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# Pathogen Inactivation Potential and Carcass Degradation in a Bio-secure Emergency Livestock Mortality Composting System

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# Pathogen Inactivation Potential and Carcass Degradation in a Bio-secure Emergency Livestock Mortality Composting System

## Abstract

An emergency swine mortality composting study at Iowa State University was conducted to evaluate the performance of six on-farm carbon source or “envelope” materials (corn silage, oat straw, cornstalks, wood shavings, soybean straw, and alfalfa hay) when used in a plastic-wrapped passively-ventilated emergency composting system that was first employed for emergency disposal of poultry in British Columbia in 2004. With the exception of tub grinding to reduce the particle size of long and fibrous materials, they were used “as is,” in their normal state — as would likely be the case during an emergency — without benefit of mixing or preconditioning to optimize C:N ratios or moisture content. Moisture content fell into two distinct groups: wood, soy, and alfalfa products had initial moisture content of < 20%; while the other materials ranged from 55-62%. After 8 weeks moisture ranged from 11-18% and 27-35% respectively for the two groups. Minimum O<sub>2</sub> concentrations occurred during the first 2 weeks of composting, and ranged from 9-16% in relatively fine-grained wood and silage materials, to 17-20% in the others. Daily temperatures in material surrounding the carcasses also were highest during the first two weeks. Mean temperature ranges during the initial 30 days of composting were 47-57 °C for the moist group, and 35-43 °C for the dry group. Total soft-tissue degradation ranged from 77-78% for silage, wood shavings, and alfalfa hay, and from 85-88% for the other three materials. The highest degradation occurred in two materials having high initial moisture, and high mean 30-day temperatures, while the lowest degradation occurred in two materials having low 30-day mean temperatures and low initial moisture. The temperature/moisture correlation was not consistent, however, as soy straw — exhibiting both low mean temperature and low initial moisture — had high carcass degradation, and silage — having high temperature and high moisture — was in the group producing lower degradation. Remains recovered from all test units after 8 weeks appeared to be desiccated, suggesting that carcass decomposition was terminated by low moisture. This is consistent with the low final moisture levels, and indicates that moisture coming from the carcasses plays a significant role in sustaining decomposition. It also suggests that airflow rates through the matrix may have been excessive and that measures need to be taken to reduce airflow and prevent excessive moisture loss. Success rates meeting USEPA Class A or B criteria for pathogen reduction were much higher for the moist materials than for dry ones, indicating that procedures for emergency composting of carcasses resulting from disease should include pre-moistening of carcass surfaces and envelope materials, and to taking measures to control excessive airflow through the composting matrix that can result in premature drying of envelope materials.

## Keywords

livestock, mortality, disposal, composting, biosecurity

## Disciplines

Bioresource and Agricultural Engineering

## Comments

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## **Pathogen Inactivation Potential and Carcass Degradation in a Bio-secure Emergency Livestock Mortality Composting System**

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### **Abstract.**

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**Comment [HA1]:** I remember that the soft-tissue degradation of wood shavings test unit were around 26% based on my new calculation. Please check the Table 7 in quarterly report #8 .

**Keywords.** livestock, mortality, disposal, composting, biosecurity

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## Introduction and Objectives

Recent regional-scale poultry and livestock death losses in North America have included avian influenza outbreaks (Virginia-2002, British Columbia – 2004, Maryland& Delaware – 2004), two hurricanes (Gulf Coast – 2005), prolonged heat stress (California - 2006), rangeland wildfire (Texas-2006), and blizzards (Kansas/Colorado -2007). When such events occur, rapid sequestration and decomposition of mortalities is essential to control air- and water-pollution, and the spread of disease.

In 2004 the Canadian Food Inspection Agency (CFIA) used a novel emergency composting system to successfully dispose of poultry following an avian influenza outbreak in British Columbia (Spencer, Rennie, and Guan 2004). To improve biosecurity, composting was carried out in passively-aerated static piles that were wrapped in plastic sheeting to reduce the potential for release of influenza viruses. The composting procedure worked reasonably well for poultry carcasses composted in poultry litter, and the Canadian government concluded that further studies should be undertaken to develop analogous procedures for bio-secure composting of larger species. The CFIA established a collaborative research project with researchers in Agricultural & Biosystems Engineering at Iowa State University to investigate the performance of different carbon sources that would be likely to be available during an emergency, and to study the effect of the plastic bio-security barrier on temperature, moisture content, O<sub>2</sub>, and other process variables. This paper presents preliminary (2<sup>nd</sup> year) results using corn silage, cornstalks, and oat straw, wood shavings, soybean straw, and alfalfa hay as envelope materials. Associated studies of VOC emissions, ventilation system performance, and moisture variability are described in 2008 ASABE conference papers by Akdeniz et. al., and Ahn et. al.

## Materials & Methods

Composting test units consisted of foam insulated (5cm thick) plywood platforms measuring 2m X 2m X 1.2 m (depth). Test units were loaded with approximately 250 kg of swine carcasses (Figure 1B) which were placed on top of 30 cm of envelope material and covered with 60 cm of the same material. Each swine carcass was loosely wrapped in coarse plastic netting to facilitate easy recovery and weighing or remains at the end of the trial.

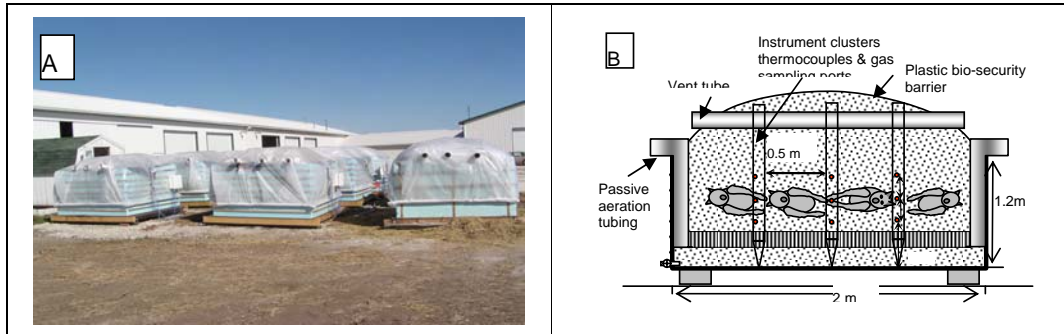
Six envelope materials were tested, each was replicated three times. During trial #2, begun in early June of 2007, corn silage, ground cornstalks, and ground oat straw were tested. Wood shavings, ground alfalfa hay, and ground soybean straw were tested during trial #3 which was begun in mid August. All trials were allowed to run for 8 weeks. (Note: trial #1, which was begun in mid October of 2006, also tested the performance of cornstalks, oatstraw, and corn silage. Due to early onset of unusually cold weather in the fall of 2006, however, performance data from trial #1 are not considered in this paper.)

To evaluate the functional impacts of the plastic bio-security barrier, the upper portion of each test unit was wrapped in plastic (Figure 1A). To simulate the original design used by CFIA, 10-cm (diameter) perforated plastic drainage tubes, spaced on 50-cm centers, were placed in the bottom of each test unit to facilitate passive entry of air. A single 10-cm tube installed on top of each test unit allowed gases to vent through the bio-security barrier (Figure 1B).

Data collected during the trial included continuous monitoring of temperatures at 27 locations within each test unit, and weekly weighing of test platforms to quantify the total change in mass. Moisture samples were collected at 9 locations in each test unit (three samples each in top, mid-depth, and bottom horizontal layers) at the beginning of the trial, after 30 days, and again at the

end of the trial. O<sub>2</sub> and CO<sub>2</sub> concentrations were measured approximately every 10 days at 27 locations in each test unit (Figure 1 B).

On completion, each test unit was disassembled, carcass remains were recovered and weighed to determine % decomposition of soft tissues, and compost samples were collected at 9 locations to determine final moisture and volatile solids content.



**Figure 1. Photo and cross section of replicated passively ventilated bio-secure composting test units.**

## Results and Discussion

### *Moisture and Volatile Solids of Envelope Materials*

Spring season precipitation caused envelope materials used in trial #2 to have moisture content in the 55-62% range, while materials used in trial #3 — begun in late summer — were not subjected to precipitation, and their moisture content ranged from 11-18% (Table 1). While such a broad range of moisture content is not ideal for comparing the performance of different envelope materials, the purpose of this research is to evaluate materials and practices likely to be used during livestock disposal emergencies, a situation that is likely to result in use of on-farm stockpiles of feed or bedding materials that may exhibit extreme moisture levels. During trial #2, average moisture content declined by 20-25 percentage points, but during trial #3 the driest material experienced a 4 percentage point increase, and moisture in the other two material declined by only 2 percentage points.

Average volatile solids (VS) content of the envelope materials changed very little during the 8-week trials. Rapid loss of moisture, and unfavorable C:N ratios, are believed to be the probable causes. As a result the majority of mass lost during the trials was caused by moisture evaporation and decomposition of animal carcasses, rather than by decomposition of envelope materials.

### *O<sub>2</sub> Concentration*

Despite the presence of an impermeable rubber or plastic lining enveloping the bottom and sides of the compost, and a plastic biosecurity cover over the top — thereby restricting air entry to 10-cm diameter perforated tubing installed in the base and over the top (penetrating the plastic cover) of the test units — O<sub>2</sub> concentrations were generally well above the 5-10% minimum recommended in most composting manuals. In all cases, the lowest O<sub>2</sub> concentrations occurred in the bottom layer where the carcasses were located. In this layer, O<sub>2</sub>

concentrations ranged from a low of 9-16% for silage, to highs of 19-21% in oat straw and soybean straw. All other materials typically operated in the 17-20% range (Figure 2).

**Table 1. Average initial and final moisture, volatile solids, and other physical characteristics of envelope materials used in trial #'s 2 and 3.**

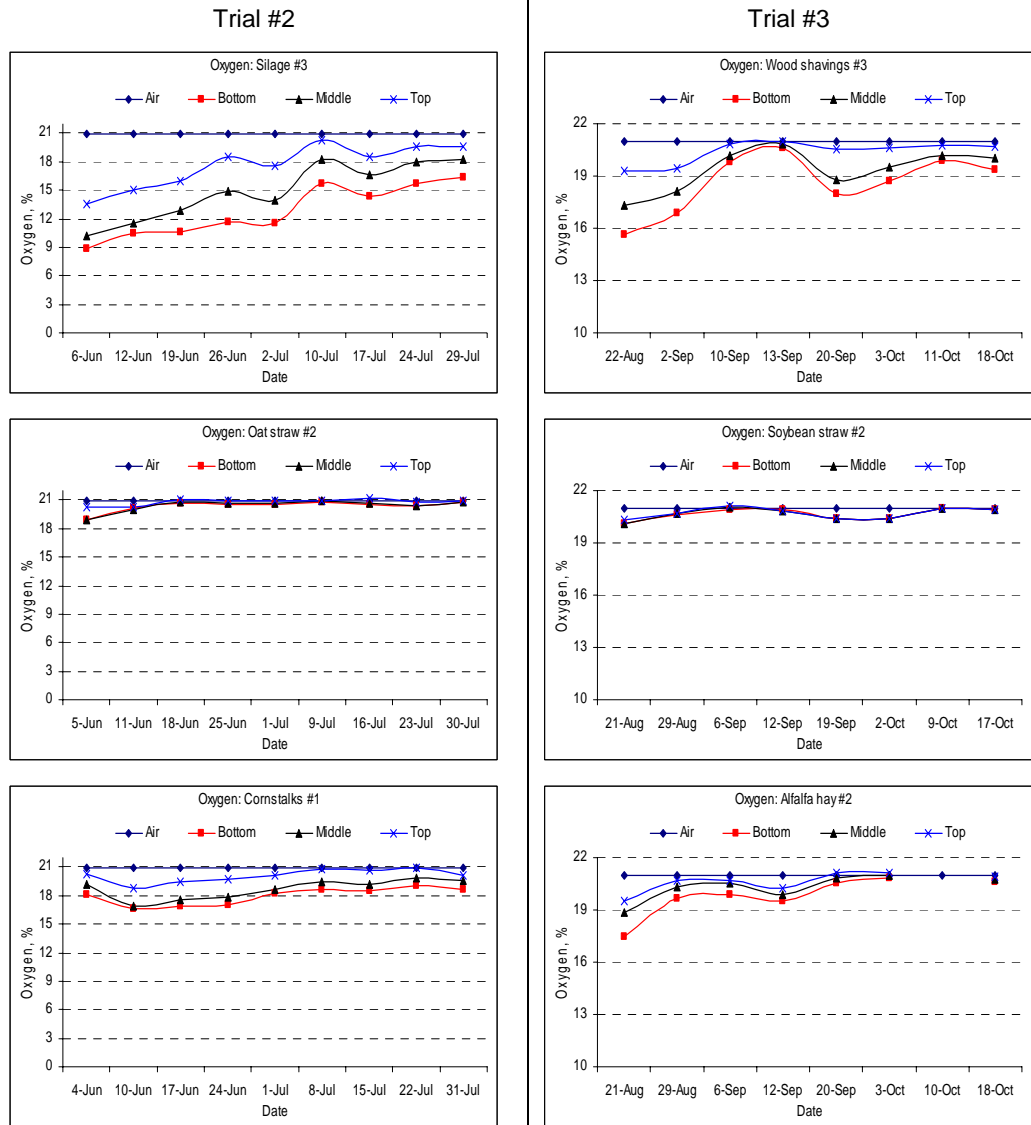
		Trial 2			Trial 3		
		Corn silage	Oat straw	Corn stalks	Wood shavings	Soybean straw	Alfalfa hay
Initial	Moisture (% w.b.)	55.6 ±7.7 <sup>A</sup>	57.5 ±11.6 <sup>A</sup>	62.1 ±9.3 <sup>A</sup>	11.2 ±2.3 <sup>a</sup>	18.3 ±3.1 <sup>b</sup>	17.7 ±6.5 <sup>c</sup>
	Volatile solids (% d.b.)	87.0 ±6.9 <sup>A</sup>	77.4 ±9.3 <sup>A</sup>	66.9 ±8.3 <sup>A</sup>	98.7 ±0.6 <sup>a</sup>	93.6 ±1.1 <sup>b</sup>	90.8 ±2.7 <sup>c</sup>
	C:N ratio	36	53	62	428	54	14
	Weight (kg)	1695 ±150 <sup>B</sup>	698 ±45 <sup>B</sup>	1258 ±159 <sup>B</sup>	603 ±21 <sup>d</sup>	423 ±33 <sup>d</sup>	511 ±41 <sup>d</sup>
	Volume (m <sup>3</sup> )	5.49 ±0.0 <sup>B</sup>	5.49 ±0.0 <sup>B</sup>	5.49 ±0.0 <sup>B</sup>	5.49 ±0.0 <sup>d</sup>	5.49 ±0.0 <sup>d</sup>	5.49 ±0.0 <sup>d</sup>
	Bulk density (kg/m <sup>3</sup> )	309 ±27 <sup>B</sup>	127 ±8 <sup>B</sup>	229 ±29 <sup>B</sup>	109 ±3.8 <sup>d</sup>	77 ±5.9 <sup>d</sup>	93 ±7.5 <sup>d</sup>
	Air-filled porosity (%)	74.6 ±2.5 <sup>B</sup>	89.6 ±0.8 <sup>B</sup>	81.0 ±2.6 <sup>B</sup>	92.7 ±0.2 <sup>d</sup>	94.7 ±0.4 <sup>d</sup>	93.7 ±0.5 <sup>d</sup>
Final	Moisture (% w.b.)	34.9 ±16.9 <sup>A</sup>	27.0 ±13.0 <sup>A</sup>	35.2 ±16.3 <sup>A</sup>	15.5 ±1.9 <sup>c</sup>	16.4 ±1.9 <sup>c</sup>	15.2 ±1.9 <sup>e</sup>
	Volatile solids (% d.b.)	83.7 ±9.4 <sup>A</sup>	81.0 ±6.1 <sup>A</sup>	66.0 ±9.1 <sup>A</sup>	98.7 ±0.8 <sup>c</sup>	93.7 ±1.7 <sup>c</sup>	91.2 ±0.8 <sup>e</sup>
	Weight (kg)	1292 ±64 <sup>B</sup>	530 ±29 <sup>B</sup>	936 ±118 <sup>B</sup>	718 ±33 <sup>d</sup>	419 ±38 <sup>d</sup>	536 ±49 <sup>d</sup>
	Volume (m <sup>3</sup> )	3.47 ±0.33 <sup>B</sup>	3.43 ±0.48 <sup>B</sup>	3.55 ±0.49 <sup>B</sup>	4.27 ±0.17 <sup>d</sup>	4.20 ±0.10 <sup>d</sup>	4.21 ±0.24 <sup>d</sup>
	Bulk density (kg/m <sup>3</sup> )	375 ±45 <sup>B</sup>	156 ±15 <sup>B</sup>	265 ±28 <sup>B</sup>	168 ±8.6 <sup>d</sup>	99.9 ±9.2 <sup>d</sup>	127.3 ±6.5 <sup>d</sup>
	Air-filled porosity (%)	72.5 ±4.2 <sup>B</sup>	89.1 ±1.4 <sup>B</sup>	81.1 ±2.9 <sup>B</sup>	88.5 ±0.6 <sup>d</sup>	93.3 ±0.6 <sup>d</sup>	91.5 ±0.5 <sup>d</sup>

\* The initial volume of envelope materials was calculated by assuming that the pile heights were all same (about 1.37m).  
for trial #2, <sup>A</sup> N=27, <sup>B</sup> N=3  
for trial #3, <sup>a</sup> N=66, <sup>b</sup> N=75, <sup>c</sup> N=78, <sup>d</sup> N=3, <sup>e</sup> N=81

The lowest O<sub>2</sub> concentrations occurred during the first few weeks of the trials. With the exception of corn silage test units, O<sub>2</sub> concentrations generally leveled out at 19% or higher after the first 4-5 weeks of composting. Suppression of O<sub>2</sub> in silage is believed to have been caused by reduced air-filled porosity (<75% for silage vs 80-90% for other materials), and perhaps by slight decay of the envelope material itself as evidenced by a small decline in VS.

### **Temperature and Pathogen Inactivation Potential**

For all materials except corn silage, the highest average temperatures during the first 30 days of composting occurred in the bottom layer where the carcasses were located (Table 2). This reflects the fact that the emergency envelope materials, by themselves, are not readily compostable and that nitrogen released by the carcasses helped to reduce relatively high C:N ratios exhibited by all materials except alfalfa hay, and that the roughly 150 kg of water in the carcasses played an important role in increasing or sustaining vital moisture needed for microbial activity in the bottom layer.



**Figure 2. Oxygen concentrations in the bottom (carcass location), mid-depth, and top layers during composting trial #'s 2 and 3.**

During trial #2, average bottom-layer temperatures during the 1<sup>st</sup> 30 days were significantly ( $p > 0.05$ ) higher for silage and cornstalks than for oat straw, and similarly during trial #3 bottom temperatures in wood shavings and alfalfa hay were significantly ( $p < 0.05$ ) higher than in soybean straw (Table 2). Materials exhibiting the highest temperatures during each trial (corn silage and wood shavings) were those with the highest bulk densities and lowest air-filled porosity, while materials with the lowest temperatures (oat straw, soybean straw) had the lowest bulk densities and highest air-filled porosities. These observations also concur with O<sub>2</sub> levels



**Table 2. Mean daily value during 1<sup>st</sup> 30 days of average temperatures (N=27) in bottom, middle, and top layers of composting test units.**

Trial	Material	Bottom (°C)	Mid Depth (°C)	Top (°C)
#2	Silage	57.17 <sup>a</sup>	62.93	61.87
	Cornstalk	57.00 <sup>a</sup>	56.13	46.07
	Oat straw	46.97 <sup>b</sup>	43.90	39.27
	Ambient	22.39		
#3	Wood	43.17 <sup>a</sup>	41.73	33.37
	Alfalfa	39.73 <sup>a</sup>	37.20	33.13
	Soy straw	35.53 <sup>b</sup>	34.50	32.13
	Ambient	20.48		

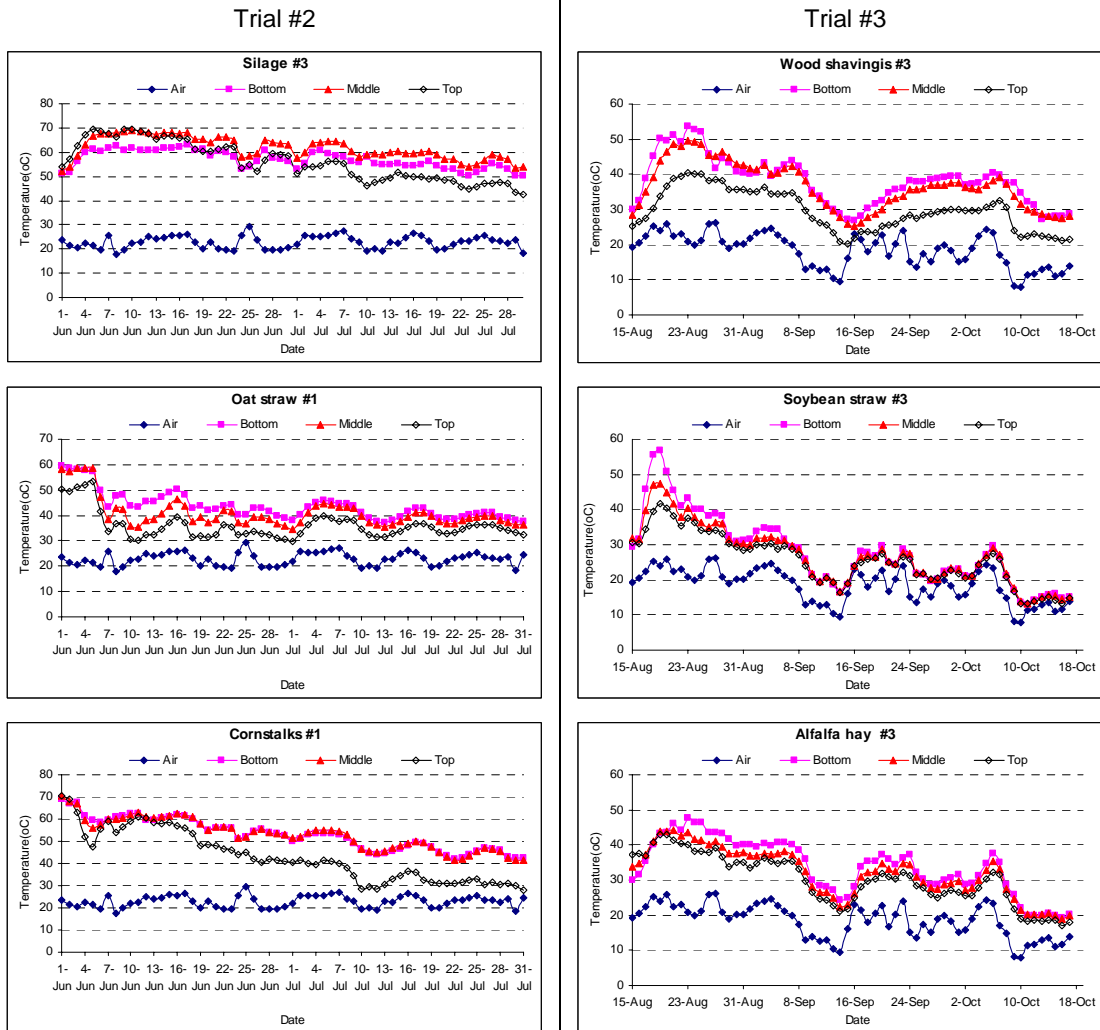
Mean values within the same trial having dissimilar superscript letter designators are significantly ( $p < 0.05$ ) different.

measured within the bottom layers of test units. As shown by the O<sub>2</sub> vs Time graphs in Figure 2, corn silage and wood shavings had the lowest O<sub>2</sub> concentrations during the first 30 days of composting indicating that the gas permeability of these materials was insufficient to meet the O<sub>2</sub> demand of the composting process. At the same time, O<sub>2</sub> concentrations in oat straw and soybean straw nearly equaled those found in ambient air (21%) indicating that — due their low density and high air-filled porosity — their gas permeability was more than adequate to meet the O<sub>2</sub> demand.

Representative time/temperature data for trials 2 & 3 (Figure 3) show that bottom-layer temperatures declined more quickly during trial #3 than during trial #2 despite the fact that average ambient air temperatures during the initial 30 days of both trials were within 2 °C of each other. Low initial moisture levels, compounded by rapid evaporation of water released by the carcasses into the lower layer, are believed to be the main cause of the relatively rapid temperature declines during trial #3. Once again, materials with lower bulk densities and higher air-filled porosities (soybean straw, oat straw, alfalfa hay) — characteristic leading to higher gas permeability and increased airflow through the compost matrix — exhibit greater temperature instability than more dense and less gas permeable materials.

Table 3 presents success rates, by zone, layer, and envelope material, for meeting USEPA time/temperature Class A and Class B criteria for pathogen reduction in biosolids (Class A: 55°C for at least 3 consecutive days; Class B: 40°C for at least 5 consecutive days and at least 4 hours above 55°C). Temperatures in each layer were monitored with nine thermocouples, eight of which were within 0.5 m of the walls (side wall zone), and one located equidistant (1m) from all walls (core zone). During both trials, success rates were always higher in the relatively small and better insulated core zone, than in the sidewall zone, and Class B success rates always equaled or exceeded those for Class A.



During the more moist and hot trial #2, 100% of monitored locations in all layers of all materials met both Class A and B criteria in the core zone. In the important bottom layer where the carcasses reside, silage and cornstalks met Class A and B criteria at 100 % of monitored sites in the sidewall zone, but oat straw success rates fell to 52% and 74% respectively for Class A and B.



**Figure 3. Daily average (N=9) internal temperatures in bottom, mid-depth, and top layers of representative composting test units in trials 2 and 3.**

During the much drier trial #3, Class A/B success rates in the lower layer of the core zone were only 33%/67% for wood shavings and alfalfa hay, and 67%/1000% for soy straw. In the sidewall zone, Class A/B bottom layer success rates ranged from a high of 25%/54% for soy straw, to a low of 4%/13% for Alfalfa hay. These results are in concert with previous research showing that the optimum moisture content of crop residue materials for composting is near their water holding capacity (Ahn et al., 2008), and further highlight the importance of having a sufficient reservoir of initial moisture in the envelope materials to sustain a moist environment for microbial activity around the carcasses, and of keeping carcasses at least 0.5 m from the exterior surfaces of compost piles to help insure pathogen inactivation.

**Table 3. Success rate (% of thermocouples monitored in each layer/zone combination) meeting USEPA time/temperature criteria for Class A / Class B biosolids.**

Trial #	EPA Criteria	Layer	Zone					
			Sidewall (0.5m from sides) <sup>a</sup> 			Core (1m from all walls) <sup>b</sup> 		
			Silage	Oat straw	Cornstalks	Silage	Oat straw	Cornstalks
Trial #2	Class A	Bottom	100	52	100	100	100	100
		Middle	100	37	93	100	100	100
		Top	100	15	74	100	100	100
	Class B	Bottom	100	74	100	100	100	100
		Middle	100	59	93	100	100	100
		Top	100	26	82	100	100	100
			Wood shavings	Soybean straw	Alfalfa hay	Wood shavings	Soybean straw	Alfalfa hay
Trial #3	Class A	Bottom	29	25	4	33	67	33
		Middle	8	4	0	100	67	33
		Top	0	4	0	0	67	0
	Class B	Bottom	42	54	13	67	100	67
		Middle	21	29	8	100	67	33
		Top	0	17	0	0	67	33

<sup>a</sup> N=24, 8 zone thermocouples in each layer X 3 test unit replicates <sup>b</sup> N=3, 1 zone thermocouple in each layer X 3 test unit replicates

**Table 4. Average initial carcass weight, carcass weight loss, and % decomposition of soft tissues for 6 different envelope materials.**

Envelope material	A Initial carcass weight (kg)	B Bone weight in initial carcasses <sup>1</sup> (kg)	C Final carcass weight (kg)	D Carcass weight loss <sup>2</sup> (kg)	E Carcass decomposition <sup>3</sup> (% of soft tissue)
Corn silage	220±10	26±1.3	69±1.6	151	78.1±1.0
Oat straw	233±10	28±1.3	58±4.7	175	85.5±1.6
Cornstalks	239±12	29±1.5	53±2.9	186	88.5±0.9
Wood shavings	256±11	31±1.3	82±10	174	77.2±5.1
Soybean straw	246±4	29±0.5	63±4	183	84.7±1.9
Alfalfa hay	255±14	31±1.6	80±5	175	77.9±3.3

<sup>1</sup>Bone weight estimated at 12% of total body weight (Kuhn et al., 1997), <sup>2</sup> Carcass weight loss = A - C

<sup>3</sup> Carcass decomposition rate (as % of soft [non-bone] tissues) = ((A-C)/(A-B))\*100

## ***Carcass Decomposition***

Carcass decomposition was calculated based on the difference in weight of initial carcasses and carcass remains recovered from each test unit. Since the bones of 45-70 kg pig carcasses were not expected to decompose during an 8 week trial, percent decomposition is expressed as the percentage of initial soft tissues (initial weight – estimated bone weight). As shown in Table 4, carcass decomposition ranged from 77-88%. The recoverable remains consisted mainly of bone and partially desiccated hide and hair suggesting that failure to achieve complete decomposition of soft tissues was caused by low terminal moisture which is in concert with average final compost moisture contents that ranged from 15-35% (Table 1).

Corn silage, wood shavings, and alfalfa hay produced the lowest decomposition rates (77-78%), and the highest decomposition rates (85-88%) occurred in soybean straw, cornstalks, and oat straw. As such, two materials exhibiting the highest temperatures and some of the lowest O<sub>2</sub> concentrations produced the lowest decomposition, while two materials exhibiting relatively low internal temperatures and high O<sub>2</sub> concentrations produced the highest soft tissue degradation.

## **Conclusions**

Six on-farm carbon sources or “envelope” materials (corn silage, oat straw, cornstalks, wood shavings, soybean straw, and alfalfa hay) were tested in a plastic-wrapped passively-ventilated emergency composting system. With the exception of tub grinding to reduce the particle size of long and fibrous materials, they were used “as is,” in their normal state — as would likely be the case during an emergency — without benefit of mixing or preconditioning to optimize C:N ratios or moisture content.

Moisture content fell into two distinct groups: wood, soy, and alfalfa products had initial moisture content of < 20%; while the other materials ranged from 55-62%. After 8 weeks moisture ranged from 11-18% and 27-35% respectively for the two groups. Final in-place air-filled porosities ranged from 72% for silage to 93% for soy straw. Minimum O<sub>2</sub> concentrations occurred in the first 2 weeks of composting, and ranged from 9-16% in the relatively fine-grained wood and silage materials, to 17-20% in the others. Daily temperatures in material surrounding the carcasses were highest during the first two weeks, with mean temperatures during the initial 30 days of composting ranging from 47-57 °C for the moist group, and from 35-43 °C in the dry group.

Total soft-tissue degradation ranged from 77-78% for silage, wood shavings, and alfalfa hay, and from 85-88% for the other three materials. The highest degradation occurred in two materials having high initial moisture, and high mean 30-day temperatures, while the lowest degradation occurred in two materials having low 30-day mean temperatures and low initial moisture. The temperature/moisture correlation was not consistent, however, as soy straw — exhibiting both low mean temperature and low initial moisture — had high carcass degradation, and silage — having both high temperature and high moisture — was in the group producing lower degradation.

Remains recovered from all test units after 8 weeks appeared to be desiccated, indicating that carcass decomposition was terminated by low moisture, regardless of the initial moisture. This is consistent with the low final moisture levels, and indicates that moisture coming from the carcasses plays a significant role in sustaining decomposition. It also suggests that measures need to be taken to reduce airflow through the composting matrix, thereby controlling excessive moisture loss.

Success rates in meeting USEPA Class A or B criteria for pathogen reduction were much higher for the moist materials than for dry ones, suggesting that procedures for emergency composting

of carcasses resulting from disease should include pre-moistening of envelope materials, and control of excessive airflow through the composting matrix that can result in premature drying of envelope materials.

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