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Performance Evaluation of a Passively-Aerated Plastic-Wrapped Composting System Designed for Emergency Disposal of Swine Mortalities

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

H. K. Ahn
Iowa State University

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

Neslihan Akdeniz
Iowa State University

Benjamin P. Crawford
Iowa State University

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Abstract

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Keywords

animal carcass, mortality, disposal, composting

Disciplines

Bioresource and Agricultural Engineering

Comments

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T.D. Glanville, Ph D

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

H.K. Ahn, Ph D

Dept. of Agricultural & Biosystems Engineering, 1320 NSRIC, Iowa State University, Ames, Iowa 50011 (hkahn@iastate.edu)

J.A. Koziel, Ph D

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

N. Akdeniz

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

B.P. Crawford

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

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***Abstract*.** Monitoring of a passively-aerated plastic-wrapped mortality composting system designed for emergency disposal of diseased swine highlighted the importance of the physical characteristics of materials used to envelop the carcasses. Inadequate moisture was a problem when using envelope materials such as ground cornstalks or straw having low density and high air-filled porosity. High O_2 concentrations throughout these materials, and significantly higher moisture levels in the top layers than in the materials surrounding the carcasses, suggested significant air movement and transport of carcass moisture away from the carcasses, resulting in carcass desiccation and incomplete decay. Although internal temperatures and moisture levels in test units constructed with corn silage were much more favorable than in those constructed with cornstalks or straw, less carcass decomposition occurred. Settling and compaction, resulting in high bulk density and low air-filled porosity, caused low O_2 concentrations that appeared to impair carcass decay in the silage test units.

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Introduction & Objectives

During an outbreak of highly pathogenic avian influenza in British Columbia in 2004, the Canadian Food Inspection Agency (CFIA) used a novel emergency composting system to successfully dispose of birds (Spencer, Rennie, and Guan 2004). To reduce the potential for escape of live viruses, composting was carried out in passively-aerated static piles that were wrapped in plastic sheeting to reduce the potential for release of avian influenza viruses. The CFIA concluded that this method of bio-secure composting worked reasonably well for poultry carcasses composted in poultry litter, and that further studies should be undertaken to develop procedures for bio-secure composting of larger species using envelope materials such as ground cornstalks, oat straw, and silage. The CFIA contracted with researchers in the Agricultural & Biosystems Engineering Department at Iowa State University to conduct studies investigating how the plastic bio-security barrier affects the composting process, the functioning and effectiveness of the passive aeration system, and to recommend ventilation system design modifications that provide sufficient control over O_2, moisture, and temperatures using a variety of envelope materials. This paper presents preliminary (first year) results from a cold-season trial using corn silage, ground cornstalks, and ground oat straw, as envelope materials. Future trials will include both warm and cool weather trials using the above three materials and three additional materials: ground soybean straw; ground alfalfa hay; and wood chips. Further analysis of the biodegradability of carcasses in the emergency composting system is provided in an ASABE conference paper by Ahn et. al. (2007).

Materials & Methods

Composting test units consisted of insulated (5cm thick styrofoam on outer walls and beneath floor) plywood platforms measuring 2m X 2m X 1.2 m (depth). Test units were loaded with approximately 250 kg of swine carcasses (Figure 1D). Approximately 30 cm of envelope material were placed beneath the carcasses, and 60 cm of the same material was used to cover them.

To evaluate the functional impacts of the plastic bio-security barrier, the upper portion of each test unit was wrapped in clear 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).

Three envelope materials (corn silage, ground cornstalks, and ground oat straw) were tested, and each material was replicated three times (total of 9 test units). The trial was begun in early October, 2006 and ran through January of 2007.

Data collected during the trial included continuous monitoring of temperatures at 27 locations within each test unit, monthly weighing of the test platforms to determine mass changes, monthly collection of nine moisture samples embedded within each test unit , and measurement of O_2 and CO_2 concentrations approximately every 10 days at 27 locations in each test unit (Figure 1 B&C).

On completion of the trial, each of the test units was carefully excavated in 0.4 m layers, to observe the condition of envelope material and carcass remains. Samples from each of the three excavated layers were tested to determine final moisture and volatile solids content. Test units were weighed following excavation of each successive depth layer, and the volume of each layer was calculated from test unit geometry, thereby permitting calculation of average bulk densities for each layer.

Air-filled porosities for each layer were calculated using equation 1 and the known density of water (ρ_w; 1000 kg m-3), the estimated densities of organic matter (ρ_{om};1600 kg m-3) and ash (ρ_{ash}; 2500 kg m-3), and the moisture content and wet bulk densities of the sample.

$$\varepsilon_a = 1 - \rho_{wb} \cdot \left(\frac{MC}{\rho_w} + \frac{DM \cdot OM}{\rho_{om}} + \frac{DM \cdot (1 - OM)}{\rho_{ash}} \right) \tag{1}$$

Identifiable carcass remains were collected during excavation, and these were weighed to determine the fraction of original carcass weight that had decomposed during the trial.

Analysis & Discussion

Operating Temperatures

Composting test units using corn silage as the carcass envelope material were much higher than for the other two materials. Most locations in corn silage test units reached peak temperatures of 50-60 ºC immediately following construction, dropping to 20-40 ºC by early January. Due to unseasonably low temperatures in October and early November, cornstalk and oat straw test units peaked in the 20-30 ºC range in the early weeks of the trial and then dropped to temperatures that were nearly the same as the ambient air (Figure 2). Attempts to reduce heat loss and increase internal temperatures by moving test units into an unheated shelter, had little effect on silage test units but did produce temporary localized increases in temperature in oat straw and cornstalk test units.

Moisture

Moisture data (Table 1) show two important trends. As might be expected, moisture content in silage test units (76-83% w.b.) was considerably higher and less variable than in oat straw (22-45%) or cornstalk units (23-57%). More interesting however, was that — unlike routine mortality composting operations where the highest moisture levels typically occur beneath the carcasses — in the passively-ventilated plastic-wrapped test units the top layers had the highest moisture levels. As shown in Figure 3, moisture in the top layers of straw and cornstalk test units was significantly ($p<0.05$) higher than in the bottom layers. Silage, which contained much higher overall moisture levels than cornstalks and oat straw, showed similar spatial trends, but the differences between top and bottom layers, while statistically significant, were not as great.

Significant increases in moisture in the top layers of the cornstalks and oat straw test units suggest that upward air movement through these highly permeable envelope materials transported much of the moisture released by the carcasses to the top of the plastic-wrapped test units where it condensed on the inside of the plastic bio-security barrier and dripped back into the top layers of envelope material.

Compaction, bulk density, and free air-space

Settling and compaction of envelope materials during composting caused significant changes in envelope materials near and beneath the decomposing carcasses. As shown in Table 2, densities in the bottom layer were typically 2-3 X those in the top layer.

Air-filled porosity is an important composting parameter indicating the ability of a composting matrix to supply air to aerobic microorganisms. As bulk density and moisture content increase, air-filled porosity decreases. Experts in composting typically recommend that air-filled porosity should be greater than 30% to adequately support an aerobic composting environment. Values in Table 2 show that — although air-filled porosity values decreased from top to bottom — they were well above 30% in all layers in cornstalks and oat straw, and in the top and middle layers of corn silage. Air-filled porosity of only 18% in the bottom silage layer, however, was significantly lower than 30% suggesting that air migration into the bottom silage layer was probably significantly impeded.

Oxygen Concentrations

O_2 concentrations at the top, middle (carcass level), and bottom (below carcasses) depths in cornstalks and oat straw test units were stable at near ambient concentrations of 20% or better.

In silage test units, however, O_2 concentrations were often below 4% in bottom and mid-depth layers, and never exceeded 14% in the uppermost layer. The persistently low O_2 concentrations within silage test units are believed to have been caused by the combined O_2 demands exerted by the decaying carcasses and the moist and readily decomposable silage. This condition was further aggravated by the inability of the silage matrix to supply O_2 due to it's high bulk density and low air-filled porosity.

Decomposition of Carcasses and Envelope Materials

Observation of carcass remains following trial completion showed that all test units contained some un-decomposed animal tissue. Cold external temperatures and resulting heat loss undoubtedly contributed to the incomplete decay.

Carcass remains in straw and cornstalk test units typically appeared to be desiccated. Internal organs were decomposed, but dry hide and hair were often found. The low initial moisture content of cornstalks and straw, as well as their ability to readily transport moisture away from the lower (carcass) layers and into the top layer, led to moisture levels in the material surrounding the carcasses that were well below the minimum of 40% typically cited as necessary to support good microbial activity.

Carcass weights prior to and at completion of trial # 1, were used to quantify carcass decomposition, and changes in moisture content and volatile solids (initial vs final) were used to calculate cover material weight loss. Although internal temperatures and moisture levels within corn stalk and oat straw test units were much less favorable than in silage test units, the percent of carcass degradation in cornstalks (75.7%) and oat straw (69.8%) were noticeably higher than in silage (58.2%). The cover material weight loss, which includes both water and organic material loss, was relatively small (<10%) compared with carcass weight losses. Low moisture content in cornstalk and oat straw test units, and low O_2 levels in silage test units (due to low air-filled porosity in bottom layer, lower O_2 content) are the most likely causes of the low cover material losses.

Conclusions

Monitoring of a passively-aerated plastic-wrapped mortality composting system designed for emergency disposal of diseased swine highlighted the importance of the physical characteristics of the materials used to envelop the carcasses. Inadequate moisture was a problem when using envelope materials such as ground cornstalks or straw having low density and high air-filled porosity. High O_2 concentrations throughout these materials, and significantly higher moisture levels in the top layers than in the materials surrounding the carcasses, suggested significant air movement and transport of carcass moisture away from the carcasses, resulting in carcass desiccation and incomplete decay. Although internal temperatures and moisture levels in test units constructed with corn silage were much more favorable than in those constructed with cornstalks or straw, less carcass decomposition occurred. Settling and compaction, resulting in high bulk density and low air-filled porosity, caused low O_2 concentrations that appeared to impair carcass decay in the silage test units.

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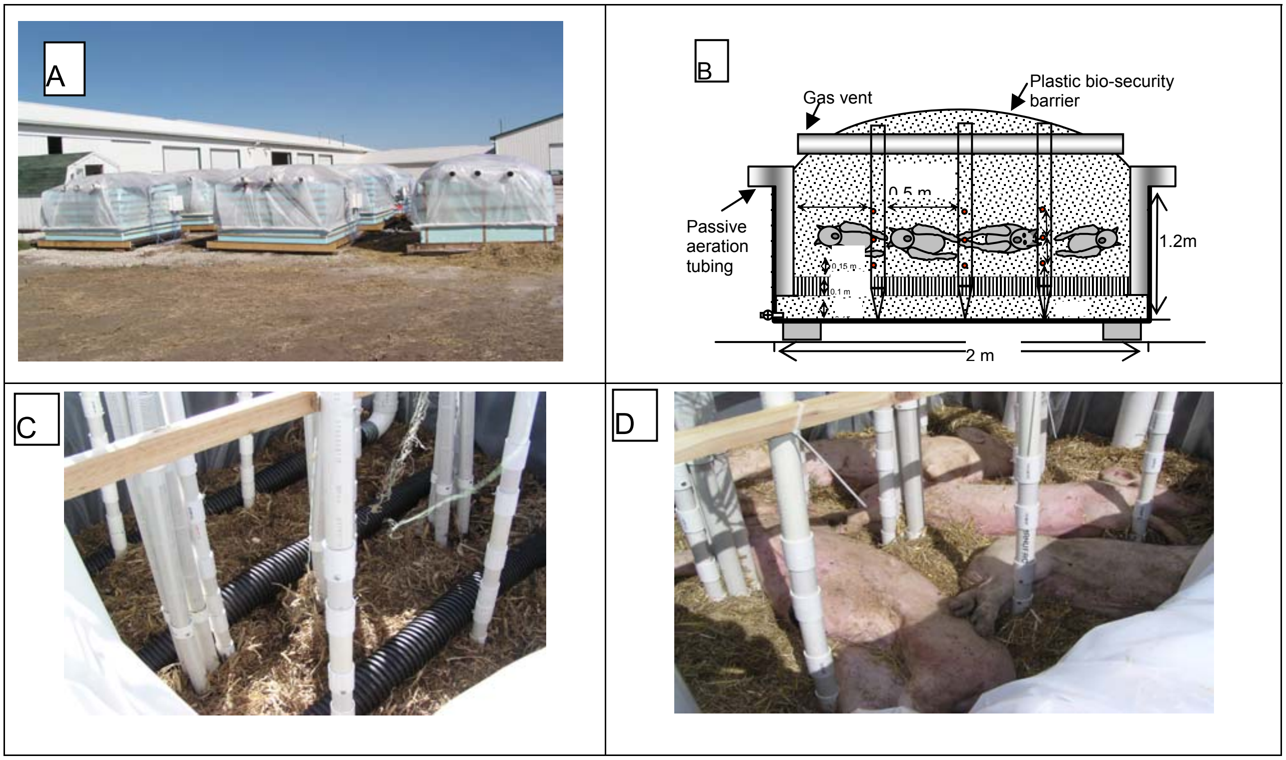

Figure 1. Test units (A), cross-section of interior (B), instrumentation and passive ventilation tubing (C), and pig carcasses and instrumentation prior to covering (D).

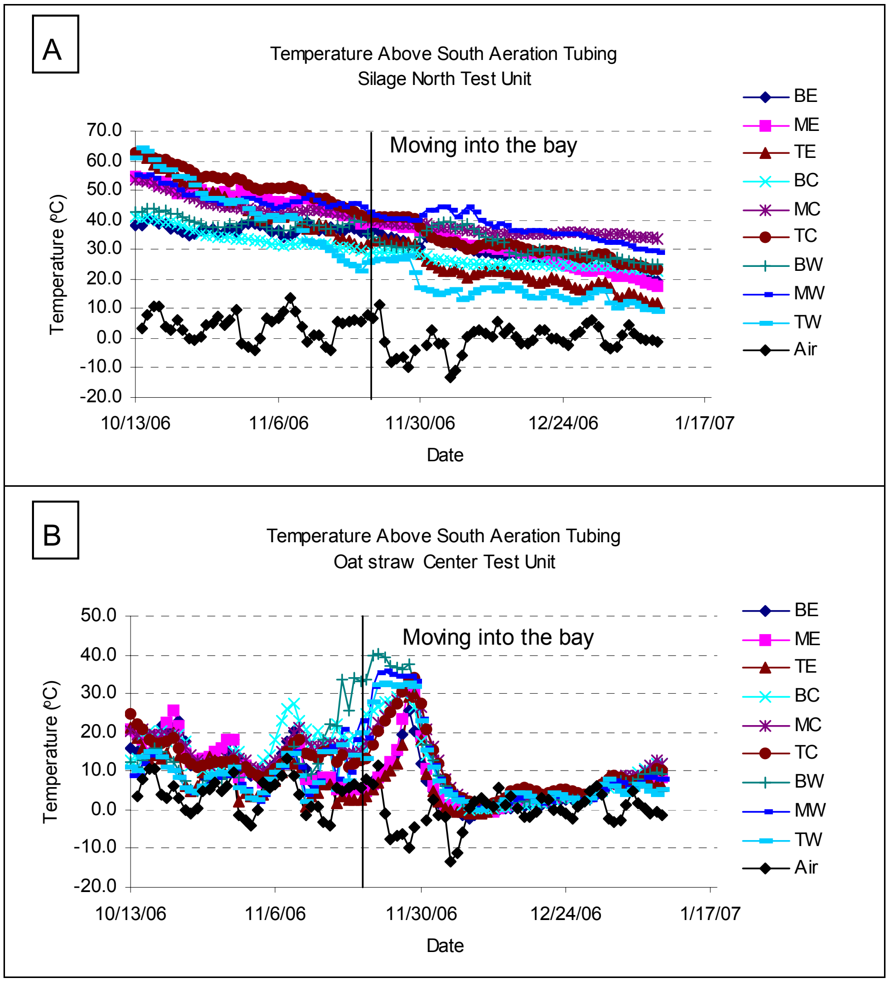

Figure 2. Representative temperature data collected in silage and oat straw test units (temperatures in cornstalks were similar to oat straw).

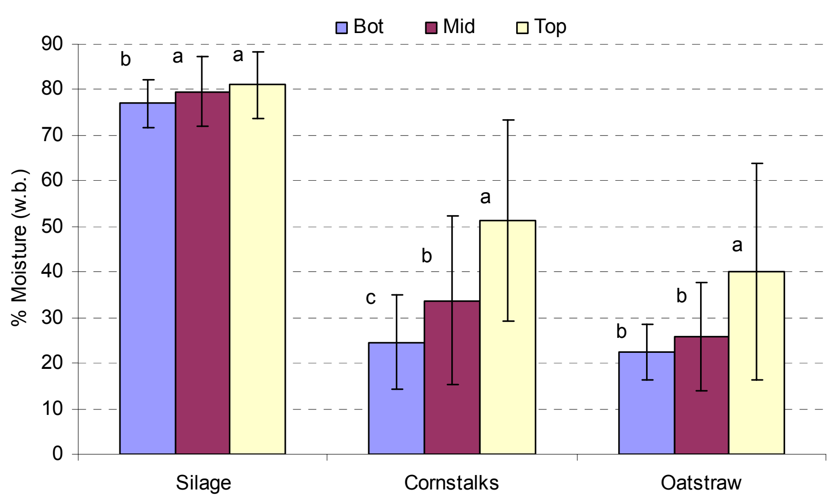

Figure 3. Mean moisture content, by depth layer (bottom, middle, top), for silage, cornstalk, and oat straw test units in trial # 1. Letters indicate statistically significant differences (P<0.05)

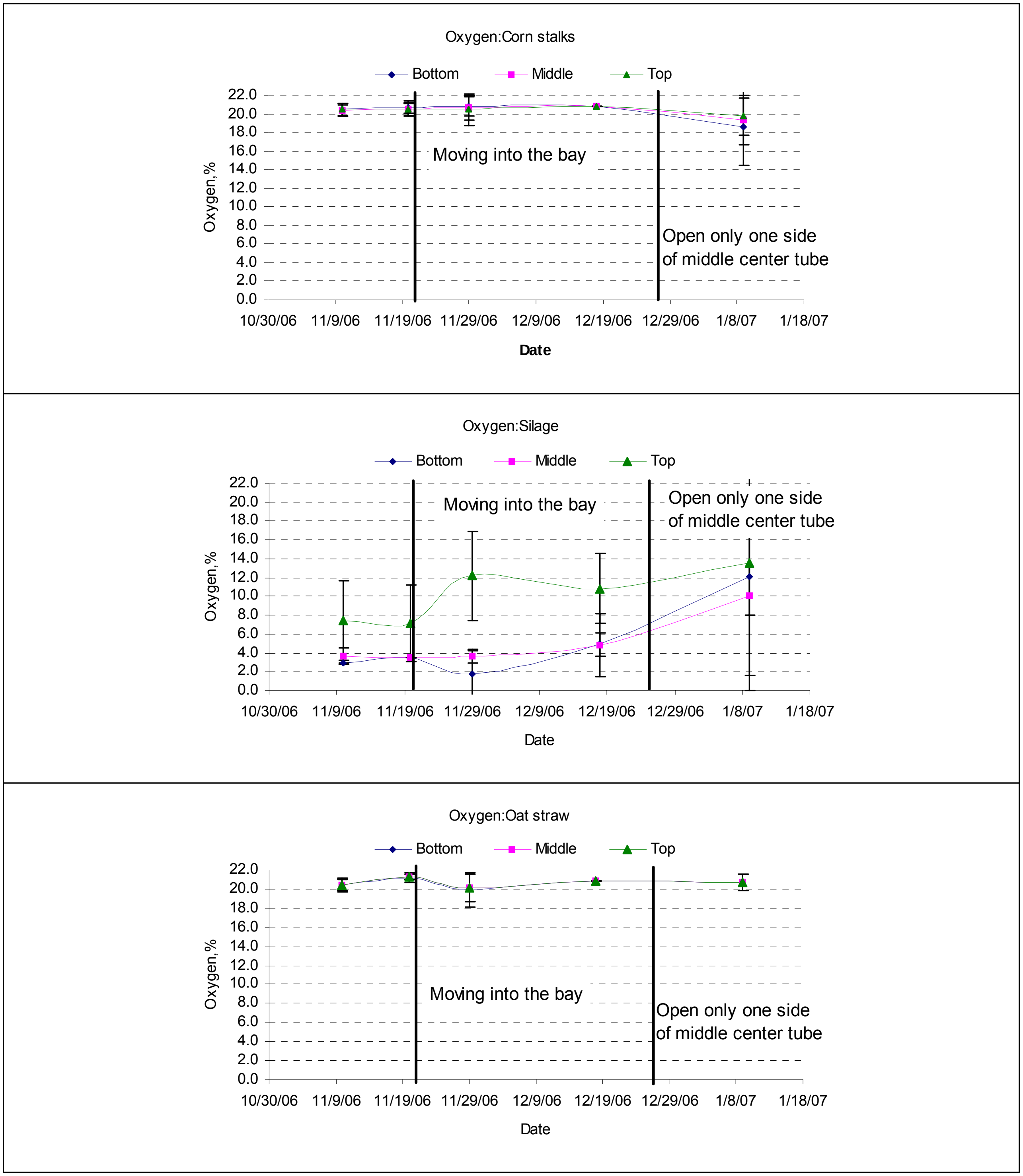

Figure 4. Average oxygen concentrations in three layers at center of replicated (n=3) composting test units.

Table 1. Average moisture content, by depth layer.

Envelope Material	**Layers**	MC (%, w.b.), Mean*±s.d.		
		Nov 21, 2006	**Jan 18, 2007**	**Feb 12, 2007**
Cornstalks	Bottom	$23.0\pm6.4^{a\underline{a}}$	$26.9\pm11.5^{a\underline{a}}$	$23.8\pm12.1^{a\underline{a}}$
	Middle	$24.9\pm8.4^{b\underline{b}}$	$43.3\pm21.7^{b\underline{a}}$	$33.0\pm18.5^{b\underline{b}}$
	Top	$45.7\pm24.8^{b\underline{a}}$	$57.3\pm20.7^{c\underline{a}}$	$50.7\pm19.6^{c\underline{a}}$
Silage	Bottom	$75.8\pm4.6^{a\underline{a}}$	$77.8\pm5.6^{a\underline{a}}$	$77.5\pm5.5^{a\underline{a}}$
	Middle	$75.6\pm10.2^{ab\underline{b}}$	$81.8\pm5.8^{a\underline{a}}$	$81.7\pm3.4^{ab\underline{a}}$
	Top	$80.5\pm9.6^{b\underline{a}}$	$83.0\pm3.3^{b\underline{a}}$	$79.5\pm7.6^{b\underline{a}}$
Oat straw	Bottom	$21.6\pm3.8^{a\underline{a}}$	$23.3\pm8.0^{a\underline{a}}$	$22.5\pm6.1^{a\underline{a}}$
	Middle	$24.4\pm10.5^{ab\underline{a}}$	$24.7\pm7.9^{b\underline{a}}$	$28.4\pm15.9^{b\underline{a}}$
	Top	$31.1\pm20.9^{b\underline{b}}$	$45.3\pm24.0^{b\underline{a}}$	$43.9\pm24.4^{b\underline{a}}$

* Superscripts indicate statistically significant differences ($P<0.05$). Superscripts without underline compare different layers within a particular envelope material on a particular sampling date. Underlined superscripts (red font) compare similar layers within a particular envelope material at three different sampling dates.

Table 2. Average measured moisture content, bulk density, and calculated air-filled porosity, on completion of trial # 1, as a function of layer depth (N=9).

		Moisture content * (%, w.b)	Bulk density (kg/m^3)	Calculated air-filled porosity (%)
Corn stalks	Top	40.8±10.3	96.7±11.3	92.7±0.8
	Middle	33.5±7.3	102.8±21.4	92.5±1.6
	Bottom	25.8±1.5	225.7±5.4	84.2±0.3
Oat straw	Top	57.7±7.3	70.7±9.0	94.1±0.8
	Middle	38.9±8.4	89.3±10.1	93.3±0.6
	Bottom	23.3±2.3	163.1±5.9	88.6±0.5
Silage	Top	77.4±6.2	315.5±32.5	71.7±3.1
	Middle	72.6±10.5	540.1±22.5	52.5±4.3
	Bottom	75.1±6.1	918.2±62.0	18.1±6.3

* Sample collected when the experiment was terminated