenomenon — water vapor leaving the upper surface of the composting windrows — can be seen whenever periods of active composting coincide with cool external temperatures. As a result of this process, relatively little contaminated water leaches out of the bottom of the piles, thereby limiting contaminant transport into the soil beneath the emergency composting operation.

The accumulated depths of leachate show a consistent trend with regard to cover material type. The total amount of leachate produced by test units constructed with corn silage was always greater than that produced by adjacent piles constructed with cornstalks or the straw/manure, and the least amount of leachate was produced by cornstalk test units.

Trial 5 exhibited considerable variability in the amount of leachate released from replicated piles within the same trial. Test units in the west half of trial 5 yielded 3-4 times the volume of leachate produced by similar materials in the east half of the trial. The reasons for this are undetermined. Trial 5 was constructed



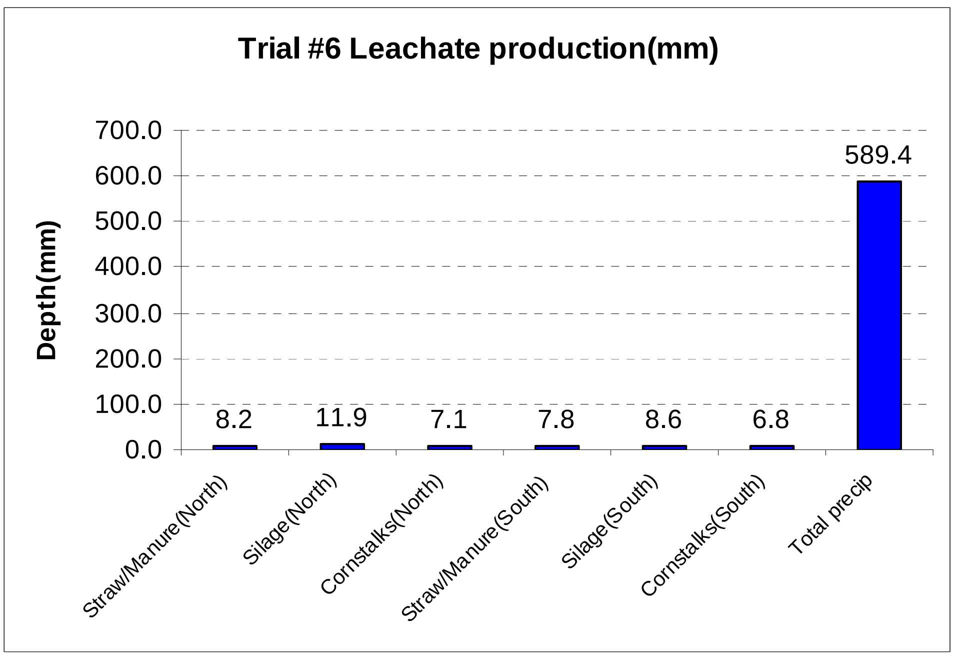


Figure 12. Total depth of leachate captured beneath test units in seasonal trials 5 and 6 compared with concurrent precipitation.

during a wet and foggy two-day period in early November of 2003, so cover materials used in the west half of the trial may have been wetter than those in the east half. Significant snowfall and drifting in December of 2003 may also have also contributed to uneven water loading on the east and west halves of the trial. Finally, trial 5 was constructed by a different research technician than the other trials and, in general, the total amount of base and cover material used in the trial 5 test units appeared to be less uniform than in other trials and this may have contributed to differences in water holding capacity among the test units.

Leachate Quality

As shown by the summary data in Table 9 (see Appendix C for all leachate data), mean nitrate-nitrogen concentrations in leachate from composting trials 5 and 6 ranged from 39 to 268 mg/L with the highest values found in leachate from straw/manure trials and the lowest from silage. Ammonia-nitrogen ranged from 190 mg/L to nearly 1400 mg/L, with the highest values again originating in straw/manure test units and the lowest values in silage. Total solids and total organic carbon (as C) ranged from 5,000 - 30,000 mg/L, and 1,000 - 10,000 respectively. For these two parameters, cornstalk test units produced the lowest concentrations, while maximum values continued to originate in the straw/manure test units.

Table 9. Mean chemical concentrations in leachate collected from trials 5 and 6.

	Trial #	NO_3-N (mg/L)	NH_3-N (mg/L)	Total Solids (mg/L)	TOC (mg/L)
Straw/Manure	**5**	99.1	1361.7	29348.5	10837.8
	6	267.5	478.1	28677.6	7137.9
Silage	**5**	38.9	186.0	15629.8	4230.1
	6	42.0	199.4	21209.6	5229.7
Cornstalks	**5**	64.1	301.4	4969.2	1319.9
	6	121.9	354.2	5677.3	986.1

Figure 13 shows pollutant mass loading rates (g/m^2) calculated from the leachate volume and pollutant concentration data. Release of total solids (dissolved + suspended) was similar for silage and straw/manure test units, but considerably higher than the mass of solids released by cornstalks.

Although total organic carbon concentrations in leachate can be quite high, organic carbon loading does not appear to contribute greatly to soil organic carbon content. Soils with 2% organic matter content, for example, typically contain about 2000 g/m^2 of organic carbon in the top 15 cm of soil. At the estimated total organic carbon loading rates shown in Figure 13, which range from 10-150 g/m^2, the mass of organic carbon in the topsoil would be increased by less than 8%.

With one exception, nitrogen loading rates also tended to be low when compared with typical nitrogen fertilizer application rates. Ammonia-nitrogen loading rates from 10 of the 12 test units in trials 5 and 6 were 5 g/m^2 or less, which is equivalent to 50 kg/ha (45 lbs/acre) of N and is well below the 140-170 kg/ha (120-150 lbs/acre) of N typically applied to corn fields. Two straw/manure test units in trial # 5, however, exhibited NH_3-N loading rates of 8 and 23 g/m^2 which are equivalent to 80 and 230 kg/ha of N respectively (71 and 205 lb/acre of N). Since the high N loading rates were observed only in the straw/manure test units, it is believed that they were caused by the cattle manure in these test units, and not by the carcasses. Nitrate-

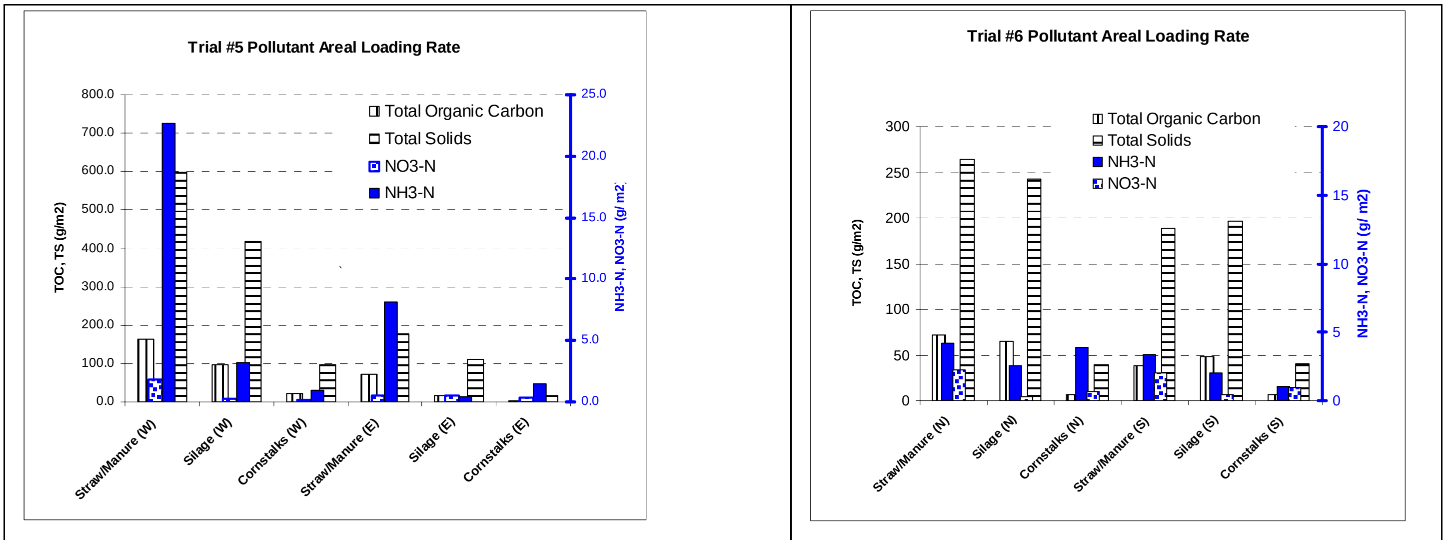


Figure 13. Calculated pollutant loading rates in soil beneath test units in trials 5 and 6.

nitrogen loading rates were even lower — typically 1 g/m^2 or less for silage and cornstalks, and 2-3 g/m^2 for straw/manure test units.

Impacts on Shallow Soil

Graphs showing % total carbon, % total nitrogen, chloride, ammonia-nitrogen, and nitrate-nitrogen — at depths from 15-120 cm (0.5 – 4.0 ft) — before and after all composting trials, are presented in Appendix D. Table 10 summarizes mean soil pollutant concentrations prior to composting, and Tables 11-15 summarize mean pollutant concentration increases (post-composting concentration – pre-composting concentration) and identify those cover materials and depth increments where statistical analysis indicates that the increases are significantly different ($p < 0.05$) from zero.

Total Carbon

As shown in Table 11, the only statistically significant ($p < 0.05$) increase in % total carbon occurred in the top 15 cm (0.5 ft) of soil beneath silage test units, where mean increases in % total carbon averaged 0.4. As indicated in Table 9, mean % total carbon concentrations at this depth prior to composting were about 2.4%, so this increase in % total carbon is only 16% of pre-composting concentrations and hence does not appear to represent a serious pollution hazard.

Total Nitrogen

Like the % total carbon data, statistically significant increases in % total nitrogen (Table 12) were limited to the top 15 cm (0.5 ft) of soil. Unlike the total % carbon data, however, statistically significant increases in % total N were identified beneath cornstalk and straw/manure test units as well as beneath silage. Although not statistically significant, the magnitudes of the % total N increases beneath test units constructed with the soil/compost blend or with leaves were equal to or greater than those for ground cornstalks. Failure to identify statistically significant differences for these two materials is believed to be the result of the smaller number of trials in which they were tested.

The statistically significant increases in % total N are roughly equivalent to 10% - 40% of pre-composting concentrations (0.21% or 2100 mg/kg). The implication of these increases relevant to soil and groundwater pollution potential are difficult to judge since total N measurements give no indication of the chemical form(s) of the N added by the composting process, or of the mobility of the N in the soil.

Ammonia-Nitrogen

Analysis of ammonia-N concentrations (Table 13) indicated statistically significant ($p< 0.05$) increases at depths of up to 90 cm (3 ft) beneath test units constructed with silage or leaves, and up to 30 cm (1 ft) beneath straw/manure test units. These increases — which range from 200 – 800 mg/kg in the top 15 cm of soil — are 40-160 times the mean NH_3-N concentration in the top 15 cm of soil prior to composting (5.2 mg/kg), and are roughly equivalent to N application rates of 360 – 1440 kg/ha.

While the above NH_3-N additions are relatively high, their environmental impacts on shallow groundwater will depend on several mitigating factors. Depending on soil pH, part of the ammonia-N will be in the form of ammonia gas which, since the bulk of the ammonia is in the upper 30 cm of soil, will volatilize into the air above the composting site after the overlying compost has been removed. Ammonia volatilization could also be enhanced by tilling the topsoil during dry weather to increase soil exposure to air.

A portion of the total ammonia in the soil also will exist as ionized ammonia (NH_4-N^+) which is readily adsorbed by the cation exchange capacity of the soil, thereby reducing leaching potential. The effect of this mechanism is exhibited by the ammonia data in Table 13 which show that statistically significant increases in ammonia were not identified at depths below 90 cm.

Nitrate-Nitrogen

To complete the picture regarding potential nitrogen pollution risks to shallow groundwater, the data in Table 14 show increases in soil nitrate-nitrogen (NO_3-N) that occurred during the composting process. Statistically significant ($p<0.05$) increases in NO_3-N concentrations that were 3-20 times the pre-composting concentrations (6-12 mg/kg) were identified beneath test units constructed with the soil/compost blend. No statistically significant increases, however, were identified beneath test units constructed with cornstalks, silage, straw/manure, or leaves. Furthermore, at all depths from 0 – 120 cm beneath silage and straw/manure test units, and at two depths beneath leaves, the data indicate small (not statistically significant) decreases in mean soil nitrate-N concentrations.

The lack of significant increases in soil NO_3-N (with exception of soil/compost blend test units) indicates that little nitrification of ammonia-N took place in the topsoil beneath the emergency composting units during the 12 month composting period. This may have resulted from suppression of nitrifying organisms in the topsoil caused by chemicals contained in the leachate, or the relatively wet and compacted layer of compost at the base of each test unit may have restricted movement of O_2 into the topsoil. This raises some potential environmental concerns since removal of the compost and subsequent movement of oxygen into the upper soil layers may lead to nitrification and subsequent movement of nitrate-nitrogen into the soil profile or shallow groundwater.

The cause of the high soil NO_3-N concentrations beneath test units constructed with the soil/compost blend is unknown. The soil/compost blend was produced by composting highly carbonaceous campus yard wastes (leaves, grass, chopped wood waste, etc.) that had been mixed with dairy manure from the ISU dairy farm. If excess manure was added to the initial compost mixture the resulting soil/compost blend may have contained relatively high NO_3-N concentrations prior to addition of the cattle carcasses.

A practical assessment of the environmental acceptability of nitrogen-related soil and groundwater pollution risks associated with emergency composting must also consider the likely impacts of other on-farm mortality disposal alternatives. When compared with the groundwater pollution potential of burial — the most common on-farm emergency disposal method — the nitrogen-related groundwater pollution risks described above appear to be much lower. Calculations based on the typical N content of animal meat and bone tissue indicate that the four 450 kg carcasses placed in each test unit contained a total of about 40 kg of N. Based on the increases in % total N shown in Table 12, the mean mass of total N added to the soil beneath the cornstalk, silage, and straw/manure composting test units were 4.2, 9.8, and 6.4 kg respectively, or about 10-25% of the total N that would have gone into the soil had the carcasses been buried. Not only would the total mass of N placed into the soil by burial have been 4 – 10 times greater than that imposed by composting, but the N from burial also would have been placed much closer to the groundwater since most burial occurs at depths of 6 feet or greater. With these facts in mind, it would appear that the risks of shallow groundwater pollution caused by composting are considerably less than those posed by carcass burial.

Chloride

As shown in Table 15, statistically significant increases in chloride concentrations in the soil were identified at nearly all depths from 0 - 120 cm beneath test units constructed with ground cornstalks, silage, straw/manure, and the soil/compost blend. Soils beneath test units constructed with leaves showed no significant increases in chloride in any depth increment.

Chloride increases were greatest in the top 15 cm of soil, ranging from 1.4 – 5 times the mean pre-composting chloride concentration (55 mg/kg) at this depth. At the 90-120 cm depth interval the increases in chloride were slightly less than the pre-composting concentrations (22 mg/kg).

Chloride is widely distributed in the environment in the form of mineral salts. It is not considered a serious water pollutant, but since it is not absorbed by the soil or converted to other chemical forms by soil microbes it is often used as an indicator of water movement. In this case, the significant increases in soil chloride concentrations at depths of 120 cm provide evidence that leachate from the composting process penetrated to this depth even though pollutants of greater concern in the leachate were retained at shallower depths. This emphasizes the importance of careful siting and construction of composting operations, particularly when groundwater or bedrock are near to the surface of the ground.

Soil pollutant loading rates predicted from measurements of leachate volume and pollutant concentrations are considerably lower than the loadings indicated by pollutant concentrations measured in the soil cores. This may have resulted from inaccurate measurement of leachate volumes, loss of chemical pollutants from the leachate, or a combination of these mechanisms. Loss of volatile compounds, such as ammonia, from collection vessels while in the field is believed to be the most likely source of this discrepancy.

Table 10. Composting-related contaminants in top four feet of soil prior to composting (N=108).

Depth Interval(cm/ft)	Total Carbon (%,d.b.)	Total Nitrogen (%,d.b.)	Chloride (mg/kg, d.b.)	Ammonia-N (mg/kg, d.b.)	Nitrate-N (mg/kg, d.b.)
0-15 / 0 - 0.5	2.40±0.69	0.21±0.04	55.0±33.0	5.2±5.1	12.5±9.4
15-30 / 0.5 – 1.0	2.16±0.78	0.18±0.04	56.2±30.5	3.2±2.6	8.4±6.7
30-45 / 1.0 - 1.5	1.41±0.68	0.12±0.03	58.5±38.0	2.9±1.8	6.4±6.7
45-60 / 1.5 – 2.0	0.91±0.70	0.08±0.03	50.9±48.2	2.5±1.5	6.0±6.4
60-90 / 2.0-3.0	0.97±1.03	0.04±0.03	25.6±20.3	1.8±1.4	6.5±7.1
90-120 / 3.0-4.0	1.20±0.97	0.03±0.02	21.8±15.2	1.6±1.3	7.1±6.7

Table 11. Increase in % total carbon in soil beneath composting test units.

	Change in % total carbon (post composting – pre-composting) (% dry basis)				
Depth interval (cm/ft)	Corn stalks (n=36)	Silage (n=36)	Straw/manure (n=24)	Soil compost blend (n=8)	Leaves (n=4)
0-15 / 0 - 0.5	-0.18±0.83	0.42±0.56*	0.18±0.93	-0.08±0.68	0.27±0.25
15-30 / 0.5 – 1.0	-0.06±0.91	0.23±0.69	-0.02±0.87	0.14±0.39	0.15±0.38
30-45 / 1.0 - 1.5	-0.22±0.93	0.24±0.65	0.22±0.72	0.62±0.57	-0.0001±0.42
45-60 / 1.5 – 2.0	-0.17±1.02	0.17±0.74	0.19±0.87	0.50±0.53	-0.16±0.68
60-90 / 2.0-3.0	-0.31±0.77	-0.36±0.95	0.11±1.13	0.16±0.43	0.29±0.49
90-120 / 3.0-4.0	-0.27±1.04	-0.08±0.91	0.10±1.18	0.48±0.56	0.32±0.89

* Indicates increase is significantly different from zero ($p<0.05$)

Table 12. Increase in % total nitrogen in soil beneath composting test units.

	Change in % total nitrogen (post composting – pre-composting) (% dry basis)				
Depth interval (cm/ft)	Corn stalks (n=36)	Silage (n=36)	Straw/manure (n=24)	Soil/compost blend (n=8)	Leaves (n=4)
0-15 / 0 - 0.5	0.02±0.05*	0.08±0.06*	0.09±0.05*	0.02±0.03	0.04±0.05
15-30 / 0.5 – 1.0	0.01±0.05	0.02±0.04	0.005±0.02	0.01±0.03	0.02±0.06
30-45 / 1.0 - 1.5	0.01±0.05	0.02±0.03	-0.005±0.02	0.03±0.03	-0.01±0.02
45-60 / 1.5 – 2.0	0.002±0.03	0.02±0.03	-0.005±0.02*	0.02±0.02	-0.01±0.03
60-90 / 2.0-3.0	0.01±0.02	0.006±0.02	-0.008±0.03	0.03±0.02	0.006±0.01
90-120 / 3.0-4.0	0.002±0.03	-0.008±0.01	0.002±0.01	0.02±0.02	0.005±0.01

* Indicates increase is significantly different from zero ($p<0.05$)

Table 13. Increase in ammonia-N concentrations in soil beneath composting test units.

	Change in ammonia (post composting – pre-composting) (mg/kg dry basis)				
Depth interval (cm/ft)	Corn stalks (n=36)	Silage (n=36)	Straw/manure (n=24)	Soil/compost blend (n=8)	Leaves (n=4)
0-15 / 0 - 0.5	301.8±376.9*	597.2±563.0*	795.8±496.8*	218.7±360.2	607.7±574.5*
15-30 / 0.5 – 1.0	41.5±60.2	161.5±228.0*	125.1±245.2*	18.3±21.7	250.5±359.3*
30-45 / 1.0 - 1.5	4.8±11.2	51.2±110.7*	14.1±26.7	0.9±2.5	602.9±882.6*
45-60 / 1.5 – 2.0	4.0±13.5	33.2±126.0*	3.7±5.8	0.2±1.5	107.3±211.9*
60-90 / 2.0-3.0	0.7±6.2	13.4±50.1*	1.5±3.8	-0.1±0.6	33.6±65.6*
90-120 / 3.0-4.0	2.5±14.1	3.3±10.1	0.4±0.9	-0.1±0.4	2.1±3.6

* Indicates increase is significantly different from zero ($p<0.05$)

Table 14. Increase in nitrate-N concentrations in soil beneath composting test units.

	Change in nitrate (post composting – pre-composting) (mg/kg dry basis)				
Depth interval (cm/ft)	Corn stalks (n=36)	Silage (n=36)	Straw/manure (n=24)	Soil/compost blend (n=8)	Leaves (n=4)
0-15 / 0 - 0.5	2.8±28.7	-6.4±11.3	-6.9±11.1	45.4±85.2*	10.8±29.8
15-30 / 0.5 – 1.0	6.2±29.1	-6.6±3.9	-5.7±6.5	91.7±104.5*	-1.9±16.7
30-45 / 1.0 - 1.5	7.6±25.6	-4.3±2.5	-4.0±6.6	136.7±152.5*	5.5±18.0
45-60 / 1.5 – 2.0	7.2±23.8	-3.4±4.1	-3.5±6.9	109.0±112.2*	10.1±20.6
60-90 / 2.0-3.0	3.7±22.6	-4.2±4.5	-4.0±6.9	52.3±46.5*	4.7±12.2
90-120 / 3.0-4.0	1.1±14.8	-4.4±4.5	-5.6±7.9	18.8±27.6*	-7.4±3.9

* Indicates increase is significantly different from zero ($p<0.05$)

Table 15. Increase in chloride concentrations in soil beneath composting test units.

	Change in chloride (post composting – pre-composting) (mg/kg dry basis)				
Depth interval (cm/ft)	Corn stalks (n=36)	Silage (n=36)	Straw/manure (n=24)	Soil/compost blend (n=8)	Leaves (n=4)
0-15 / 0 - 0.5	79.2±71.3*	121.8±60.5*	257.4±92.1*	148.6±82.0*	31.9±77.6
15-30 / 0.5 – 1.0	47.4±41.7*	68.7±50.6*	145.3±59.4*	166.8±72.9*	11.8±41.5
30-45 / 1.0 - 1.5	18.7±28.3	32.2±46.6*	72.3±43.9*	142.4±87.8*	23.3±55.8
45-60 / 1.5 – 2.0	31.8±74.1*	14.2±56.7	35.1±25.2*	112.4±86.4*	-57.2±22.7
60-90 / 2.0-3.0	25.0±49.6*	24.6±23.4*	23.0±26.6*	67.8±66.7*	-34.1±20.3
90-120 / 3.0-4.0	16.5±39.7*	13.3±17.2*	14.8±15.2*	27.8±35.6*	3.7±1.8

* Indicates increase is significantly different from zero ($p<0.05$)

Impacts on Crop Growth

Following dismantling of all test units, soybeans were no-till planted on the project research site in the spring of 2005. As shown in photos taken at the end of the growing season (Figure 14), areas formerly occupied by composting test units exhibited very poor soybean emergence. This may have been caused by chemical contamination of the topsoil, or possibly by compaction. Current literature suggests that sensitive agricultural crops can tolerate chloride concentrations in soil of 350 mg/kg. Since chloride concentrations in the topsoil beneath most composting test units were less than 300 mg/kg (USDA-ARS, 2006), it appears unlikely that the poor soybean emergence was caused by chloride in the topsoil. High concentrations of ammonia in soil are widely recognized as detrimental to seedling emergence and root growth (Brittoe and

Figure 14. Suppressed soybean growth exhibited in areas previously covered by mortality composting windrows.

Kronzucker, 2002, Dowling, 1998). Some literature suggests that soybeans may be among the more sensitive crops to ammonia injury, and that the injury threshold may be in the range of 200-400 mg/kg which is at or well below the concentrations identified in topsoil beneath the composting test units. The adverse impact on crop emergence may have been further exacerbated by use of no-till planting. Had the soil been tilled prior to planting some ammonia-nitrogen would have been lost to volatilization or nitrification, surface compaction would have been reduced, and deeper soil with lower pollutant concentrations would have been mixed into the contaminated topsoil, thereby potentially reducing the adverse effects of phytotoxic chemicals in the topsoil.

BIOSECURITY ASSESSMENT

Virus Inactivation

Example data showing NDV survival ratios (number of positive samples / number of samples tested) at various times during trial 1are shown in Table 16. Table 17, summarizes similar AE and NDV survival data for all trials (see Appendix G for all biosecurity data). (Note: AE inactivation data collected during trials 1-3 were declared invalid because laboratory control samples failed to test positive for active viruses.)

In general, the summary data indicate that virus survival times depended on the type of virus, weather conditions at the time of test unit construction, and the type of vessel (vial or cassette) used to contain the virus samples. With respect to virus type, AE virus consistently survived longer than NDV. During trials 4-6, when simultaneous survival data could be obtained for both types, AE viruses (housed in vials) survived 1–7 weeks, while the less robust NDV (in vials) lived for 2 days – 4 weeks.

Seasonal temperatures at the beginning of the trials also appeared to have a significant impact on virus survival. NDV (in vials) survived 1 week or less during two warm season trials, and 1-4 weeks during four cool or cold season trials. Similarly, AE in vials survived about 7-12 days during a warm season trail, and 2 to 7+ weeks during cool or cold season trials.

The type of sample vessel used to contain the virus samples — vial or cassette — also significantly affected virus survival. In all but one trial, NDV samples contained in cryogenic vials survived 1–4 weeks, while NDV contained within dialysis cassettes generally survived one week or less. Similarly, AE in vials survived 1-7+ weeks, while AE in cassettes were inactivated within 2 – 7+ days. These substantial differences are believed to reflect differences in exposure to environmental stresses associated with the composting environment. Viruses housed within sealed vials were exposed only to the heat of composting, while those housed in the gas permeable dialysis cassettes were exposed to additional environmental stresses — such as drying, or exposure to potentially toxic decomposition gases — that may have shortened virus survival times.

Table 16. Viability of Newcastle Disease in virus samples from test units in trial 1.

Sample Time	Sample Location	No of Samples Positive / Sample Total			
		Vials	Control Vials @ +4°C	Cassettes	Control Cassettes @ +4°C
Day 1	Corn Stalk	6/6		8/8	
	Silage	6/6	7/7	0/6	8/8
	Soil/Compost Blend	6/6		8/8	
Day 2	Corn Stalk	5/5		8/8	
	Silage	5/5	7/7	2/8	8/8
	Soil/Compost Blend	3/4		4/8	
Day 3	Corn Stalk	4/6		4/8	
	Silage	7/7	7/7	0/8	6/6
	Soil/Compost Blend	6/6		8/8	
Day 6	Corn Stalk	8/8		1/8	
	Silage	0/8	7/7	0/8	10/10
	Soil/Compost Blend	1/8		NS	
Day 7	Corn Stalk	0/7		0/8	
	Silage	0/7	7/7	0/7	10/10
	Soil/Compost Blend	1/8		NS[1]	
Day 10	Corn Stalk	0/8			
	Silage	0/7	6/6		
	Soil/Compost Blend	1/7			
Day 13	Corn Stalk	0/7			
	Silage	0/8	7/7		
	Soil/Compost Blend	0/8			
Day 16	Corn Stalk	0/7			
	Silage	0/7	7/7		
	Soil/Compost Blend	0/8			
Positive Control	NDV	8/8			
Negative Control	PBS	0/7			

[1]NS - No sample due to cassette damage

Table 17. Summary of virus inactivation times for all trials.

	NDV- Vials	NDV-Cassettes	AE – Vials	AE - Cassettes
Trial # 1 Warm/Dry				
Cornstalks	1w [1]	-	-	-
Silage	1w	-	-	-
Soil/Compost Blend	1w	-	-	-
Trial # 2 Cold/Dry				
Cornstalks	2w	NS	-	-
Silage	1w	1w	-	-
Soil/Compost Blend	3w	2w	-	-
Trial # 3 Cool/Wet				
Cornstalks	7d [2]	7d	-	-
Silage	6d	3d	-	-
Soil/Compost Blend	10d	-	-	-
Trial # 4 Warm/Dry				
Cornstalks	2d	2d	12d+	5d
Silage	5d	2d	7d	5d
Straw/Manure	5d	1d	7d	5d
Trial # 5 Cold/Dry				
Cornstalks	2w	7d	7w+	5d
Silage	2d	1d	2w	2d
Straw/Manure	2w	5d	7w+	7d
Trial # 6 Cool/Wet				
Cornstalks	4w+	3d	7w+	7d+
Silage	4w	3d	6w	7d+
Straw/Manure	4w	2d	7w	7d

[1] w = weeks
[2] d = days

Virus survival times did not appear to be strongly associated with type of cover material. In light of the relatively high success rate of silage test units in meeting Class A and Class B time/temperature criteria for pathogen reduction, it was anticipated that test units constructed with silage would consistently exhibit significantly shorter virus survival times than other types of test units. However, in only two of six seasonal trials for NDV in vials, and one out of three trials for AE in vials, were survival times in silage test units significantly shorter than in cornstalk or straw/manure units. For samples contained in dialysis cassettes — where, as noted earlier, survival times were generally much shorter than in vials — the differences in survival times for silage and other cover materials were only a few days at best.

Bio-containment – Serology

Table 18 shows results of bio-containment tests conducted during trials 1, 4, and 6. (Due to harsh weather and test animal welfare considerations, bio-containment tests were not conducted during trials 2, 3, and 5.) Sentinel poultry serology data indicate that the 45-60 cm (18-24 in) envelope of straw, cornstalk, or silage cover material placed over contaminated interior surfaces of the composting piles was successful in preventing live virus from leaving the composting test units. Only one out of 72 sentinel poultry housed in cages at the edge of the test units showed a positive immune system response to either of the vaccine strains of AE and NDV that were liberally applied to the internal surfaces of the composting test units at the time of construction.

Table 18. Serology results from sentinel poultry exposed to emergency mortality composting windrows containing cattle carcasses contaminated with live AE and NDV vaccine.

	Sample Times (Number Positive Birds / Total Number Birds)							
	1 day	**1 week**	**2 weeks**	**3 weeks**	**4 weeks**	**6 weeks**	**8 weeks**	**10 weeks**
Trial # 1 (note AE virus problem)								
NDV	0/24	0/24	0/24	0/24	0/24	0/24	0/24	0/24
AE	0/24	0/24	0/24	0/24	0/24	0/24	0/24	0/24
Trial # 4								
NDV	0/24	0/24	0/24	0/24	0/24	0/24	0/24	0/24
AE	0/24	0/24	**1/24**	**1/24**	**1/24**	**1/24**	**1/24**	**1/24**
Trial # 6								
NDV	0/24	0/24	0/24	0/24	0/24	0/24	0/22	0/22
AE	0/24	0/24	0/24	0/24	0/24	0/24	0/22	0/22

Three un-replicated supplemental field tests were conducted to further assess biosecurity and the validity of the sentinel bird tests results. In the first of these, sentinel poultry were placed downwind of test units from trial # 1 as they were excavated and loaded into spreading equipment following trial completion. As shown in the upper half of Table 19 (Trial # 1 – Pile Removal), repeated blood serum sampling indicated that none of the birds exposed to airborne compost dust particles produced antibodies indicative of exposure to live AE or NDV viruses, further adding to evidence suggesting that the emergency windrow composting procedure successfully inactivated these viruses.

During the second supplemental field trial, external surfaces of test units in trial # 6 were contaminated with liquid containing live vaccine strains of AE and NDV, and sentinel poultry were then re-exposed to the externally contaminated piles for four weeks. Six of the re-exposed birds (lower half of Table 19) produced serologic antibodies to the NDV virus indicating airborne, or perhaps insect-borne, transport of live viruses from the pile to the sentinel birds. None of the birds showed evidence of exposure to the AE virus.

Table 19. Serology results from sentinel poultry exposed to compost dust, and to externally contaminated composting windrows.

	Sample Times (Number Positive Birds / Total Number Birds)				
	0 day	**1 week**	**2 weeks**	**3 weeks**	**4 weeks**
Trial # 1 – Pile Removal					
NDV	0/24	0/23	0/23	0/23	0/23
AE	0/24	0/23	0/23	0/23	0/23
Trial # 6 – Surface Contamination					
NDV	0/22	0/22	**3/22**	**5/22**	**6/22**
AE	0/22	0/22	0/22	0/22	0/22

During the 3rd supplemental test, six SPF chickens were exposed to soil beneath an infected test unit by placing them in a cage located on the soil following pile excavation. The birds were exposed for a period of 1 week, and then were kept for a period of about one month and monitored for serologic antibody as evidence of exposure. All birds tested negative.

LABORATORY TESTING AND RANKING OF ALTERNATIVE COVER MATERIALS

Tables summarizing results of all physical and biological tests for each of the 13 potential cover materials are contained in Appendix F.

Selection of Key Performance Categories and Recommended Laboratory Tests

Based on performance observed during mortality composting field tests conducted with silage, ground cornstalks, straw/manure, leaves, and a soil/compost blend the research team concluded that the most important measures of cover material performance included the ability to:

- generate and retain sufficient heat to kill pathogens;
- sustain oxygen concentrations that support aerobic carcass degradation and decomposition of odorous gases;
- maintain pile integrity (shape, gas permeability, coverage of carcasses) without frequent turning, reshaping, or addition of new cover materials; and
- retain excess precipitation and contaminated liquids that can pollute soil and water.

Based on a joint assessment of field performance and laboratory test results for five cover materials tested in the field, the research team concluded that four laboratory tests — biodegradability, gas permeability, mechanical strength, and available water-holding capacity — offered the best potential for predicting carcass composting performance. Biodegradability tests indicate a cover material's ability to supply energy (carbon) to heat the pile and thereby kill pathogens. Gas permeability provides a measure of a material's ability to allow oxygen into the pile; and to permit water vapor, decomposition gases, and excess heat to escape. Mechanical strength is vital to support the initial weight of carcasses and overlying cover material without undergoing severe compaction that can adversely affect gas and heat transport. Good mechanical strength also helps to avoid pile cracking and slumping which can lead to carcass exposures and need for constant pile maintenance. Finally, available water-holding capacity is essential to absorb and retain carcass liquids and rainfall that would otherwise be released as highly contaminated leachate.

Cover Material Ranking and Suggested Applications

The cover material rankings and use recommendations summarized in Table 21 are based on field performance and on laboratory test values for each of the four key test parameters. With regard to biodegradability, for example, silage exhibited excellent ability in the field to quickly generate and maintain high temperatures, and it also showed good energy production in the laboratory. Based on this information silage was assigned an "excellent" biodegradability rating, while a material such as the soil/compost blend, which performed poorly in the field and exhibited low values in lab as well, was assigned an "unacceptable" biodegradability rating. Materials that were not tested in the field, but which had lab biodegradability values similar to silage, were subsequently rated "excellent" in this category, while those with values similar to straw or cornstalks were rated "acceptable," and those resembling the soil/compost blend received a similar "unacceptable" rating. Using the above approach for each of the four key parameters, laboratory test values were rank ordered and subsequently grouped into the three general performance categories as shown in Table 20. Readers will note that the ranges of values in each performance category are not contiguous. They reflect actual values observed during laboratory testing and no attempt has been made to identify an exact boundary between adjacent categories.

Table 20. Performance ranges observed for key parameters in 13 potential cover materials.

	Total absorbable water (kg H_20 / kg sample wet basis)	**Mechanical strength**[3] (Nm^{-2})	**Permeability**[4] (mm^2)	**Energy production**[5] (J/g VS d)
Excellent	0.67- 4.23	34,700-80,700	0.14-0.34	512-1,356
Acceptable	0.30-0.32	12,900-27,000	0.65-6.49	169-320
Unacceptable	<0.26		<0.1	24-58

Numeric values were subsequently assigned to each rating — 1 for excellent, 2 for acceptable, and 3 for unacceptable — and a composite rating for use in scenario #1 (routine mortality disposal) was obtained by summing the four values.

To rate cover materials with regard to their use in emergency situations, it was necessary to revise the rating system to give higher weight to performance characteristics required by scenarios 2 and 3. This was done with a weighting factor. For non-disease emergencies, for example, the water-holding capacity rating was given a 2X weighting factor since carcass loading rates are likely to be higher, and there may be insufficient time or money to protect the windrows from excess precipitation. Applying a 2X weighting factor for water-holding capacity, an excellent water-holding rating becomes a 2, while an unacceptable rating becomes a 6. While this raises all composite scores, materials with excellent water-holding capacity are increased by only 1, while materials with unacceptable biodegradability are increased by 5 thereby producing a significantly larger composite rating number that results in a much lower ranking. The same approach was used for scenario #3, but in this case both water-holding capacity and biodegradability were assigned 2X weighting factors to account for the additional desire to achieve rapid heating necessary to kill pathogens.

The two right-hand columns in Table 21 show composite cover material rankings relative to the three scenarios described earlier. While the 2X weighting factor for water-holding capacity used in scenario #2 changed the composite scores, it did not cause a change the composite rankings from those for scenario # 1. As a result, material recommendations for these two scenarios are shown in the same column. Eight materials were ultimately judged to have excellent prospects for use in either scenario # 1 or #2, but only four of these materials were rated excellent for use in the heat-demanding scenario # 3. Lower degradability ratings brought the remaining four materials down into the “acceptable” category for scenario #3. As such, these materials would be expected to function — carcass decay would occur without serious leachate, odor, or maintenance problems — but their prospects for rapid heating and pathogen inactivation are judged to be lower.

Table 21. Rating and use recommendations for 13 potential emergency cover materials.

Cover material	Water holding capacity*	Mechanical strength	Permeability	Biodegradability**	Potential limitation	Use Scenario	
						Routine (#1) & non-disease emergency (#2)	Disease emergency (#3)
Turkey litter	Excellent						
Corn Silage	Acceptable				Moisture content		
Oat straw							
Cornstalks							
Alfalfa hay					Moisture content		
Soybean straw							
Wood shavings							
Sawdust							
Leaves-large					Moisture content		
Leaves-small					Moisture content		
Wheat straw					Moisture content		
Beef manure					Moisture content		
Soil/compost blend	Unacceptable						

MODELING OF FREE AIR SPACE TO PREDICT MAXIMUM DEPTH

To minimize the amount of land area affected by emergency disposal operations, livestock and poultry producers are likely to consider stacking of carcasses to make composting piles taller and more compact. Excessive stacking, however, can lead to saturation and compaction of cover materials at the base of the piles, thereby reducing free air space and restricting movement of vital oxygen and other gases into and out of the pile. Loss of mechanical strength caused by wetting, followed by compaction and partial blockage of pore spaces, are believed to be the primary mechanisms leading to significant loss of free air space. Materials having low mechanical strength, high bulk density, and/or small pores that are easily filled with water are most prone to loss of free air space, and their depths must be limited to avoid this.

Using laboratory measurements of permeability, mechanical strength, bulk density, and water content for each of the 13 proposed cover materials, and mathematical relationships linking free air space to these characteristics, a free air space model was developed to predict maximum recommended pile heights for each type of cover material at varying moisture levels. This model was run for pile heights up to 3 meters; taller piles are not considered to be practical for most on-farm loaders.

Table 22. Maximum recommended emergency windrow pile heights at various levels of material saturation.

	Pile Height (m)		
	@ 20% of water-holding capacity	**@ 50% of water-holding capacity**	**@ 80% of water-holding capacity**
Corn stalks	3	3	3
Oat straw	3	3	3
Silage	3	3	3
Alfalfa hay	3	3	3
Wood shavings	3	3	3
Soybean straw	3	3	3
Soil/compost blend	3	**2.3**	**0.5**
Leaves-large	3	3	3
Leaves-small	3	3	3
Saw dust	3	3	3
Bedded beef manure	3	3	**1**
Turkey litter	3	3	**2**
Wheat straw	3	3	3

As shown in Table 22, 10 of the 13 potential cover materials that were modeled are predicted to maintain free air space of at least 30% at depths of 3m and moisture levels up to 80% of water-holding capacity. Three of the materials — soil/compost blend, bedded beef manure, and turkey litter — are predicted to fall below 30% free air space as the materials are wetted to 80% of water-holding capacity. Based on the free air space model it is recommended that the soil/compost blend (which is not recommended for mortality composting), bedded beef manure, and turkey litter, be limited to depths of 0.5m, 1m, and 2m respectively. For further details on how the free air space model was developed, see the paper by Ahn et. al listed in Appendix H.

CONCLUSIONS

Carcass degradation rates, environmental impacts, and biosecurity were monitored in replicated seasonal trials to assess the feasibility and effectiveness of un-turned windrow-type composting systems for emergency disposal of cattle and other large livestock carcasses resulting from a disease outbreak or agro-terrorism.

The composting system consisted of a parabolic (cross-section) windrow with a base width of approximately 5.5m (18 ft) and initial height of 2.1m (7 ft). Full sized (450 kg) cattle carcasses were placed in a single layer on a 45-60 cm (18-24 in) absorptive base and covered with approximately 60 cm (24 in) of the same material that was used in the base. Three different base/cover materials that are typically available on cattle farms —corn silage, ground cornstalks, and straw/manure — were tested in replicated trials begun during spring, summer, and winter weather conditions. All construction was done with a tractor equipped with a front bucket loader.

GENERAL COMPOSTING SYSTEM PERFORMANCE

Carcass Degradation

Periodic temporary excavation and observation of small sections of selected windrows showed that all soft tissues associated with the 450 kg carcasses were fully decomposed within 4-6 months in units constructed during warm weather, and in 8-10 months in units constructed during cold-weather. Significant pile subsidence usually occurred during the first 30-60 days, occasionally requiring addition of material to fill in cracks and voids and maintain cover over the carcasses.

Despite substantial differences in internal temperature and O_2 concentration (described below) measured in test units constructed with silage, ground cornstalks, and straw/manure, carcass soft tissue degradation times appeared to be about the same regardless of the type of cover material. It is believed that the less favorable (lower) temperatures within the cornstalk test units may have been offset by significantly higher O_2 concentrations that tend to favor rapid decomposition.

Internal Temperature

Continuous internal temperature monitoring showed that test units constructed with corn silage heated up the quickest, produced the highest core and carcass surface zone temperatures, and sustained high temperatures the longest of any of the materials tested. Test units constructed with ground cornstalks or straw and manure were generally 10-20°C cooler than those constructed with corn silage, and sometimes took a week or more to reach peak temperatures if their initial moisture content was low.

Internal Oxygen Concentrations

Composting experts typically recommend that minimum O_2 concentrations within the pore spaces of composting piles not be allowed to drop below 5% (by volume) for significant periods of time, and concentrations of 10% or greater are preferred for good composting. Reflecting their high gas permeability, mean O_2 concentrations within the core, carcass surface, and outer envelope zones of all cornstalk test units exceeded 15% and minimum values never dropped below 11%. Mean O_2 concentrations in the core zone of corn silage and straw/manure test units, however, were in the 5-10% range during the initial weeks of the trials and minimum values dropped below 5%. In the carcass surface and outer envelope zones, mean O_2 concentrations for silage and straw/manure units exceeded 10% at all times, and minimum values were above 5%. Based on these measurements, all three cover materials appeared to perform satisfactorily during all or most of the carcass degradation period.

AIR QUALITY

Odor

Odor threshold data for air samples collected from the surface of composting treatments and stockpiles were compared. For silage and straw/manure treatments it was found that the compost piles had mean ODT that were not significantly larger than those for stockpiles ($P>0.05$) while that for cornstalk compost was significantly larger ($P<0.05$) than the stockpile. Cornstalk ODT samples had a lower variance and it is theorized that the statistical test was more powerful in this case and not that cornstalks are a poorer co-compost material. Cornstalk compost and stockpiles produced the least odor for their respective categories.

Because peak odors would be considered more of a concern than mean values, the 75th percentile was calculated for each treatment. Values for the 75th percentile of odor threshold were near that of pond water for cornstalk and straw/manure piles, and less than 1400 for silage, a level considered low for manure-related facilities. Due to the low ODT, small pile area in comparison to an anaerobic lagoon, and dilution between the pile and a neighboring residence, it is concluded that properly managed compost piles would not present an odor nuisance problem.

Hydrogen Sulfide and Ammonia

Hydrogen sulfide and ammonia concentrations taken from the surface of the compost piles and corresponding stockpile were not significantly different ($P>0.05$). It should be noted that these values are for samples taken directly from the surface of the piles and not downwind readings.

GROUNDWATER POLLUTION POTENTIAL

Leachate Quantity and Quality

Leachate monitoring results suggest that the mortality composting piles have low potential to impact surface water or shallow soil or groundwater. Due to the relatively high porosity and water holding capacity of the cover materials evidence of runoff from the composting windrows was rarely noted. Mean contaminant concentrations within leachate captured at the base test units in trials 5 and 6 ranged from 42-267, 199-1,361, 4969-29,348, and 986-10,837 respectively for NO_3-N, NH_3-N, total solids, and TOC (total organic carbon) with the highest concentrations consistently originating in straw/manure test units.

Due to high water holding capacity and ability to temporarily absorb and subsequently evaporate water, the amount of leachate released by the test units was less than 5% of the precipitation (500-600 mm) that fell on them throughout the year. As a result, the total mass loading of chemical contaminants into the soil beneath the windrows appeared to be relatively low in most cases. Organic carbon loadings from leachate were calculated to be less than 8% of the estimated total carbon in the top 15 cm of soil, and NH_3-N loadings were generally less than 40 kg/ha (35 lb/acre) although in one instance the NH_3-N loading was calculated to be equivalent to 188 kg/ha (170 lb/acre).

Soil Pollution

Statistically significant increases in chloride concentrations were noted in all depth increments of soil cores collected beneath the composting test units, indicating that leachate penetrated to depths of 120 cm or more. These increases were moderate, ranging from 1.5-5 times the pre-composting concentrations in the top 15 cm of soil, and from 0.60 - 1.2 times pre-composting concentrations in the 90-120 cm depth interval.

Significant increases in % total carbon, and % total nitrogen were limited to the top 15 cm of soil. Increases in % total carbon were found only beneath silage test units, while significant increases in % total nitrogen occurred beneath silage, cornstalk, and straw/manure test units. The increases in these pollutants also were moderate, amounting to less than 20% of pre-composting concentrations of % total carbon, and 10-40% of % total N concentrations prior to composting.

Ammonia-nitrogen was the most significant soil pollutant. Statistically significant increases in total ammonia-nitrogen were noted at depths of up to 90 cm beneath test units constructed with silage or leaves, and at 30 cm and 15 cm depths respectively beneath test units constructed with straw/manure and cornstalks. Unlike the increases in chloride, carbon, and total nitrogen, the ammonia-nitrogen additions were very large ranging from 200 – 800 mg/kg in the top 15 cm of soil. These are 40-160 times the pre-composting levels of ammonia in the topsoil, and are equivalent to fertilizer or manure nitrogen applications of 360 – 1440 kg/ha.

No significant increases in nitrate-nitrogen occurred during the composting process beneath test units constructed with cornstalks, silage, or straw/manure (materials recommended for mortality composting). High residual concentrations of ammonia-nitrogen in the topsoil following composting, however, would ultimately be expected to nitrify following removal of the finished compost from the disposal site. This could lead to subsequent nitrate pollution of the subsoil or shallow groundwater. Further monitoring of soil N at the composting research site is recommended to better understand the dynamics of ammonia dissipation in the soil, and to evaluate mitigation measures that can help to minimize groundwater pollution risks.

When compared with the groundwater pollution potential of carcass burial — the most common on-farm emergency disposal method — the nitrogen-related groundwater pollution risks associated with composting appear to be much lower. The total mass of N contained in the composted cattle carcasses was 4–10 times greater than the increases in N that were measured in the soil beneath composting test units. Furthermore, burial would have placed the carcass N much closer to the groundwater, further increasing the risks of groundwater pollution.

BIOSECURITY

Virus Inactivation

Field biosecurity tests using vaccine strains of AE and NDV showed that these viruses were reliably inactivated during emergency composting of large animal carcasses in unsheltered windrows. When the test viruses were contained in sealed vials that protected them from stress factors other than heat, survival times ranged from 2days - 4 weeks for NDV, and 1-7 weeks for AE. When the viruses were contained in dialysis cassettes —exposing them to heat and to other simultaneous stress factors — both types were inactivated within 1 week. In general, survival times for both viruses were noticeably shorter during trials begun during warm weather than in trials started during cool or cold weather. Despite consistently higher temperatures in silage test units, survival times for virus samples contained in vials were not consistently shorter than in the other types of test units within the same trial. In instances where differences did occur, they were often by only a few days, particularly for samples contained within dialysis cassettes. This does not necessarily imply that time/temperature criteria are not important factors in virus inactivation, but it suggests that other factors may also play important roles in pathogen reduction.

Analysis of carcass surface zone temperatures showed that test units constructed with corn silage met USEPA Class A time/temperature criteria for pathogen reduction in biosolids in 89% of the seasonal units tested. Class A requirements in the carcass surface zones of straw/manure test units were achieved in 67% of test units, and in 22% of the cornstalk units. Less stringent USEPA Class B requirements for significant reduction of pathogens in biosolids that cannot be spread on public areas (but that can be safely spread on non-public agricultural land) were attained in the carcass surface zones of 100%, 67%, and 22% of the silage, straw/manure, and ground cornstalk test units respectively. As noted in the previous paragraph, AE and NDV virus inactivation times observed during field studies indicate a greater degree of biosecurity than suggested solely by the success rates in achieving Class B criteria. This is consistent with the fact that the USEPA time/temperature criteria are conservative, and that — as noted earlier — pathogen inactivation times are affected by other environmental stress factors in addition to time and temperature. This is the basis for recommendations in this report indicating that ground cornstalks, ground straw, and similar cover materials — while not as desirable as silage and similar cover materials that produce and retain heat more reliably — are nevertheless acceptable for use in non-disease-related emergencies as long as a sufficient thickness of cover material is applied and maintained during the composting process.

Bio-Containment

Results of bio-containment studies using specific pathogen free poultry as bio-indicators of virus exposure indicate that 45-60 cm of cover material was effective at retaining live viruses within the composting windrows. Negative serum antibody results during supplemental tests in which poultry were exposed to dust from finished compost, and to soil beneath composting test units, provide further evidence of that the emergency composting procedures tested are biosecure and that the composted material is safe to handle and spread. Positive serum antibody results following sentinel poultry exposure to test units with contaminated cover materials emphasize the importance of using uncontaminated materials for the outer envelope of emergency composting systems.

Cover Material Ranking and Suggested Applications

Based on comprehensive physical and biological testing of 13 potential cover materials — combined with field performance data for 5 of those materials — project researchers concluded that water-holding capacity, gas permeability, mechanical strength, and biodegradability are the most useful variables for predicting cover material performance.

Using these variables, the 13 potential cover materials were ranked according to their potential for success when used for routine mortality composting, non-disease-related emergency composting, and disease-related emergency composting. Based on this analysis, turkey litter, corn silage, oat straw, and alfalfa hay were top ranked for use in disease-related carcass disposal scenarios where production and retention of heat and ability to retain liquid are important in reducing pathogens and retaining leachate in un-turned windrows. These four materials as well as four additional materials — cornstalks, wood shavings, sawdust and soybean straw — were top ranked for use in composting of routine mortalities or those caused by non-disease-related emergencies. In these scenarios, where disease transmission is less of a threat, heat production becomes less critical and pile turning can be used to help manage excess liquid.

COVER MATERIAL DEPTH/FREE AIR SPACE MODELING

A mathematical model linking free air space to gas permeability, mechanical strength, bulk density, water content, and pile depth was developed and used to predict maximum recommended pile heights for each type of cover material. This model, which was run for 13 different cover materials, indicates that 10 of the materials can sustain a minimum recommended free air space of 30% at pile depths of three meters or more. Three cover materials — the soil/compost blend (which is not recommended for mortality composting), bedded beef manure, and turkey litter — should be limited to pile depths of 0.5m, 1m, and 2m respectively to sustain adequate free air space for good composting.

GUIDELINES FOR EMERGENCY COMPOSTING

One of the main objectives of the research described above is to provide IDNR with emergency composting guidelines for possible inclusion in the agency's foreign animal disease response plan or similar policies. The following emergency cattle mortality composting guidelines are based on observations of practices that proved effective during comprehensive performance, environmental, and biosecurity testing of full-scale multi-season field trials conducted in Iowa during the period from August 2002 – July 2005. They are based on performance observed under Iowa environmental conditions (temperature, wind, precipitation, soil type), and using specific types of cover materials produced in Iowa. As such, these guidelines may not be appropriate for use in locations having climatic or environmental conditions that are much different from those in Iowa, or when using cover materials having physical, chemical, or biological characteristics that differ greatly from the materials that were tested.

COMPOSTING SYSTEM & CONFIGURATION

- During the 3-year study by Iowa State University, un-covered and un-turned emergency windrows, constructed on level soil, proved to be relatively easy to construct and maintain using a tractor-loader and organic cover materials commonly found on cattle farms (silage, cornstalks, straw). Retention of odors, soil and water pollutants, and test viruses were acceptable — impacts on air, soil, and water quality were minimal — as long as the proper types and thickness (specific recommendations are given later in this section) of organic base/cover material were used during windrow construction and throughout the composting process.
- To promote oxygen penetration, release of excess heat, and evaporation of excess water, a long and narrow windrow configuration is preferable to a broad-based pile. For full-sized (1,000 lb) cattle, a maximum base width of 16-18 ft is recommended (this is sufficient for two full-sized cattle laid side-by-side). Piles that are significantly wider than this will lengthen the lateral distance that oxygen must travel to reach the carcass decomposition zone, and this can lead to reduced O_2 concentrations and evaporation of excess moisture.
- Siting of emergency mortality composting operations should be done using the same criteria used for any animal waste facility. Observe typical setbacks from roadways and other public land, private dwellings, wells, streams, and active poultry and livestock operations. To the extent possible, select a reasonably level location that will not be subject to overland flow of runoff during rainfall or snowmelt.

BASE/COVER MATERIALS AND THICKNESS

- Disease-related emergencies - moderately moist corn silage has proven effective in producing and sustaining high temperatures that are desirable for composting carcasses resulting from death caused by disease. Laboratory testing suggests that alternative materials that are likely to have heating and heat retention characteristics similar to corn silage include alfalfa hay, turkey litter, and oat straw. If these materials are not available, ground cornstalks, ground soybean straw, wood shavings, sawdust, leaves, ground wheat straw, and dry bedded beef manure will sustain carcass decay and retain excess water, but are less likely to provide high temperatures desired for rapid pathogen reduction.
- Non-disease-related scenarios - turkey litter, corn silage, oat straw, ground cornstalks, ground alfalfa hay, ground soybean straw, wood shavings, and sawdust are top-rated base/cover materials. Dry leaves, wheat straw, and bedded beef manure are less desirable but acceptable alternatives.
- Avoid using any base/cover materials that are wet. To test wetness, squeeze a handful tightly. If any water drips out, the material is too wet and may perform poorly due to reduced water absorbing and oxygen transmitting capacity.
- Note that any of the long and fiberous agricultural residues recommended above must be ground (2-inch recommended maximum length) to enhance their water absorbing capacity and to minimize formation of large voids in the outer envelope that could lead to carcass exposure, excessive heat loss, and leachate release.
- To minimize the risks of excessive leachate release a 24-inch deep base layer beneath the carcasses is recommended.
- To minimize the risks of both odor and leachate release, a 24-inch thick envelope of cover material over the carcasses is recommended.
- To avoid excessive compaction and subsequent loss of free air space in the base layers of the windrow, pile heights should be limited to a maximum of 2m for turkey litter, 1m for dry bedded beef manure, and 0.5m for dense soil-like materials (not recommended for emergency composting) such as the soil/compost blend. For the remaining 10 materials tested, compost modeling indicates that pile heights of up to 3m can be used without serious compaction.

ORGANIC LOADING RATES

- Every 1,000 lbs of carcasses contains approximately 650 lbs of water, so stacking of large (> 750 lbs) carcasses greatly increases the likelihood of excessive leachate production, severe compaction of base layers and pile settling, and development of anaerobic conditions beneath the carcasses.

- To avoid the problems listed above, it is recommended that large (> 750 lb) carcasses be composted in single layers (no stacking of carcasses) and that no more than two 1,000-lb carcasses be placed in an 8-ft length of composting windrow (with 18 ft base width as described above).
- Smaller carcasses (< 750 lbs) may be stacked if at least 12-inches of absorptive material are placed between layers.
- During the IDNR/ISU emergency composting research, successful composting was achieved when two 1,000-lb cattle carcasses were placed in each 8 feet of windrow length (with 18-ft windrow base width). Although higher mass loading rates were not tested, it is anticipated that increased water and organic loading associated with higher mass loading rates may lead to low internal oxygen concentrations, reduced decay rates, and possible release of leachate from the sides of the windrow. With these concerns in mind, it is recommended that total mass loading rates, regardless of carcass size, be limited to no more than 2,000 lbs in every 8-ft length of windrow.

OPERATION

- Windrows constructed with cover materials that are sufficiently permeable (see material recommendations) to air flow need not, and should not, be turned if mortalities were caused by disease, until all soft tissues are fully decayed.
- Non-disease-related mortalities may be turned to improve oxygen transfer and moisture distribution, but turning of large carcasses too early in the decay process can release odors or cause undue cooling during cold weather. It is recommended to wait at least 90 days before turning heavily loaded emergency composting windrows, and extra cover material should be kept on hand to control odor releases if they occur following turning.

AMOUNT OF BASE/COVER MATERIALS NEEDED

- Using the windrow geometry and carcass loading rates suggested above, approximately 12 cubic yards of base/cover material will be needed for every 1,000 lbs of carcasses composted in an emergency windrow system. At typical cover material densities in newly-constructed windrows, this is equivalent to 1.0 ton of ground hay or straw, 1.4 tons of ground cornstalks, or 3.2 tons of corn silage.

- Livestock operations intending to use composting for emergency mortality disposal should stockpile sufficient quantities of cover materials, or develop a plan for quickly locating and hauling sufficient material, to meet emergency needs.

SITE CLEANUP AND REMEDIATION

- Finished cattle mortality compost may include large bones that can interfere with tillage and planting, or offend nearby residential property owners. Additional tillage operations may be needed to break up or cover the bones. Use of a manure spreader equipped with a hammer-mill type discharge can help to reduce the size of large bones. Screening and burial of the large bones is another option.
- The uppermost layers of topsoil located beneath carcass composting windrows may accumulate salts or other phytotoxic materials that suppress crop emergence and growth. Tillage of these soils may help to break up the affected layer and mix it with uncontaminated soil, thereby improving 1st year crop production.

WORKS CITED

Britto, D.T and H.J. Kronzucker. 2002. NH_4+ toxicity in higher plants: a critical review. Journal of Plant Physiology. 159: 567-584.

Bundy, D. 2004. Personal Communication. Professor of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA. July, 2004.

Dowling, C.W. 1998. Seed and seedling tolerance of cereal, oilseed, fibre and legume crops to injury from banded ammonium fertilizers. Ph.D. thesis, Griffith University, Queensland, Australia.

Ott, L. 1984. *An Introduction to Statistical Methods and Data Analysis.* 2nd Edition. Boston, MA. PWS Publishers.

Rynk et. al. 1992. *On-Farm Composting Handbook*, NRAES-54, Ithaca, NY. p 8.

USDA-ARS, National Salinity Laboratory Website, “Chloride tolerance of agricultural crops”, (http://www.ussl.ars.usda.gov/pls/caliche/CLTT49), viewed 3/01/2005.