6-2009

Performance of a Bio-secure Emergency Composting System for Disposal of Swine Carcasses

Thomas D. Glanville
Iowa State University, tglanvil@iastate.edu

H. K. Ahn
United States Department of Agriculture

Benjamin P. Crawford
Iowa State University

Jacek A. Koziel
Iowa State University, koziel@iastate.edu

Neslihan Akdeniz
University of Minnesota–Twin Cities

Performance of a Bio-secure Emergency Composting System for Disposal of Swine Carcasses

Abstract
A plastic-wrapped passively-ventilated composting system used by the Canadian Food Inspection Agency for bio-secure emergency disposal of poultry mortalities during an avian influenza outbreak in 2004, was adapted and field tested to determine its feasibility for emergency disposal of infectious swine carcasses. System performance was evaluated during triple-replicated 8-week long trials, and 10-day long lab-scale studies were carried out to supplement the field results. Treatment variables included season (warm or cool), type of envelope material (cornstalks, oat straw, corn silage, wood shavings, alfalfa hay, and soybean straw), and initial moisture content of the envelope materials (low< 20% w.b; moderate 40-65%). Performance variables included: final moisture content and leachate production; ability to sustain desirable internal O2 concentrations; % carcass (soft tissue) decomposition; and ability to attain and sustain pathogen-killing temperatures. Despite release of significant amounts of water from carcasses, and being wrapped in plastic sheeting, little leachate accumulation was observed and the moisture content of envelope materials was generally lower at the end of the trail than at the beginning. All materials, except corn silage, were able to maintain internal O2 concentrations of 10% or higher when air was supplied through flexible 10 cm diameter ducts spaced at 2m intervals. O2 concentrations in corn silage often dropped below 10% even though aeration ducts were spaced at 0.5m intervals. Corn silage demonstrated superior pathogen killing potential. Average daily temperatures in the carcass layer of silage test units during the first 30 days of composting (T30) exceeded 50 oC, and USEPA Class B criteria for pathogen reduction were achieved at 90% of monitored locations. T30 values for cornstalks, soybean straw, and alfalfa hay are about 40 oC, and Class B criteria were achieved in only 45-57% of monitored locations in the carcass layer. Wood shavings and oat straw had the worst temperature performance with T30 values of only about 30 oC, and a Class B success rate of about 35%. Mean soft tissue decomposition in the field was lowest in corn silage (72%), and highest in cornstalks and soybean straw (87% and 85% respectively).

Keywords
livestock, mortality, disposal, composting, emergency, bio-security

Disciplines
Bioresource and Agricultural Engineering

Comments
This is an ASABE Meeting Presentation, Paper No. 096342.

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 096342

Performance of a Bio-secure Emergency Composting System for Disposal of Swine Carcasses

T.D. Glanville, PhD.

Department of Agricultural & Biosystems Engineering, 201 Davidson Hall, ISU, Ames, Iowa 50011, (tglanvil@iastate.edu)

H.K. Ahn, PhD.

Environmental Management and Byproduct Utilization Laboratory, USDA-ARS, Bldg 306, Rm 113 BARC-East, Beltsville, MD 20705, (heekwon.ahn@ars.usda.gov)

B.P. Crawford, M.S.

Dept. of Agricultural & Biosystems Engineering, 3155 NSRIC, Iowa State University, Ames, Iowa 50011 (benius@iastate.edu)

J.A. Koziel, PhD.

Dept. of Agricultural & Biosystems Engineering, 3103 NSRIC, Iowa State University, Ames, Iowa 50011 (koziel@iastate.edu)

N. Akdeniz, PhD.

Bioproducts/Biosystems Engineering, University of Minnesota, Twin Cities. (akdeniz@umn.edu)

Written for presentation at the
2009 ASABE Annual International Meeting
Sponsored by ASABE
Grand Sierra Resort and Casino
Reno, Nevada
June 21 – June 24, 2009

Abstract. *A plastic-wrapped passively-ventilated composting system used by the Canadian Food Inspection Agency for bio-secure emergency disposal of poultry mortalities during an avian influenza outbreak in 2004, was adapted and field tested to determine its feasibility for emergency disposal of infectious swine carcasses. System performance was evaluated during triple-replicated 8-week long trials, and 10-day long lab-scale studies were carried out to supplement the field results. Treatment variables included season (warm or cool), type of envelope material (cornstalks, oat straw, corn silage, wood shavings, alfalfa hay, and soybean straw), and initial moisture content of the envelope materials (low< 20% w.b; moderate 40-65%). Performance variables included: final moisture content* *and leachate production; ability to sustain desirable internal O_2 concentrations; % carcass (soft tissue) decomposition; and ability to attain and sustain pathogen-killing temperatures. Despite release of significant amounts of water from carcasses, and being wrapped in plastic sheeting, little leachate accumulation was observed and the moisture content of envelope materials was generally lower at the end of the trail than at the beginning. All materials, except corn silage, were able to maintain internal O_2 concentrations of 10% or higher when air was supplied through flexible 10 cm diameter ducts spaced at 2m intervals. O_2 concentrations in corn silage often dropped below 10% even though aeration ducts were spaced at 0.5m intervals. Corn silage demonstrated superior pathogen killing potential. Average daily temperatures in the carcass layer of silage test units during the first 30 days of composting (T_{30}) exceeded 50 ^oC, and USEPA Class B criteria for pathogen reduction were achieved at 90% of monitored locations. T_{30} values for cornstalks, soybean straw, and alfalfa hay are about 40 ^oC, and Class B criteria were achieved in only 45-57% of monitored locations in the carcass layer. Wood shavings and oat straw had the worst temperature performance with T_{30} values of only about 30 ^oC, and a Class B success rate of about 35%. Mean soft tissue decomposition in the field was lowest in corn silage (72%), and highest in cornstalks and soybean straw (87% and 85% respectively).*

Keywords. livestock, mortality, disposal, composting, emergency, bio-security

(The ASABE disclaimer is on a footer on this page, and will show in Print Preview or Page Layout view.)

Introduction and Objectives

During an outbreak of highly pathogenic avian influenza (AI) in British Columbia in 2004, the Canadian Food Inspection Agency (CFIA) biologically heat treated and decomposed poultry mortalities in composting windrows that were wrapped in plastic sheeting to reduce the risks of pathogen escape caused by wind or release of leachate (Spencer, Rennie, and Guan 2004). Passive aeration was provided through flexible 10-cm diameter slotted plastic drainage tubing installed crosswise in the base of the windrows at 1.2 m intervals, and heated air, water vapor, and decomposition gases were vented through holes in the plastic at the top of the windrows.

Successful implementation of the enhanced bio-security composting design during the 2004 emergency led Canadian animal health officials to undertake further studies to evaluate its potential for emergency disposal of swine and cattle. CFIA contracted with researchers in the Department of Agricultural & Biosystems Engineering at Iowa State University (ISU) to assess the feasibility of using plastic-wrapped composting for emergency disposal of swine.

Key concerns were: suppressed evaporation and accumulation of excess leachate during prolonged composting of large carcasses in unturned plastic-wrapped piles; and how different envelope materials that are likely to be used for emergency swine composting would perform — with regard to O_2 transport, ability to develop and sustain elevated temperatures, and decomposition of carcasses — when enclosed in a plastic envelope.

Five research questions were to be addressed by the CFIA/ISU research. They included:

1. Would use of an impermeable plastic bio-security barrier; passive ventilation through relatively small pipes; and unturned piles; seriously suppress moisture evaporation, causing significant leachate accumulation during swine composting?

2. Would envelope materials typically available to swine producers (cornstalks, oat straw, corn silage, soybean straw, alfalfa hay, and wood shavings) retain their ability to: 1) transport O_2 and water vapor; 2) generate and sustain elevated temperatures; and 3) decompose large carcasses (relative to poultry); when functioning in a plastic-wrapped compost matrix ventilated through relatively small (compared with open piles) ducts?

3. What are the critical factors affecting the performance of the passive ventilation duct system, and how do they impact air movement, O_2 concentrations, and internal temperature?

4. Can volatile organic compounds (VOC's) released by decaying carcasses and envelope materials be used to monitor and track decomposition of pathogenically contaminated carcasses without breaching the plastic bio-security barrier? and

5. Are viral pathogens reliably inactivated within a passively ventilated plastic-wrapped composting matrix?

This paper focuses on objectives 1 and 2. Results of objective #4 are reported in papers by Akdeniz et al. (2008, 2009).

Materials & Methods

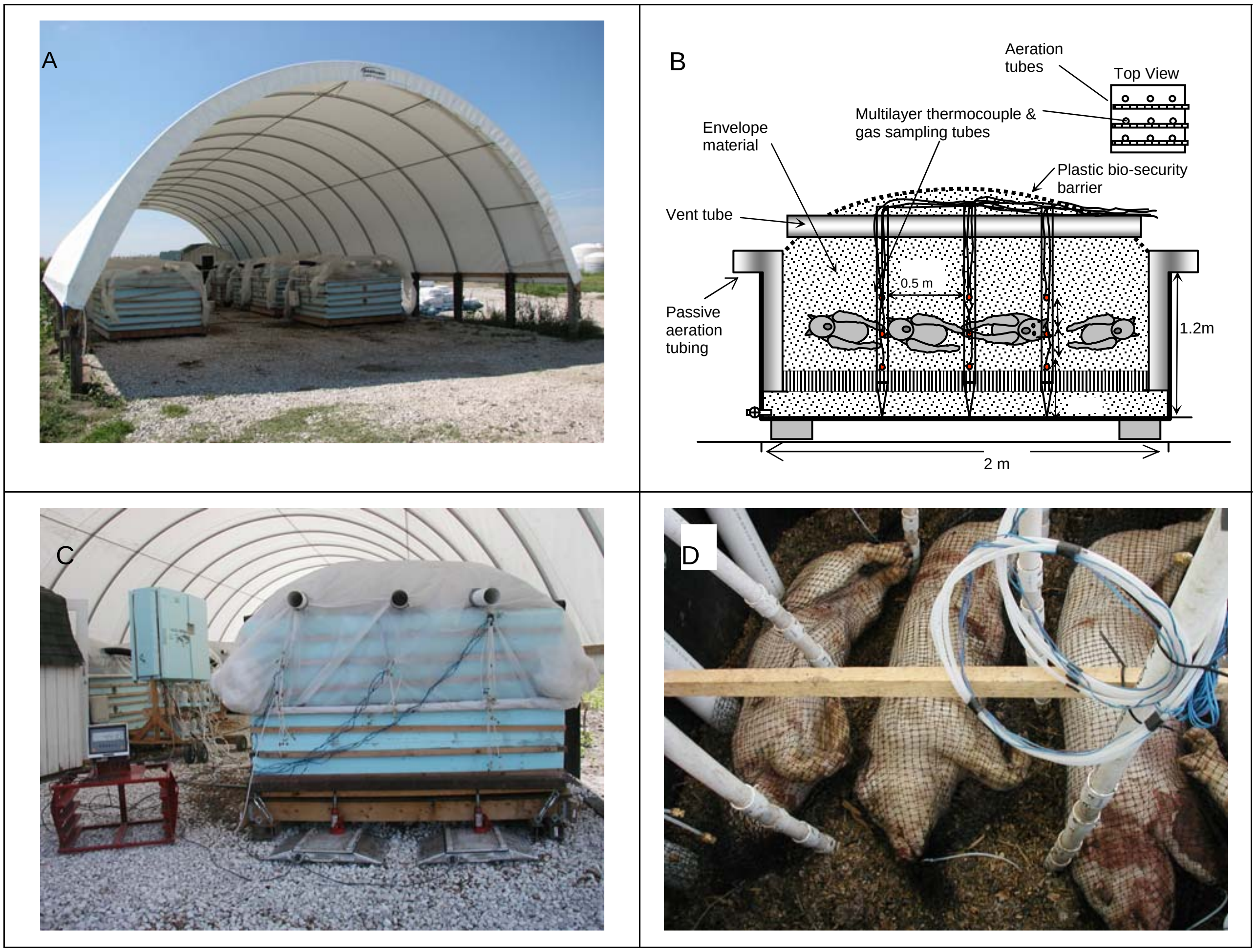


Figure 1. Replicated test units (A), cross-section of loaded test unit & instrumentation (B), test unit being weighed to determine mass loss (C), swine carcasses (wrapped in plastic netting) in test unit amidst vertical thermocouple and gas sampling tubes (D).

Test Units

Composting was done in 2m X 2m X 1.2m (high) test units. The fixed dimensions and moderate size of the test units was planned so that the compost matrix could be weighed periodically to determine total mass, average bulk density of the compost matrix, and changes in total mass.

Test units were weighed by placing small hydraulic jacks on four portable electronic scale pads (part # S-W1120) manufactured by Schrran Engineering, Inc. (Griswold, IA) for weighing trucks, trailers, and similar mobile equipment. By extending the jacks sufficiently to raise each corner of the loaded test unit a fraction of an inch off the ground, the weight of the platform was transferred to the scale pads thereby allowing them to be quickly and safely weighed in place (Figure 1C).

The floor and sides of the test units were insulated with 5-cm thick Styrofoam insulation to reduce heat loss and simulate conditions within the core of a larger compost pile.

Test units were passively aerated (to simulate CFIA model for bio-secure composting) through 10-cm diameter perforated drainage tubing embedded in a 30-cm thick layer of envelope material placed in the bottom of each unit. Three aeration tubes were installed at 0.5 m intervals in each test unit (Figure 1 B & C).

Test units were lined with a waterproof membrane, to retain leachate, and covered with plastic bio-security sheeting to simulate the CFIA bio-secure emergency composting procedure.

Each test unit was loaded with approximately 225 kg of pigs each weighing 45-65 kg. The carcasses were placed on top of the 30-cm base layer, and covered with an additional 60 cm of the same envelope material used in the base. Each swine carcass was loosely wrapped in coarse plastic netting to facilitate recovery and weighing of remains at the end of the trial (Figure 1D).

Experimental Design

To observe the effects of seasonal changes in ambient air temperature, trials were conducted during cool- and warm-season trials lasting eight weeks. Warm-season trials were begun in June and August of 2007, and cool-season trials in November of 2006 and April of 2008. Three envelope materials were tested during each seasonal trial, and each material was triple replicated resulting in a total of nine test units in each trial.

To observe the effects of initial moisture content, envelope materials used in trials 1 & 3 had low initial moisture content (15-30% w.b.), typical of baled bedding materials stored in sheltered or partially sheltered conditions. In trials 2 & 4, the same materials were stored in piles exposed to spring precipitation, or they were artificially moistened to bring their initial moisture content into the 40-65% w.b. moisture range preferred for good composting. The exception was corn silage (trials 1 & 2) which is an inherently moist material that exceeded 65% during trial 1.

Although it would have been desirable to test all six materials simultaneously to expose them to exactly the same ambient temperatures, this was impractical due to the large quantities of swine carcasses and envelope materials, experimental space, instrumentation, and personnel that would be needed to construct and monitor 18 test units at one time. Average daily temperature during the first 30 days of trials 1, 2, 3, and 4 were 4.4, 22.4, 20.5, and 13.7 ^{o}C respectively.

Instrumentation and Data Collection

Temperatures within field test units were logged at two-minute intervals at 27 locations in each test unit (nine thermocouples in “bottom” layer beneath carcasses, nine in middle layer surrounding carcasses, and nine in “top” layer covering the carcasses). Temperature data were aggregated to obtain hourly and daily average temperatures at each point, and daily whole-layer values were calculated by averaging daily average temperatures at the nine monitoring locations in each layer.

Since seasonal field trials did not permit evaluation of internal temperatures under identical conditions of ambient temperature and initial moisture content, supplemental lab scale studies were conducted to further evaluate the ability of envelope materials to generate and retain heat. Swine tissue samples (10 cm diameter X 1 cm thick consisting of muscle, adipose tissue, and hide) weighing approximately 56 grams were enveloped in approximately 0.7 L of envelope material and incubated in OxiTop respiration bottles at 45 ^{o}C for 10 days. Tests were triple replicated, and envelope materials were pre-moistened to 15, 25, 35, and 60% w.b. to quantify microbial activity across a typical a range of starting moisture conditions. Oxygen uptake rates were evaluated at two-day intervals, and total oxygen uptake (TOU) was calculated for the 10-day test period. Previous research has shown oxygen uptake to be proportional to heat energy production (13.6 kJ/g O_2, Haug, 1993) (14 kJ/gO_2, Finstein, Miller, and Strom, 1986), allowing oxygen uptake data to be used as a reliable measure of microbial heat production.

Internal O_2 concentrations were monitored each week at the same internal locations where temperatures were measured. Data were averaged to obtain mean weekly O_2 concentrations for each layer, and the percentage of sampling events (by layer) that failed to meet the desired O_2 concentrations of 5% and 10% was used as a measure of O_2 transport performance for each material. All tests units in trial 1 were operated with three passive aeration ducts, as were silage test units during trial 2. Results from trial 1 showed, however, that envelope materials other than silage could maintain acceptable O_2 levels using only one aeration tube, and subsequent O_2 data collected from non-silage test units in trials 2, 3, and 4 were obtained using only a single functional aeration duct (others were capped) in the base of each test unit.

Envelope materials were sampled and tested for moisture content at the start, mid-point, and end of each two-month field trial. During each sampling event, three samples of envelope material were collected from layers directly beneath (“bottom”), surrounding (“middle”), and above (“top”) the swine carcasses.

Carcass decomposition in the field was quantified by weighing the carcasses and remains in each test unit at the beginning and end of an 8-week composting period. Carcasses were individually wrapped in coarse plastic netting to facilitate recovery and weighing of remains at the end of each trial. The focus was on soft-tissue decomposition since little if any skeletal decomposition was observed during the 8-week trials. Research by Kuhn et al. (1997) concluded that bone weight in pigs is typically about 12% of total body weight. Using this information, decomposition was calculated as a percentage of initial soft tissue wet weight which was calculated at 88% of total initial weight.

Lab-scale study of soft tissue decomposition was also carried out during the previously-described tests of oxygen uptake and heat production potential. By carefully weighing swine tissue sample mass at the beginning and end of the 10-day respiration tests, it was possible to observe and compare decomposition within various envelope materials under identical conditions of ambient air temperature and initial envelope moisture content.

Results and Discussion

Moisture

Since test units were loaded with approximately 225 kg of carcasses containing an estimated 150 L of water (65% moisture), initial expectations were that the plastic bio-security barrier enveloping the piles might hinder evaporation of moisture released by the carcasses, leading to accumulation of chemically- and biologically-contaminated leachate in the base of the test units.

Despite release of water from the carcasses, moisture levels declined during the course of most trials (Figure 2). In the layer containing the carcasses, statistical comparison of moisture content at 0 and 2 months (beginning & end of trial) indicated a significant ($p < 0.01$) decline in average moisture content of all materials of nearly 7 percentage points. In the bottom layer where gravity aided accumulation of excess moisture was expected, final moisture levels averaged about 5 percentage points lower than initial levels ($p<0.05$). Furthermore, for all materials but one (silage, trial 1) average moisture at the end of two months was below 65% — the level where aeration problems or leachate production are likely to occur — even when materials were pre-moistened (trials 2 & 4) to bring their initial moisture content into the desired 40-65% moisture range. No significant leachate was observed when test units were dismantled, and carcass remains frequently appeared to be desiccated, suggesting significant evaporation

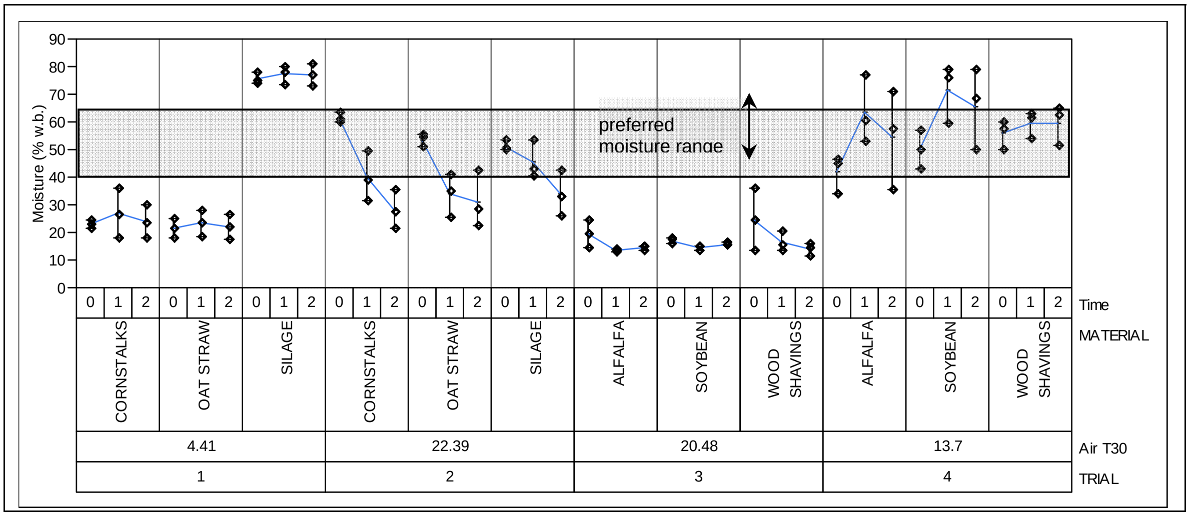


Figure 2. Moisture in bottom layer of each test unit (N=3), by trial and envelope material, at beginning (time = 0), middle (time = 1 month), and end (time = 2 months) of each trial.

from the carcasses, and/or wicking of moisture into adjacent envelope material followed by evaporation at a rate sufficient to preclude moisture accumulation.

O_2 Concentrations

The minimum O_2 concentration necessary to support aerobic composting is typically considered to be 5% (Rynk,1992) and concentrations above 10% are preferred. Failure to meet these minimum and preferred O_2 concentrations for composting occurred only in test units using silage as the envelope material (using 3 aeration ducts at 0.5 m spacing). O_2 concentrations in all other materials exceeded the 5% and 10% levels at all times and in all layers (using 3 aeration ducts during trial #1, and only one aeration duct during trials 2-4).

During trial 1 (cold), O_2 concentrations in the bottom and middle layers of silage test units were below the 5% minimum during 27% of sampling events, and below the preferred O_2 concentration (10%) in 67% of sampling events. During the warmer trial 2, O_2 in silage always exceeded the 5% minimum, but fell below the preferred 10% O_2 concentration 4% of sampling events. The failure of silage to meet O_2 requirements during trial 1 is believed to have been caused by high mean initial moisture content (~75%), and to unusually cold temperatures that caused the upper layers of the test units to freeze. At such high moisture content corn silage loses its mechanical strength, resulting in significant settling and compaction that can impair air movement through the composting matrix. During trial 2, external air temperatures were at or above 20 ^{o}C, and initial mean moisture content of the silage was slightly below 60% which is more favorable for retention of mechanical strength and maintenance of matrix porosity and gas permeability.

Internal Temperature

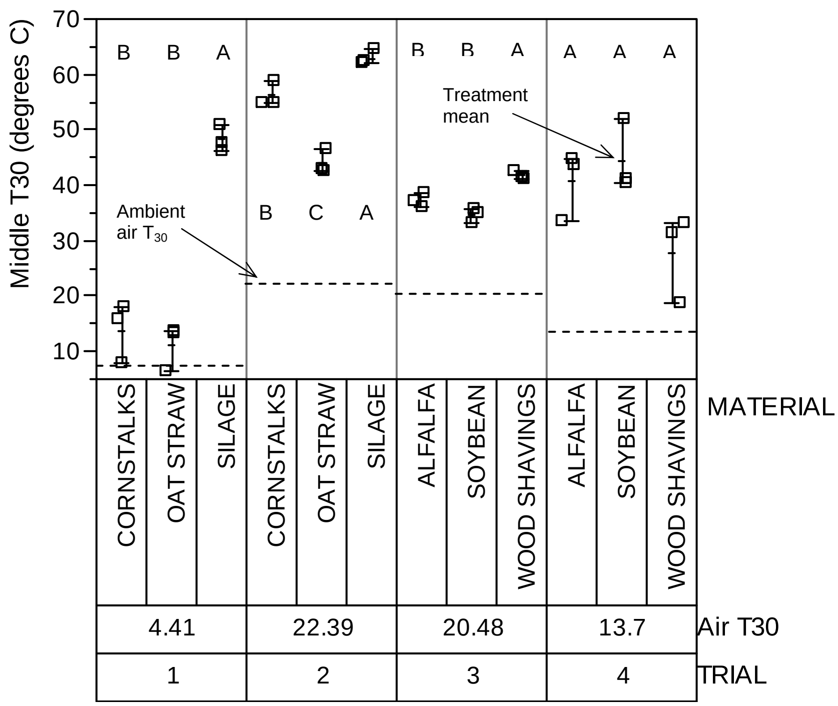
Field temperature data were evaluated in two ways. The ability of different envelope materials to quickly develop elevated temperatures — and hence to rapidly inactivate pathogens — was evaluated by calculating and comparing T_{30} values within the compost layer surrounding the carcasses (middle layer). T_{30} is defined as the mean daily temperature throughout a whole layer (N=9) during the first 30 days of composting.

Envelope materials also were ranked on the basis of their ability to achieve U.S. Environmental Protection Agency (USEPA) Class A and Class B time/temperature criteria throughout the middle (carcass) composting layer. Class A criteria require sustained temperatures of 55 ^oC or greater for at least 3 consecutive days. Class B criteria call for sustained temperatures of at least 40 ^oC for 5 or more consecutive days, AND temperatures must exceed 55 ^oC for at least 4 hours during this period.

Early Development of Elevated Temperature (Field T_{30})

T_{30} data (N=3 for each material in each trial) are shown in Figure 3. Since internal temperature is the combined result of heat production (biodegradation) and heat loss (convective and evaporative cooling), the T_{30} data reflect a complex interplay of envelope material and carcass characteristics— such as biodegradability, gas permeability, thermal conductivity, and specific heat capacity—and the effect of ambient air temperature.

As noted earlier, the purpose of this research was to assess the overall acceptability of six envelope materials when used in a range of ambient temperature and initial moisture content that would be likely to occur during a livestock emergency, and to determine if some materials perform noticeably better or worse than others.



(Materials within a trial that have different letters are significantly [$p < 0.05$] different)

Figure 3. T_{30} in middle layer of all test units, by trial and envelope material.

To separate the effects of ambient air temperature and initial moisture from those directly attributable to the envelope materials, two-way ANOVA models for T_{30} in the carcass (middle) layer were explored using envelope material, air T_{30}, ,middle layer initial moisture, possible interactions between the aforementioned variables, and replication, as predictor variables. Four models with adjusted R^2 values ranging from 0.81 to 0.92 were identified. The one that performed best (adjusted R^2 = 0.92, root mean sq error 4.3) yielded the predicted least square

Table 1. Least square mean values of T_{30} predicted for middle layer of 6 envelope materials.

Material				**Predicted least squares mean T_{30} in middle layer (^oC)**
SILAGE	A			52.5
ALFALFA	A	B		41.4
SOYBEAN	A	B		41.4
CORNSTALKS		B	C	37.9
WOOD SHAVINGS			C	29.7
OAT STRAW			C	30.1
Levels not connected by same letter are significantly ($p < 0.05$) different				

mean T_{30} values shown in Table 1. These values fall into three groups with corn silage having predicted average temperatures greater than 50 ^oC; alfalfa hay, soybean straw, and cornstalks in the second tier with predicted T_{30} around 40 ^oC; and wood shavings and oat straw having the lowest predicted temperatures of about 30 ^oC.

Heat Production Potential (Laboratory)

Two–way ANOVA modeling of TOU data indicated highly significant main effects on O_2 uptake by both initial moisture content ($p<0.0001$) and material type ($p<0.0001$). The predicted effects of moisture suggest that a relatively modest increase in initial moisture may have significant payoffs. Raising initial moisture from 15% to 35% is predicted to nearly double O_2 uptake, bringing it to a level equivalent to that observed at moisture levels of 60%

Table 2).

Table 2. Comparison of predicted least square mean of the natural log of total oxygen uptake within four moisture treatment levels. (Equivalent oxygen uptake in natural units of mg O_2 are shown to provide a performance-based reference.)

Initial Moisture Content % (w.b.)				**Natural Log Least Sq Mean**	**Equivalent Total O_2 Uptake** (mg O_2)
60%	A			3.63	37.8
35%	A			3.43	31.0
25%		B		3.15	23.4
15%			C	2.82	16.8

Levels not connected by same letter are significantly different ($p<0.05$).

Furthermore, at equivalent moisture levels, O_2 uptake (and hence heat production potential) by oat straw, cornstalks, and soybean straw is predicted to be 3 – 5X greater than for corn silage (Table 3). This suggests that the relatively low internal temperatures observed within oat straw, cornstalk, and soybean straw test units during field tests units may not be caused by an inherent inability to produce heat, but rather by heat loss associated with excessive air movement through the matrix. This idea is supported by the earlier discussion of internal O_2 concentrations which showed that corn silage suffered low O_2 concentrations even when supplied by three functional aeration ducts spaced 0.5 m apart, while O_2 concentrations in the other materials were consistently high when served by only a single aeration duct. If this is indeed the case, it is conceivable that the T_{30} performance of these materials could be improved by restricting the cross-sectional area of inlets to the aeration tube(s), thereby reducing airflow and convective heat loss.

Table 3. Two-way ANOVA ranking of 10-day mean O_2 uptake at 45°C for six envelope materials and four different initial moisture levels.

Material					Natural Log Least Sq Mean	Equivalent Total O_2 Uptake (mg O_2)
Oat Straw	A				3.93	51.4
Cornstalks	A	B			3.87	48.2
Soybean		B			3.55	35.1
Wood Shavings			C		3.06	21.5
Alfalfa			C	D	2.72	15.3
Silage				D	2.39	10.9

Levels not connected by same letter are significantly different ($p<0.05$).

USEPA Class A/B Success Rate

Table 4 shows the percentage of 54 temperature monitoring locations (6 test units per envelope material [3 warm season + 3 cool season] X 9 temperature monitoring locations per test unit) within the middle layer of each type of envelope material. Silage test units had the highest rate of success (85% of monitored locations) for achieving USEPA Class A time/temperature criteria throughout the middle (carcass) layer. Cornstalks — with a success rate of 48% — were the next best performer, and the remaining materials achieved Class A in less than 25% of monitored locations. Class B success rates were slightly higher than for Class A, and again silage success rates were highest, achieving Class B in slightly more than 90% of monitored locations. Ground soybean straw was successful in more than 57% of locations. Class B success occurred in 44-48% of locations within alfalfa and cornstalks, and in 33-35% of locations within wood shavings and oat straw test units.

Table 4. Success rate meeting USEPA Class A and B criteria for pathogen reduction in the middle composting layer of all trials.

Material	Success Rate (% of locations monitored in carcass layer)	
	Class A	Class B
Silage	85.19[a]	90.74[a]
Oat Straw	24.07[b]	35.19[c]
Cornstalks	48.15[c]	48.15[bc]
Wood Shavings	22.22[b]	33.33[c]
Soybean	27.78[b]	57.41[b]
Alfalfa	18.52[b]	44.44[bc]

Data within same class having different letters are significantly ($p<0.05$) different.

Carcass Decomposition

Decomposition in Field Test Units

Eight-week soft tissue decomposition of 45-65 kg swine carcasses within individual field test units ranged from 61-93% (Figure 4). One-way analysis of variance by material type (Table 5) shows that mean 8-week decomposition occurred in three ranges: 85-87% for cornstalks and soybean straw; 81-82% for alfalfa hay, wood shavings, and oat straw; and a low of 72% for corn silage. Decomposition within cornstalks and soybean straw was significantly higher ($p < 0.05$) than decomposition in corn silage, a somewhat surprising result in light of the consistently high internal temperatures observed within corn silage trials.

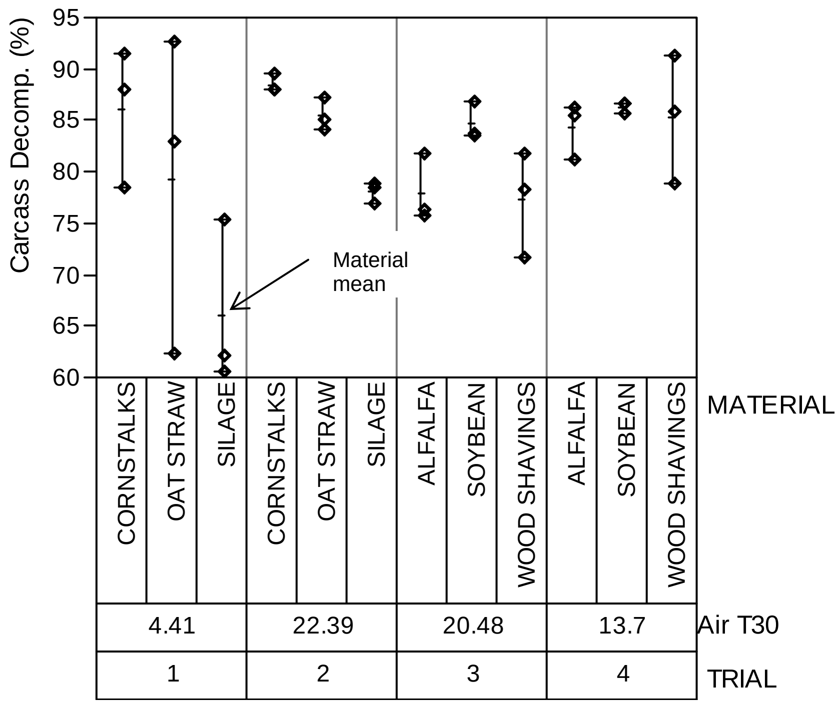


Figure 4. Percent of soft tissue decomposition by trial and material.

Table 5. Mean and ranking of 8-week carcass decomposition within six emergency envelope materials.

Material			Mean Soft Tissue Decomposition %
CORNSTALKS	A		87.2
SOYBEAN	A		85.4
OAT STRAW	A	B	82.3
WOOD SHAVINGS	A	B	81.2
ALFALFA	A	B	81.1
SILAGE		B	72.0

Levels not connected by same letter are significantly different ($p<0.05$).

As with the T_{30} data, two-way ANOVA models were used in an attempt to identify variables, in addition to envelope material, that may have a significant effect on carcass decomposition. Based on frequent field observation of desiccated carcass remains at termination of many field trials, it was hypothesized that the incomplete carcass degradation may have been caused by low terminal moisture. With this in mind, models were constructed using initial and final envelope moisture, ambient air $T_{30,}$ and internal T_{30} in the middle layer as predictor variables. No strong multivariate models for decomposition were discovered, however, as none of the models had adjusted R^2 values greater then 0.5, and envelope material was the only variable found to be significant in more than one or two models.

It should be noted that decomposition estimates based on the previously-described weighing and calculation procedures may have resulted in over estimation of decomposition in cases where significant amounts of particulate organic matter drains from the carcasses into the surrounding envelope material. If this organic matter is not subsequently decomposed during the trial period, then the true extent of carcass organic matter decomposition is less than that estimated on the basis of carcass weight loss. Field observations on termination and dismantling of some wood shaving test units revealed dark-stained shavings beneath the carcasses that appeared to be contaminated with un-decomposed organic matter. In this situation, it also was noted that total (envelope material + carcasses) test unit weight loss was less than the weight loss of the carcasses alone, suggesting transfer of carcass residuals and water from the carcasses to the envelope material. This phenomenon was only observed in wood shavings trials.

Decomposition in Controlled Laboratory Tests

Decomposition of animal tissue samples for each treatment was determined as a percentage of total initial mass. To determine the main effects of material and initial moisture on decomposition, as well as possible interaction effects, a two-way ANOVA model was developed. Predictor variables included material type, initial moisture level, material × initial moisture, and replication was included as a block. Envelope material type had a strong effect ($p<0.0001$) on decomposition, and several materials showed significantly different ($p<0.05$) least square mean decomposition values (Table 6). The top three performing materials were wood shavings, cornstalks, and oat straw, and all were predicted to have significantly ($p<0.05$) higher decomposition than the poorest performing materials (alfalfa and silage).

Initial moisture also had a strong effect ($p<0.0009$) on tissue decomposition. Predicted least squares mean decomposition values for each moisture treatment are shown in Table 6. The 60%, 35%, and 25% initial moisture treatments had the highest decomposition (and were within 3 percentage points of each other), and all were significantly higher than decomposition in the 15% initial moisture treatment. The interaction effect of moisture × material on decomposition

Table 6. Animal tissue decomposition during 10-day laboratory studies, as a function of envelope material and initial moisture content.

Envelope Material				**Least Sq Mean % Decomposition**
Wood Shavings	A			69.71
Cornstalks	A			69.32
Oat Straw	A			65.89
Soybean	A	B		64.92
Alfalfa		B	C	55.79
Silage			C	54.34

Initial Moisture Content			**Least Sq Mean % Decomposition**
35%	A		66.54
25%	A		66.31
60%	A		63.89
15%		B	56.57

Levels not connected by same letter are significantly different ($p<0.05$)

was fairly strong at $p<0.0483$, but the effects of material and moisture treatment individually appear to have a greater influence on tissue decomposition.

Laboratory decomposition rankings for the different envelope materials are similar to results from the field. In both cases, cornstalks are top ranked, and silage has the lowest decomposition.

The lab decomposition data also closely parallel microbial activity as measured by oxygen uptake data. Oat straw and cornstalks had relatively high decomposition and O_2 uptake, soybean straw has an intermediate ranking on both accounts, and silage and alfalfa have the lowest decomposition and O_2 uptake rankings. Decomposition and oxygen uptake results for wood shavings disagree, however, indicating moderate oxygen uptake and high predicted animal tissue decomposition.

Conclusions

Results of replicated field trials during warm and cool weather using six different envelope materials showed that composting of 45-65 kg swine carcasses in unturned piles that were wrapped in plastic sheeting and ventilated through small ducts did not result in moisture retention or leachate accumulation as feared. Average moisture content of compost materials declined slightly or remained the same during 8 week trials, and when test units were disassembled no leachate was observed and un-decomposed swine carcass remains appeared to be desiccated.

Ground cornstalks, ground oat straw, ground soybean straw, wood shavings, and ground alfalfa hay exceeded the desired internal O_2 concentration of 10% at all times in all composting layers, even when supplied by only one 10 cm diameter ventilation duct serving a 2m length of pile. Wet corn silage (initial moisture > 70% w.b.) failed to meet the minimum allowable O_2 level of 5% about 25% of the time, and fell below the desired concentration of 10% during more than 65% of sampling events, even though three aeration ducts were used in a 2m length of pile. Silage with average initial moisture content of 55% performed better, exceeding the 5% minimum O_2 level at all times, and falling below the 10% desired level less than 4% of the time and only in the bottom layer of compost (again using 3 aeration ducts however).

In terms of ability to generate and sustain high temperatures and kill pathogens, corn silage was superior to all other envelope materials. Silage is predicted to achieve average temperatures exceeding 50 ^{o}C in the carcass (middle) layer during the first 30 days (T_{30}) of composting, and it achieved USEPA Class B criteria for pathogen reduction in 90% of monitored locations within this layer. Cornstalks, soybean straw, and alfalfa hay have predicted T_{30} values of about 40 ^{o}C, and were able to meet Class B criteria in only 45-57% of monitored locations in the carcass layer. Wood shavings and oat straw had the worst temperature performance with T_{30} values of 30 ^{o}C, and a Class B success rate of 35%.

While the results for meeting time/temperature criteria for pathogen reduction are disappointing, laboratory measurements of O_2 uptake indicate that cornstalks and oat straw, — materials that exhibited low T_{30} and Class B success rate — have potential to produce 3-5X more heat than two materials (silage and alfalfa hay) that exhibited the highest T_{30} values in the field. This suggests that the field performance of cornstalks and oat straw may be due to high heat loss rather than low heat production, and that it may be possible to significantly improve their performance by controlling the rate of passive air flow through them. Since cornstalks and oat straw are among the most plentiful and lowest cost envelope materials available to swine producers, additional field trials need to be undertaken to investigate simple operational modifications that may improve their ability to kill pathogens.

Soft-tissue decomposition performance results were surprising because the material having the highest predicted T_{30} (silage) also had the poorest decomposition (72%), while a material with low T_{30} (cornstalks) had the best decomposition (87%). Similar results were seen in highly controlled laboratory tests where decomposition in oat straw and cornstalks (66 & 69% respectively) were significantly better than in silage and alfalfa hay (54 and 56% respectively). Both the field and laboratory decomposition results appear to support the notion that cornstalks and oat straw support good microbial activity, but also readily lose the resulting heat under uncontrolled field aeration.

Finally, laboratory tests under controlled initial moisture content point to practical and very effective measures when using very dry envelope materials. Both heat production and decomposition were significantly improved by only modest increases in moisture content. Tissue decomposition was significantly improved to levels observed at an initial moisture of 60% by simply increasing initial moisture content from 15% to 25%. Similarly, heat production was improved to that observed at 60% by raising initial moisture from 15% to 35%.

Acknowledgements

This project was funded by the Canadian Food Inspection Agency through a grant from the Canadian Research & Technology Initiative (CRTI project # 04-0052 R).

References

Akdeniz, N., J.A. Koziel, H. Ahn, T.D. Glanville, B.P. Crawford, and D. Raman. 2009. Air sampling and analysis method for VOCs related to field-scale mortality composting operations. Journal of Agriculture and Food Chemistry. accepted.

Akdeniz, N., J.A. Koziel, H.K. Ahn, T.D. Glanville, B.P. Crawford, P.C. Hermiston, N. Shah, D.R. Raman, A.L. Pometto III, S. Beattie. 2008. Identification and evaluation of VOCs evolved from warm season swine mortality composts. ASABE Paper No. 085047. 2008 ASABE Annual International Meeting, Rhode Island Convention Center, Providence, RI, June 29-July2, 2008.

Finstein, M.S., F.C. Miller, and P.F. Strom. 1986. Waste treatment composting as a controlled system. In: Biotechnology, vol. 8: Microbial degradations.Weinheim, FRG: Verlag Chemie (German Chemical Society). p. 363–98.

Haug, R.T. 1993. The Practical Handbook of Compost Engineering. Lewis Publishers; Boca Raton, FL.

Kuhn, G.K., W. Ender, U. Hackl, K. Küchenmeister, C. Nürnberg, and C. Rehfeldt. 1997. Effects of porcine somatotropin on the chemical body composition and fat quality in growing-finishing pigs. Z Ernährungswiss 36: 294-298.

Rynk, R. 1992. On-Farm Composting Handbook. NRAES Cooperative Extension. Ithaca, NY p.8.

Spencer, J.L., B. Rennie, and J. Guan. 2004. Emphasis on biosecurity for composting poultry and manure during an outbreak of highly pathogenic avian influenza in British Columbia. Canadian Animal Health Net Bulletin. Winter 2004, Edition 9: 21-23