Title: Comparison of efficacy, emissions, compost characteristics, and costs of in-vessel rotating drum and open static pile composting of swine carcasses, whole and ground. **NPB #09-078**

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Industry Summary: In the U.S. the use of composting to manage on-farm swine mortality has increased from 10.5 to 35.9% from 1994 to 2006 (USDA:APHIS, VS, CEAH 2001 and 2007). Very little is known about the emissions coming from the composting of on-farm mortality. Traditionally, the most popular method of composting has been the open static pile (OSP) in bins, piles, or windrows, with management of primary, secondary and curing stages. In recent years, other systems of composting have been introduced to farmers, including the use of in-vessel (IV) systems; of which the most popular are rotating drums. The claimed advantages of IV composting of mortality are accelerated decomposition, odor control, little or no leachate leaving the composting site as a potential discharge, and greater control of the composting process. It is not known if the acceleration of the IV system results in less gaseous losses occurring during composting. The impacts of using rotating drum IV or OSP composting systems and of composting whole or ground carcasses on air emissions were assessed in this research.

The objectives were to: 1) Compare the quantity of emissions from IV and OSP mortality composting systems; 2) Measure the impact of grinding carcasses on emissions when composted in IV and OSP composting systems; and 3) Estimate energy consumption and economic costs of the IV and OSP animal tissue composting systems.

Dairy manure compost, horse stall bedding, wood shavings and swine mortality compost were blended to achieve initial moisture content of 40 to 60%, and a carbon-to-nitrogen ratio of 25:1 to 30:1, based on chemical analyses of materials used. Carcasses were placed in IV units or OSP's, either whole or ground.. In-vessel and OSP systems were housed in individual chambers at the Michigan State University Animal Air Quality Research Facility when emissions, including ammonia, hydrogen sulfide, carbon dioxide, and oxygen, were measured continuous for days 1 through 20 (primary phase) and 65 through 80 (secondary phase) of composting.

In-vessel and OSP composting systems were used in the primary phase only and all composts were in OSP's during the second phase or collection period. No emissions measures were taken during the 45-d interim between phases because of limited resources available to conduct this project. The two phases or periods for emissions sampling were chosen when planning the experiment to represent two portions of active composting during which different amounts of emissions would be anticipated.

Temperature within each batch was measured daily, while moisture content of the compost batches was measured twice weekly. Moisture contents of 40 to 60% were maintained during composting. Compost stability or maturity was determined by measuring oxygen consumption or carbon dioxide evolution rates in the last week of the secondary phase. Temperatures achieved in both phases indicated excellent composting activity.

Oxygen consumption was not affected by compost system, carcass form and phase of composting. Carbon dioxide emission was greater ($P < 0.05$) in the primary phase than in the secondary phase. Mass of carbon dioxide per day tended to be greater with use of the IV system of composting ($P = 0.07$). These findings suggest that the decomposition was occurring at a greater rate early in the process and in the IV system.

When considering the emissions from both phases together, the IV system emitted more ($P < 0.05$) non-methane total hydrocarbons, ammonia, and sulfur dioxide, and less ($P < 0.05$) methane, nitric oxide, and nitrous oxide than the OSP system. When considering the primary phase alone, the IV system generated about 95% less methane than did the OSP system (0.31 vs. 6.7 g/d), less nitrous oxide (-1.00 vs. 1.94 g/d), more non-methane total hydrocarbons (4.13 vs. 0.19 g/d), and more ammonia (86.96 vs. 5.04 g/d); all differences $P < 0.05$ and amounts shown being for the IV and OSP systems in the primary phase, respectively. The emissions in the two phases were compared and were greater ($P < 0.05$) for methane, non-methane total hydrocarbons, ammonia, nitric oxide, and sulfur dioxide in the primary phase as compared to the secondary phase, but not for nitrous oxide which was greater ($P < 0.05$) in the secondary phase than it was in the primary phase. Carcass form did not affect amounts of emissions. Emission patterns or emission rates over time were examined to determine at what time in the composting process differences in emission amounts occurred.

For a 2000 head finishing swine farm with a 2% mortality rate, we estimate that mortality composting on the farm for a 20-d primary phase would emit 1.40 and 0.94 tons of carbon dioxide equivalents (CO_2e) annually depending on which method of composting was used (IV or OSP, respectively). Carbon dioxide emissions accounted for 99.9 and 80.3% of the CO_2e from IV and OSP systems in the 20-d primary phase. A 10 to 20-fold greater amount of CO_2e would be emitted from primary composting as compared to secondary composting. Our measurements indicate that from days 65 to 80 of composting, only 0.07 and 0.08 tons of CO_2e would be emitted for IV and OSP, respectively. The dramatic decrease is believed to be a reflection of the greater anaerobic and aerobic microbial activity in the primary phase. Carbon dioxide emissions accounted for 99.8 and 35.9% of the CO_2e from IV and OSP systems in the 15-d secondary phase. If we assumed that emissions we observed in the secondary phase of composting would be emitted for all the other days of a complete composting process that would last a total of 6 months (i.e. 20 d in primary emission amounts and 160 d of secondary emission amounts as measured in the present study) then the total CO_2e annually from mortality composting would be 2.10 and 1.76 tons for IV and OSP systems, respectively. As a portion of the total CO_2e emitted annually from a 2000-head finishing farm, that from composting (either method) is much less than the emissions from animal production, manure storage, and manure application to fields (32.9, 116.7, and 29 ton, respectively; Maycher, 2003). But this is a very conservatively estimate and likely inaccurate as the time from our primary phase to our secondary phase, the time during turning of OSP compost material, and the time from our secondary phase to completion were not measured and the emission amounts may differ from those we measured in our 15-d secondary phase. After conducting our study, we still do not know how much the mathematical modeling done here underestimates or overestimates the GHG emission from the entire composting process. In conclusion, whether carcasses were ground or left whole did not change greenhouse gases (GHGs) emission and so air quality improvements is not a justification for the added expense and energy used to grind carcasses pre-composting. Total emissions of GHGs emitted during the first weeks of very active composting are greater with the IV composting system, than those emitted from an OSP system.

The results of this research were presented at the annual meeting of the US Composting Council in Santa Clara, California on January 26, 2011 and included as preliminary data in a grant proposal submitted to USDA/NIFA/AFRI – Research Climate Change in 2010 (not funded). A CIG grant focused on GHG emission from composting swine mortality was written for submission in February 2011 (not funded).

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Scientific Abstract: Swine carcasses (292 ± 7.3 kg per batch), whole (W) or ground (G), were composted using rotating drum in-vessel (IV) or open static pile (OSP) composting systems. Dairy manure compost, horse stall bedding, finished swine mortality compost, and dry wood shavings were mixed together (analyzed percent H_2O, percent N, and C:N were 48.7 ± 0.32%, 0.76 ± 0.075%, and 31.8 ± 2.51, respectively) and added as the only amendment to each batch of mortality compost. Total mass per batch was 812 ± 7.3 kg. The eight batches were placed in eight individual rooms (2 replications per treatment). Oxygen consumption and air emissions of CO_2, CH_4, NMTHC, NH_3, NO, NO_2, N_2O, H_2S, and SO_2, were measured continuously for 20 d during the primary phase (d 1 to 20), and a 15 d period 1.5 mo later (secondary phase), where all batches were further composted as open static piles (identity preserved). Oxygen consumption did not differ among treatments, being unaffected by compost system, carcass form and phase of composting. Carbon dioxide emission was greater ($P < 0.05$) in the primary phase than in the secondary

phase. Mass of CO_2 per day tended to be greater with use of the IV system of composting (*P* = 0.07). The IV system emitted more (*P* < 0.05) NMTHC, NH_3, and SO_2, and less (*P* < 0.05) CH_4, NO, N_2O than the OSP system. Composting system did not affect the daily mass of NO_2 and H_2S emitted. In the primary phase, the IV system generated about 95% less (*P* < 0.05) CH_4 than did the OSP system (0.31 vs. 6.7 g/d, respectively). Other environmentally-interesting differences (*P* < 0.05) between the IV and OSP systems in the primary phase were NMTHC (4.13 vs. 0.19 g/d), NH_3 (86.96 vs. 5.04 g/d), and N_2O (-1.00 vs. 1.94 g/d) emissions for IV and OSP systems, respectively. The amount of CH_4, NMTHC, NO, and SO_2 gases emitted in the second phase did not differ among treatments. Nitrous oxide emissions were greater (*P* < 0.05) with the use of the OSP system than with the IV composting system in the secondary phase. Emissions were greater (*P* < 0.05) for CH_4, NMTHC, NH_3, NO, and SO_2 gases in the primary phase as compared to the secondary phase, but not for N_2O, which was greater (*P* < 0.05) in the secondary phase than it was in the primary phase. Carcass form did not affect amounts of emissions. For a 2000 head finishing swine farm with a 2% mortality rate, we estimate that CO_2e emitted annually from the composting of mortality for 6 months 1908 and 1596 kg depending on which method of composting was used (IV or OSP, respectively). In conclusion, whether carcasses were ground or left whole changed did not result in differences in gas emissions. In-vessel and OSP composting systems emitted different amounts of gases in the early, active phases of composting; including those gases considered greenhouse gases.

Introduction: Very little is known about the emissions coming from the composting of on-farm mortality. Traditionally, the most popular method of composting has been the open static pile (OSP) either uncontained or contained in a bin, with management of primary, secondary and curing stages. In recent years, other systems of composting have been introduced to farmers, including the use of in-vessel (IV) systems; of which the most popular are rotating drums.

Emissions from OSP with bovine mortalities have been reported by Xu and coworkers (2007 a and b) and Thomson and Van Heyst, (2008). Emission samples were collected using flux rooms. Carbon dioxide, CH_4, and N_2O emissions were greater in mortality OSP's than in those containing only manure (Xu et al., 2007a & b). Collection was for 310 days and GHG surface fluxes during composting were measured weekly during the first 4 weeks and every 2–4 weeks for the remainder of the experimental period. Gas concentration profiles were described using a vented room technique. Cumulative emissions were approximated by assuming that daily fluxes represent the average for the whole week. Turning of piles caused greater CH_4, and N_2O emissions, with them being even greater if a shredder bucket was used instead of a front-end loader (Xu et al., 2007a). Currently, no published data exist for emissions from IV systems or from the composting of poultry or swine mortalities.

Objectives: 1) Compare the quantity of emissions from IV and OSP mortality composting systems; 2) Measure the impact of grinding carcasses on emissions when composted in IV and OSP composting systems; and 3) Estimate energy consumption and economic costs of the IV and OSP animal tissue composting systems.

Materials and Methods: *Experimental Design.* Swine mortalities were composted in sealed rooms at the Michigan State University Animal Air Quality Research Facility

(AAQRF) to measure gas emissions during active decomposition. Four treatments were employed which were combinations of IV or OSP compost system and whole (W) or ground (G) carcass form. Treatment designations were IVG, IVW, OSPG, and OSPW. The experiment was planned to use two observations per treatment, which were randomly assigned to eight rooms in the AAQRF.

Compost Amendment and Carcasses. Dairy manure compost, horse stall bedding, finished swine mortality compost, and dry wood shavings were blended at the Michigan State University Composting Facility to achieve a desired initial moisture content of 40 to 60%, and a carbon-to-nitrogen ratio of 25:1 to 30:1. A chemical analysis of the final amendment for composting is shown in Table 1. Three batches of amendment were made by loading specific proportions of each feedstock into a rear-delivery manure spreader and then discharging the mixture into a pile. That pile was then loaded and run through the manure spreader a second time, and then loaded a third time for transport in same manure spreader to the AAQRF.

Either whole or ground carcasses were mixed with the amendment. The carcasses were the remains of 24 hogs, which were approximately 4.5 months of age and ranging in weight from 70 to 100 kg from the MSU Swine Farm. Animals for whole carcasses (n = 12) were euthanized with an injection of 86.24 mg/kg Na-pentobarbital IV. Animals for ground carcasses (n = 12) were transported to a local butcher plant where they were electrically-stunned and euthanized by exsanguination. The blood was not collected and retained for composting. Viscera were removed, sealed in black plastic 3 mm bags (55.9 ×50.8 ×121.9 cm) for transport back to the AAQRF; they were not ground. Carcasses were sawn into 4 portions (quartered) and then were ground using a 20 hp Rietz Prebreaker/Grinder (Model No. PB-10-H3228 and Serial No. P-740353; Rietz Manufacturing, Santa Rosa, CA 95402). It was operated without a die or plate. Large bones were reduced to “sheared fragments or slivers” of approximately 10 cm in maximum length. Ground carcasses were then placed into 208 L barrels and sealed appropriately for transporting to the AAQRF.

Based on known weights of the whole carcasses and the measured weights of ground carcass and viscera, similar amounts of animal tissue (292 ± 7.3 kg per batch) were added to IVG, IVW, OSPG, and OSPW compost batches. When initiating batch formation, all animal tissues were placed on a layer of amendment approximately 30 cm thick to absorb any effluent leaving the carcasses. A total of 520 kg amendment was included in each batch of mortality compost so that a “mortality-to-amendment ratio (volume coefficient) of 160 kg/m^3 (10 lb/ft^3) was achieved. Total mass per batch was 812 ± 7.3 kg. The mass of carcasses and compost amendment were predetermined so that IV’s and OPS’s initially contained approximately 2.2 and 3.8 m^3 total compost (amendment and mortality combined), respectively. The resulting bulk density estimates were 424 kg/m^3 (713 lb/yd^3) and 256 kg/m^3 (431 lb/yd^3) for IV and OSP, respectively. The difference in BD is believed to be a result of significant packing of amendment and tissue into the IV units but no packing of the same into OSP batches. The OSP batches settled noticeably, from about 90 cm in height to about 75 cm by the end of one week of composting. In addition to bulk density, the desired conditions for initial moisture content and carbon-to-nitrogen ratio (On-Farm Composting Handbook, 1992).

Compost Systems. Four IV rotating drum composters (Model 408; BW Organics, Inc., Sulphur Springs, Texas), one per room, were used. Each IV unit consisted of an insulated steel (0.635 mm thick) drum (2.44 m long, 1.22 m in diameter, 2.29 m^3 capacity), a #100 chain power drive unit with duel sprockets, two steel channel frames plus one power driven channel frame, three slide gate unloading doors, mounted on four steel rotor casters or plastic glides. Materials were loaded through the 45.7 cm circular-shaped opening on one end of the drum and removed through 3 rectangular doors, cut into the curvature of the opposite end of the drum.

Open static piles were formed as parabolic windrows 1.524 × 3.048 m, which sat in plastic coated pans of the same dimensions. Pans had 20 cm sides and were sealed so that no effluent would be lost. They sat on steel casters for portability and had four hooks on the sides for weighing of the pan with/without material.

Compost Phases. Emissions were measured continuously during two phases of active composting: a 20-d primary phase (d 1 to 20) and a 15-d secondary phase (d 65 to 80 d after initial formations of batches). In the secondary phase the OSP system was used for all batches. The IV composters were used in the primary phase only as is commonly done on-farm or in commercial composting. The primary phase was October 28, 2009 through November 16, 2009. Compost was then removed from the AAQRF rooms and randomly allotted to and placed in open-fronted, concrete-sided bins at another location for 44 days. After composting at that location, the compost was brought back into the AAQRF rooms (randomly allotted to room) and emissions were measured for another 15 days. This, the second or secondary phase was from December 31, 2009 through January 14, 2010. The emissions-measuring portion of the experiment was concluded after the secondary phase.

Measurements. Composting was conducted in individual, sealed rooms that were supplied with air. The positive static pressure of the room forced all air through a single exhaust duct that was fitted with an air sampling tube, a thermocouple, and a Campbell Scientific temperature and relative humidity probe.

Air was supplied at regulated rates based on maintaining constant room temperatures. Sampling lines were made of Teflon-coated PTFE tubing. Air flow into each room was monitored continuously using a calibrated orifice meter fitted with a pressure transducer. Each room and the air supplied to the rooms were sampled. Sampling occurred for a period of 15 minutes with the first 10 min representing a purge period. Data from the last 5 min of sampling were recorded into a comma separate value file, created daily. The eight rooms and the air supplied to the rooms were sampled consecutively resulting in a sampling cycle that lasted 135 min. Ammonia concentration was monitored using a TEI17C chemiluminescence analyzer (Thermo Fisher Scientific, Waltham, MA). Hydrogen sulfide was monitored using a TEI 450i Pulsed Fluorescence SO_2-H_2S-CS Analyzer (Thermo Fisher Scientific, Waltham, MA, USA). Methane and non-methane total hydrocarbons (NMTHC) were monitored using a TEI 55C methane analyzer (Thermo Fisher Scientific, Waltham, MA, USA). Nitrous oxide was monitored using an Innova 1412 Field Gas Monitor (LumaSense Technologies, Ballerup, Denmark). Gas sampling and data acquisition were controlled by LabView 8.2.1 software and the FieldPoint system (National Instruments, Austin, TX, USA).

The 24-hr maximum temperature was measured in both the IV and OSP compost systems using a Fisher Scientific minimum/maximum digital thermometer. A single compost temperature probe was placed in the OSP piles at a location approximately twothirds of the height of the compost pile. A single temperature compost probe was mounted to the outer wall at mid-length of the IV. Moisture content and pH were measured weekly in samples collected from the IV systems, and then in both OSP and IV compost when removed from the AAQRF rooms (AOAC, 2000). Moisture content, pH and electrical conductivity were measured in all composts at the beginning and end of the secondary phase. Compost stability or maturity was assessed using CO_2 and O_2 measures. The mass of each compost treatment was measured at the end of the primary phase, and then again at the beginning and end of the secondary phase.

Compost Management. Moisture content was increased by water addition to maintain a concentration of 40 to 60% H_2O. Open static piles were left undisturbed for the entire phase. In-vessel drums rotated continuously for the first 3 days, but when temperatures failed to increase a decision was made to turn off the IV motors for 8 hr each day. The 8-off/16-on regimen was followed for d 3-13 of the primary phase. Generally, rotating drum IV systems are operated intermittently based on the achievement of desired temperatures of 54 to 65°C.

Global Warming Potential (GWP) Calculation. Carbon dioxide equivalents (CO_2e) were estimated as the sum of the 100-yr GWP for CO_2, CH_4, and N_2O. The CO_2e's from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Forster et al., 2007) were used and are 1, 25, and 310, times the potential of CO_2 for CO_2, CH_4, and N_2O, respectively;.

Statistical Analyses. Average daily mass of gas emission and oxygen consumption of treatments were determined and compared using analysis of variance (MIXED) procedures of SAS (SAS Inst., Inc., Cary, NC). The model used included 'treatment' and 'phase' as fixed effects and the random effects of 'date' and 'total initial carcass weight per batch'. 'Date' was modeled as a repeated variable. Data transformations (cube root) were used for all gases when analyzing the data as preliminary analyses of data before transformation indicated that residuals were not normally distributed for these gases. Tables in this manuscript provide back-transformation of the least squares mean; with the back-transformation of the 95th percentile confidence interval values as indicators of variation in the mean estimate. Treatment differences were compared using the PDIFF option of SAS and considered significant at $P < 0.05$. Contrasts were used to compare composting system (IV vs. OSP) and carcass form (W vs. G).

Average daily mass of gas emission and oxygen consumption within phase, system, and carcass form were determined and compared using analysis of variance (MIXED) procedures of SAS (SAS Inst., Inc., Cary, NC) once again. In these analyses, models included 'phase', 'system', and 'carcass form' as fixed effects and 'date' and 'total initial carcass weight per batch' the random effects. Again, 'date' was modeled as a repeated variable. Pattern of O_2 consumption and the patterns of emission of all other gases then could be drawn.

To determine differences among treatments in rate of gas emitted (or consumed in the case of O_2) per minute within day, the MIXED procedures of SAS (SAS Inst., Inc., Cary, NC) were again used with the treatment × date interaction included in the model statement. Differences within day were determined using pair-wise comparisons of treatments.

Results: *Gas Measurements.* Eight measurements were taken daily in each of room resulting in sixteen observations recorded each day for each treatment, except for the IVG treatment in the primary phase. Data from one room used during the primary phase, was excluded from the final data analysis, when it was confirmed that equipment failure had been experienced during gas measurement.

Compost Temperatures. The temperatures achieved in both phases are indicative of microbial activity. Figure 1 shows the temperatures in the primary phase. Open static pile temperature rose more quickly as did those with whole carcasses. In the first days of the primary phase, IV systems were releasing heat faster than they could accumulate heat because of the rotation. On October 30, an '8-hr off/16-hr on' regimen was followed for the IV units. Temperatures increased within 24 hr. This continued until November 10. We met the safety criteria of the Canadian Council of Ministers of the Environment (CCME, 2005) in observing temperatures of 54°C or greater for at least 15 d during OSP composting and at least 3 d for IV composting.

In the secondary phase, a slow increase in temperatures was observed (Figure 1). The IVW batches attained a temperature of greater than 54°C on only 3 d. An average temperature of OSP material was greater than IV compost material. Material had been brought into heated rooms from outside bins at the Boar Test Station. Between the primary phase and the secondary phase compost was placed in individual bins in a covered, open fronted building. Bins were exposed to outdoor ambient temperatures in Michigan in December, which ranged from -13 to 13°C from November 17 to December 30 (mean daily average temperature was 0°C). During this time compost temperatures ranged from 6.4 to 80°C.

Consumption of O_2 and Evolution of CO_2. Oxygen consumption did not differ among treatments, however CO_2 emissions differed ($P < 0.05$) among treatments (Table 2). Carbon dioxide emission was greater ($P < 0.05$) in the primary phase than in the secondary phase. Mass of CO_2 per day tended to be greater with use of the IV system of composting ($P = 0.07$), providing the strongest indication that the tenet is true, that the IV system, with its mixing and aeration, does result in greater microbial activity. Mass of CO_2 emitted daily did not differ because of carcass form.

Compost Maturity. In this study we used respiration in the last week of the secondary phase and the change in compost temperature after the secondary phase to describe compost maturity (a.k.a. stability, completeness, doneness, finishing). Respiration is O_2 consumption (a.k.a. intake, demand) and CO_2 evolution (a.k.a. emission, production). An increase in temperature in recently aerated and moistened compost reflects microbial activity and nutrient availability in, and maturity of, that compost.

The standards for compost maturity most often referred to are those of the California Compost Quality Council (CCQC, 2001) and those of the CCME (2005). In order to be considered mature or stable, compost material must meet one or more requirements of ≤ 12 or 9.6 mg O_2 per g of organic matter per day, ≤ 2 or 4 mg C (as CO_2) per g of organic matter per day, and a temperature rise of the compost above ambient temperature of ≤ 46 or 50 °F, for CCQC (2001) and CCME (2005), respectively. When 'active' composting ends and 'curing' starts is not an exact science, and in the present study we planned to monitor two phases of what we believed would be 'active composting', not knowing when the compost would or could have been characterized as in the 'curing' phase.

We chose to use the O_2 consumption and CO_2 evolution measures taken in the last week of the secondary phase to assess if active composting had ended and curing had started. Oxygen consumption was 3.47, 2.51, 9.25, and 5.95 mg O_2 per g of organic matter per day and carbon dioxide evolution was 1.49, 1.90, 2.52, and 1.95 mg CO_2 per g of organic matter per day for IVG, IVW, OSPG, and OSPW, respectively. Oxygen consumption of the two IV treatments was less ($P < 0.001$) than OSP treatments. Oxygen consumption in the last 7 d of the secondary phase was less ($P = 0.05$) when carcasses were left whole as compared to when ground prior to composting. Carbon dioxide evolution in the last week of the secondary phase did not vary by treatment, composting system, or carcass form.

Consumption of O_2 and evolution of CO_2 at the end of the secondary phase, of all treatments, indicates that the compost was very mature by both CCQC (2005) and CCME (2005) suggested standards. It is noteworthy to recognize that the O_2 uptake limit of the CCME in 1996 (previous version of guidelines for compost quality), was ≤ 3.6 mg O_2 per g of organic matter per day. If the earlier standard was considered in assessing the maturity of the compost in the present study, then the IVG and two OSP treatments would be considered moderately mature. The reason for the increase in O_2 per g of organic matter per day is not stated in the 2005 CCME document.

Using these methods and the current guidelines of California and Canada, we could not make a decisive conclusion about the maturity of the compost as influenced by compost system or carcass form. There are numerous methods to estimate compost maturity and whether those we employed, or others, are most accurate is debatable (Briton, 2010). We chose to measure respiration after our planned secondary phase, but conspicuously our compost in both the primary and secondary phases would have been considered very mature by O_2 consumption standards. It leads us to question the legitimacy of our respiration methodology as compared to the bench-top lab methodology followed by both CCQC (2001) and CCME (2005). We may have observed too much variation in our O_2 consumption measures to draw conclusions about the biology of composting. Two replications per treatment may not have been statistically powerful enough to get full agreement among CO_2 evolution, O_2 consumption, and temperature rise. Furthermore, the CCQC (2001) and CCME (2005) respirometry tests are typically conducted with a subsample, in a laboratory, at a constant moisture and temperature, immediately following mixing or aeration. The respiration assessment we completed was at the end of a 15-day period in which the material was left undisturbed. We measured O_2 consumption and CO_2 evolution on entire open static piles and this test technique has not been validated and reported previously. Comparisons of our approach to the same tests done in a laboratory setting were not made.

Temperature of compost indicated typical compost activity in the primary and secondary phases (Figure 1). As note above, average temperatures of OSP material was greater than IV compost material, possibly indicating that the material was less mature going into the secondary phase. Again, we chose to assess maturity at the end of the secondary phase. Temperature change may be used as an indicator of maturity (CCME, 2005). A temperature increase of the compost above ambient temperature of 46 degree units (Fahrenheit) suggests that the compost is not mature. After the secondary phase was concluded and the batches were moved from the AAQRF to bins, the increase in temperature of all batches was greater than 46 Fahrenheit degree units above ambient temperatures, suggesting that all compost material was not mature or stable (Figure 2).

The temperature techniques followed in the present study have not been validated previously, and the "rise tests" of CCME (2005) are typically conducted in a more controlled or standardized laboratory setting than the procedure employed in the present study.

Total Gas Emission: CH_4, NMTHC, NH_3, NO, NO_2, N_2O, H_2S, and SO_2. The amount emitted daily for *CH_4, NMTHC, NH_3, NO, N_2O, and SO_2* differed ($P < 0.05$) among treatments (Table 2). Whether compost system or phase contributed to this variation, was not consistently the same for these gases, but carcass form did not affect the emission of any gas. The IV system emitted more ($P < 0.05$) NMTHC, NH_3, and SO_2, and less ($P < 0.05$) CH_4, NO, N_2O than the OSP system. Composting system did not affect the daily mass of NO_2 and H_2S emitted.

The primary and secondary phases of this study involved the same compost material, with different systems (IV and OSP) used in the first phase and the same OSP approach used in the second phase. Emissions were greater ($P < 0.05$) for CH_4, NMTHC, NH_3, NO, and SO_2 gases in the primary phase as compared to the secondary phase, but not for N_2O, which was greater ($P < 0.05$) in the secondary phase than it was in the primary phase.

In the primary phase, the IV system generated about 95% less ($P < 0.05$) CH_4 than did the OSP system (0.31 vs. 6.7 g/d, respectively). Other environmentally-interesting differences ($P < 0.05$) between the IV and OSP systems in the primary phase were NMTHC (4.13 vs. 0.19 g/d), NH_3 (86.96 vs. 5.04 g/d), and N_2O (-1.00 vs. 1.94 g/d) emissions for IV and OSP systems, respectively.

The amount of CH_4, NMTHC, NO, and SO_2 gases emitted in the second phase did not differ among treatments. Nitrous oxide emissions were greater ($P < 0.05$) with the use of the OSP system than with the IV composting system in the secondary phase. Why is not known for sure, but possibly related to differences in compost maturity noted above; with IV compost being more mature in the second phase.

The treatment × phase interaction was significant for CH_4, NMTHC, NH_3, NO, and N_2O, but not for SO_2. For NMTHC and NO the interaction reflected that there were treatment differences in the primary phase, but none in secondary phase. Methane emission of IVW, OPSG, and OSPW treatments decreased from the primary to secondary phase, but a similar decrease was not observed with the IVG treatment. Very little methane was emitted by IVG in both phases. The amount of NH_3 emitted was greater for IV treatments than OSP treatments in the primary phase, but in the secondary phase only IVW and OSPG treatments differed ($P < 0.05$) from one another. Nitrous oxide emissions decreased ($P < 0.05$) overtime (primary phase vs. secondary phase) for IV treatments, but not for OSP treatments.

Emission Pattern. Rates (average mg per min daily) of oxygen consumption and the emission of all other gases are illustrated in Figures 2 through 12. Patterns of changes in rate reflect the treatment, system, and phase differences described in Table 2. The second statistical approach of evaluating treatment × date effects revealed incidental daily differences (not presented herein), but essentially confirmed differences already identified when comparing total daily gas mass amounts.

Energy Use. Electricity use was measured for each IV unit and it was 80 kWh total per IV unit for the entire 20-day primary phase; or 4 kWh per IV unit per day.

Discussion: 1) Compare the quantity of emissions from IV and OSP mortality composting systems; 2) Measure the impact of grinding carcasses on emissions when composted in IV and OSP composting systems; and 3) Estimate energy consumption and economic costs of the IV and OSP animal tissue composting systems.

Objective 1 - IV and OSP Emissions. We measured air emissions during two short periods, early in the composting process. We did not measure emission during the entire composting process or to a known point of maturity. What this point is and when it is reached with an IV or OSP system may differ. We do not know if the speed of the IV composting process in the primary phase results in less curing time and less total emissions if maturity of the compost is kept equal. If the OSP system takes longer to reach maturity, with rate of decomposition being slower because of less acceptable aerobic conditions, then if the total amount of emissions N_2O and CH_4 could be greater and then we may consider using an IV system. Future research will is needed to compare total emission during the entire process from start to end (cured or mature), with the end being a point of stability as defined as little or no microbial respiration, and complete decomposition of phytotoxic substances. This process may take months for mature market hogs. So ammonia emission is much greater with the IV system than with the OSP system in the first 20 d of composting. We did not measure the NH_3 emission during the turning (mixing, moving) of the OSP compost material. It is during this activity that the OSP is first disturbed and anecdotally, a great deal of NH_3 is emitted. In-vessel composting also resulted in greater SO_2 emission than did OSP. When SO_2 is oxidized in the presence of a catalyst such as NO_2, H_2SO_4 is formed leading to acid rain. So again, based on the present study, we cannot comment on the total emission over the entire time needed to decompose the swine carcasses.

Although the respiratory O_2 and CO_2 measurements we recorded suggested that the compost was mature and ready for application to the fields as a nutrient source, we did not measure the phytotoxic potential of the compost after composting and this is the maturity indicator of significant interest to plant growers who include compost in container mixes. Further research is needed to assess whether this material if used as potting medium would hinder germination or plant growth. Although not researched, we think that the 80-d old compost would not be a detriment to field-crop growth if applied to cropland similar to agronomic application of raw manure. A major concern about 80-d old compost would be presence of intact bones. Bones take much longer to decompose and to be brittle enough to shatter when spread. We did not measure bone breaking strength in the present study, but we do not think that the bones of these 5-mo old hogs would be brittle enough to shatter into acceptably small pieces when encountering the beaters, chains, or paddles of a manure spreader.

Objective 2 - Grinding Carcasses and Emissions. Whether or not the carcass has to be sawn into pieces is a consideration. In this study, the hog carcasses were eviscerated into 208 L drums and then the carcass was quartered in order fit into the hp Rietz Prebreaker. A loader that does not leak would be needed for moving the ground carcass and viscera to the IV system. Grinding is a challenge aesthetically. Grinding is difficult in the winter because equipment may freeze-up in colder environments.

Based on the findings of this study, grinding of the carcasses does not appear to be necessary. The energy cost of grinding (10 sec per 45.4 kg of carcass; size of the motor on the grinder may vary), the transportation associated with hauling carcasses to grinder and the ground carcasses back to AAQRF (88.5 km, $0.31/km) could be avoided. All other handling of compost, whether in the IV or OSP system, was considered to be equal (tractor, spreader, and loader for amendment incorporation into each batch).

The results of our study evaluating the combined effects of grinding in an OSP must be considered in light of all of our composting procedures. We did not grind and mix carcasses with amendment simultaneously as is common when vertical grinder/mixers currently sold to composting firms, are used. A homogenous mixture of tissue and carbon source is achieved. Alternatively, we ground the carcasses in a separate process and then layered the ground tissue into our OSP's. In taking this thought further, we did however simulate a homogenous mixing of tissue and amendment in our IV system with ground carcass. The emissions from the IVG treatment were not noticeably different from the other treatments, supporting our conclusion above, that grinding is not justified.

Objective 1 and 2 - Greenhouse Gas: For a modern swine farm with 2000 head finishing capacity and a 2% mortality rate, we estimate that mortality composting on the farm for a 20-d primary phase would emit 1273 and 850 kg (1.40 and 0.94 tons) of CO_2e annually depending on which method of composting was used (IV or OSP, respectively). Carbon dioxide emission accounted for 99.9 and 80.3% % of the CO_2e from IV and OSP systems in the 20-d primary phase.

In our study, the amount of CO_2e emitted was 10 to 20-fold less in the secondary phase as compared to primary phase of composting. Our measurements indicate that from days 65 to 80 of composting, only 0.07 and 0.08 tons of CO_2e would be emitted for IV and OSP, respectively. The dramatic decrease is believed to be a reflection of the greater anaerobic and aerobic microbial activity in the primary phase. Carbon dioxide emissions accounted for 99.8 and 35.9% of the CO_2e from IV and OSP systems in the 15-d secondary phase. Substantially more CO_2e was derived from N_2O emitted from OSP material in later composting.

If we assumed that emissions we observed in the secondary phase of composting would be emitted for all the other days of a complete composting process that would last a total of 6 months (i.e. 20 d in primary emission amounts and 160 d of secondary emission amounts as measured in the present study) then the total CO_2e annually from mortality composting would be 1908 and 1596 kg (2.10 and 1.76 tons) for IV and OSP systems, respectively. As a portion of the total CO_2e emitted annually from such a farm, that from composting (either method) would be much less than the emissions from animal production, manure storage, and manure application to fields (29,836, 105,864, and 26,300 kg [32.9, 116.7, and 29 ton], respectively; Maycher, 2003).

This estimate may be inaccurate as the time between our primary phase and secondary phase, the time during turning of OSP compost material, and the time after our secondary phase were not measured. In our assessment of CO2e, we used an assumption that the emissions we measured during d 65 to 80 were the same as those which would be emitted from d 20 to 65 and from d 80 to 180 of a 6-mo complete composting process. It is possible that our assumption underestimates the emissions during d 20 to 45 and overestimates the emissions from d 80 to 180. Further research is needed to evaluate the emission patterns during these times in the complete composting process.

Objective 3 - Energy Consumption and Economic Costs of IV and OSP Systems. Both IV and OPS systems were loaded and emptied 'by-hand" using shovels, brooms, and 208-L drums. The IV unit we used was one of the smallest models manufactured by BW Organics; not as large as would be typically used on commercial swine operations. The loading of the BW Organics IV unit required considerable labor because the opening for loading was about 45.7 cm and located vertically on the end of the drum. The diameter of the opening limits the size of hog carcasses to about 100 to 125 kg, after rigor mortis has occurred. The loading of the ground material and viscera required a custom-built chute. This allowed for complete inclusion of all liquids that had accumulated in the bottom of the drum. It would be less labor to have an in-vessel system that has an opening large enough to allow the additions of whole carcasses. It required about 0.6 hr and 2 people to load each IV unit in this study. However, all compost and carcass was weighed in 208-L drums during the filling process, slowing the process slightly. To empty an IV unit, the material would fall out of 3 small doors (0.14 m2 each) onto the floor.

The construction of the open-static piles required about 0.4 hr and 2 people. Again, all compost and carcass was weighed in 55-gallon drums during the filling process, slowing the process slightly.

Electricity cost for operating a Model 408, BW Organics, IV unit would be $0.44 per d (4 kWh per IV unit per d × $0.11/kWh. Energy cost per 45.4 kg (or cwt) of carcass for grinding is estimated to be 0.5 cents per cwt of mortality.

$0.0052 = (0.85 kwh/hp-hr × 20 hp motor) × (10 sec ÷ 3600 sec per hr) × $0.11/kwh

This was estimated using 0.85 kwh/hp-hr (Smajstrla and Zazueta, 2003), the 20 hp motor of the Rietz Prebreaker/Grinder, and a $0.11/kwh price of electricity. Karl Jones (personal communication) operates the grinder 10 seconds for every 45.4 kg of carcass. Not included is the cost of the saw to split the carcass into quarters so that it could be ground.

Admittedly, the costs realized in our experimentation do not reflect a realistic assessment and comparison of fixed and variable costs for a modern commercial swine farm. To do so, the economic costs of OSP and IV mortality composting systems were evaluated using a case study approach involving two Michigan farrow-to-wean operations of 3300 and 2500 sows, respectively. Information was gathered directly from two farms currently utilizing the different composting systems. Estimates are presented below in English units of measures.

The IV system used on the first farm is a horizontal rotating drum system, being 4 feet in diameter and 42 feet long. It is located about 30 yards from the animal buildings. It is operated continuous flow with mortality loaded and compost material discharged from the unit on a daily basis. Fresh shavings are added in proportion to the amount of mortality added (0.07 ft^3 of shavings per pound of mortality unless finished compost is used; then the ratio is 0.015 ft^3 of shavings and 0.055 ft^3 finished compost per pound of mortality). The stainless steel insulated (R8) drum has openings unit for aeration. To obtain optimal aeration during operation, filling to more than 75% of capacity is avoided. The number of rotations varies by season, more in summer and less in winter (average about 10 per day annually). Consequently, retention time also varies, about 7 days in summer and 14 days in winter. Likewise, electrical use would be twice as much in summer. If too much moisture has been added or not enough shavings, then moisture can leak out of the unit. Material reaches the discharge end in less than a week. Compost material is screened when exiting the IV unit to separate bones from fine, carbonaceous material. The bones are reintroduced into the IV unit for further composting. The remainder of the compost is stacked in the open-sided pole building with mono-slope roof. It stays there for about 5 to 6 months, where it is turned inconsistently, before being spread on cropland as a soil amendment. If mortality rate is greater than “normal” and IV unit capacity is exceeded for a short period, the farm places extra mortalities into a short-term OSP. When mortality rate decreases once again and within the IV unit’s normal loading recommendations, the farm puts compost material from the short-term OSP into the IV unit.

The OSP system used on the second farm consists of six 12’ x 22’ x 6’, three-sided bins with concrete floor. There was no roof over the bins, and a 25’ x 75’concrete apron in front of the bins. Fresh bulking agent is stored in one of the bins. Compost batches are initially established in 2 bins over a 30 day period. Labor works to separate carcasses of young and adult pigs. Bins with small pig carcasses are turned twice, at 30 days, and again at 60 to 90 day of composting. Bins or batches with adult pigs are turned three times, 30, 60 and at 90 to 120 days of composting. With the last turn, the material is moved to a temporary in-filed stack; to be spread on the fields at a future date. Bones are collected and recycled at all turns and composted further, until brittle. Since the composting facility is not covered and subject to precipitation, runoff is collected and directed to earthen manure storage.

Fixed costs include depreciation, interest on the remaining (un-depreciated value; 5%), insurance (0.005% of replacement value of IV unit and tractor, and 0.01% on physical structures around the IV unit and the OSP physical structure), repairs (0.01% of purchase price), and taxes (average 23 mills). For our estimations, both systems were given an estimated useful life of 15 years. To provide a legitimate comparison to the estimate of Henry and Bitney (2010) a similar definition of fixed costs was used. These authors stated that fixed costs included: depreciation, interest on the un-depreciated balance of the item, repairs, property taxes, and insurance.

Operating costs for the IV system included the electricity used by the 1-hp motor and is estimated to be 1.56 kW x hr used. The IV unit rotates completes a rotation in 20 minutes, and averages 10 rotations per day annually. Using an electricity cost of $0.11/kW total electric cost was $130 per year. No electricity was used in the OSP system. Fuel used by the tractor loader differs only because of hours this equipment is used on the two farms; 182.5 verses 273 for the IV and OSP systems, respectively. For this estimate, an 80 hp tractor at 65% maximum power 50% of the time and idle speed the remainder, will use 2.8 gallons per hr. Fuel was priced at $3.53 per gallon on May 31, 2011. The tractor loader is used for the removal of mortality from the production facility, the loading of bins and the IV unit, the movement of compost material from bin to bin for aeration, and from IV unit discharge to piles for further composting, the movement of recycled compost to new batches of compost, and for loading the manure spreader when moving compost to fields.

The labor cost per hr is $15.75. The amount of labor used per year was 273 and 182 hr, for OSP and IV farms, respectively (including the employer's portion of SS, Medicare, health insurance, and other monetary benefits.

On a per pound of mortality basis and a per cubic yard of finished compost basis, the costs associated with the removal of mortality from the production facility and those for the use of a tractor and spreader for hauling finished compost to cropland, are assumed to be equal for all composting systems. Custom compost spreading (tractor and spreader) is $75/hr and 6.6 tons spread per hour, using a weight reduction ratio of 0.83 (i.e. every 1.0 lb of mortality results in 0.83 lb of finished compost; Henry and Bitney, 2010). Spreading compost on the field requires about 13.9 hr and 16.8 hrs per year for the two farms and is directly a reflection of size of the operation and mortality rate.

The only other cost incurred by both farms was that of shavings. The amount of this carbon source used per year as reported by the farms is similar. Price of amendment per bag is $3.50 per bag (0.33 yd^3).

The cost comparison of these two systems and to the "Low Investment" OSP system of Henry and Bitney (2010) is shown in Table 3. Using a 15-yr life for both systems, the annual cost per lb of mortality is less for the OSP systems as compared to the IV system. Both Michigan systems were less expensive to operate than the Nebraska system described by Henry and Bitney (2010). Energy cost was similar for both units.

Costs on other farms may vary because of differences in mass of mortality (rate and weight), slight differences in composting system (composting facilities and equipment and siting relative to production units), and management (frequency of aeration and carbon source utilized). These are the factors influencing the costs of using composting to manage mortality and afterbirth on-farm. Using the $ per pound of mortality estimates derived in the case study, and stipulating that the composting system is sized appropriately, sited efficiently, and operated at maximum capacity, a 2000-head finishing operation would generate about 8800 pounds of mortality annually and have annual costs of $598 and $378 if an IV or OSP system was used, respectively.

Table 1. Amendment composition on as-is basis[a].

Item	Measure
Moisture, %	48.3
Mineral matter, %	5.91
N, %	0.761
P, %	0.176
P_2O_5, %	0.402
K, %	0.512
K_2O, %	0.617
Ca, %	0.864
Mg, %	0.190
Na, %	0.129
S, %	0.146
C, %	24.113
B, ppm	7.4
Fe, ppm	1308.6
Mn, ppm	86.8
Cu, ppm	16.5
Zn, ppm	46.7
C:N	31.8
pH	8.72

[a]The analysis was completed at Brookside Laboratories, Inc., New Knoxville, OH 45871, except for bulk density, which was completed at the AAQRF.

Table 2. Oxygen consumption (g per d) and daily gas emissions (g per d) and of compost containing 5-month old dead swine in primary and secondary phases of composting.[a]

	Treatment[b]				P - value[c]			
Gas	IVG	IVW	OSPG	OSPW	Trt	Phase	Syst	Carc
O_2	-5595.195 [-9794.300, -2809.428] -1401.882 [-2513.071, -678.734]	-6496.181 [-8427.517, -4885.135] -1006.675 [-1667.927, -548.368]	-3688.455 [-5602.574, -2269.058] -2017.715 [-3089.808, -1227.655]	-2772.143 [-3782.561, -1959.883] -2214.181 [-3398.205, -1343.088]	0.56	< 0.001	0.38	0.65
CO_2	4760.963$^{d, x}$ [678.039, 15364.523] 330.197^{y} [41.544, 1111.999]	5595.857$^{e, x}$ [3509.660, 8378.291] 316.155^{y} [89.585, 766.111]	3376.755$^{f, x}$ [889.583, 8474.192] 174.893^{y} [33.940, 501.891]	2186.219$^{f, x}$ [1298.739, 3406.825] 98.164^{y} [8.751, 367.877]	0.01	< 0.001	0.07	0.70
CH_4	0.090^{d} [0.000, 0.574] 0.007 [-0.001, 0.100]	0.481$^{d, x}$ [0.160, 1.075] 2.989E-04^{y} [-0.009, 0.040]	6.924$^{e, x}$ [4.676, 9.798] -1.261E-04^{y} [-0.034, 0.011]	6.641$^{e, x}$ [4.410, 9.521] 0.010^{y} [-4.312E-04, 0.125]	< 0.001	< 0.001	< 0.001	0.16
NMTHC	4.183$^{d, x}$ [1.952, 7.676] -7.116E-05^{y} [-0.032, 0.013]	4.645$^{d, x}$ [2.943, 6.901] -3.434E-04^{y} [-0.035, 0.007]	0.194$^{e, x}$ [0.037, 0.562] 0.001^{y} [-0.005, 0.040]	0.218$^{e, x}$ [0.054, 0.565] -2.848E-05^{y} [-0.026, 0.013]	< 0.001	< 0.001	< 0.001	0.82
NH_3	73.397$^{d, x}$ [30.850, 143.664] 4.704$^{de, y}$ [1.312, 11.490]	78.326$^{d, x}$ [55.905, 106.059] 2.102$^{e, y}$ [0.574, 5.187]	6.951^{e} [1.769, 17.729] 7.742^{d} [3.554, 14.358]	5.582^{e} [2.620, 10.207] 3.931^{de} [1.334, 8.688]	< 0.001	< 0.001	< 0.001	0.28
NO	2.441E-02^{d} [-0.003, 0.382] 0.001 [-0.006, 0.053]	0.020^{d} [9.990E-05, 0.120] 0.049 [0.003, 0.210]	3.251$^{e, x}$ [1.706, 5.525] 0.014^{y} [1.829E-06, 0.105]	2.614$^{e, x}$ [1.632, 3.929] 0.020^{y} [2.851E-05, 0.134]	< 0.001	< 0.001	< 0.001	0.60
NO_2	0.236 [0.038, 0.728] 0.071 [0.007, 0.262]	0.665 [0.312, 1.218] 0.072 [0.008, 0.252]	0.976 [0.506, 1.672] 0.017 [7.671E-05, 0.108]	0.520 [0.233, 0.977] 0.011 [-7.301E-09, 0.088]	0.22	< 0.001	0.83	0.88
N_2O	-0.606$^{d, x}$ [-2.813, -0.022] -0.002$^{d, y}$ [-0.089, 0.009]	-1.166$^{d, x}$ [-2.250, -0.502] 0.004$^{d, y}$ [-0.001, 0.069]	1.649^{e} [0.555, 3.658] 0.533^{e} [0.174, 1.201]	1.799^{e} [0.986, 2.969] 1.099^{e} [0.443, 2.206]	< 0.001	0.01	< 0.001	0.45
H_2S	0.262 [0.039, 0.834] 8.108E-06 [-0.003, 0.006]	0.718 [0.452, 1.072] 1.654E-05 [-0.001, 0.003]	0.340 [0.133, 0.696] 0.001 [-7.223E-06, 0.011]	0.221 [0.124, 0.359] 1.042E-04 [-0.001, 0.006]	0.15	< 0.001	0.58	0.63
SO_2	0.189$^{de, x}$ [0.035, 0.549] -0.001^{y} [-0.011, 8.848E-05]	0.134^{d} [0.067, 0.235] -0.001 [-0.007, 8.024E-06]	0.144^{d} [0.046, 0.330] -0.003 [-0.017, -7.917E-05]	0.040$^{e, x}$ [0.016, 0.083] -0.006^{y} [-0.026, -3.681E-04]	< 0.001	< 0.001	0.03	0.12

[a]Least squares mean and [95% confidence interval] for the primary and secondary phases (described in footnote [c] below) are presented in each cell (lines 1 through 4, respectively). Emissions were measured continuously during two phases of composting: 1) a 20-d primary phase (d 1 to 20), and 2) a 15-d secondary phase (d 65 to 80 after initial formations of batches). Eight measurements were taken daily in each of room resulting in 16 observations recorded each day for each treatment, except for the IVG treatment in the primary phase, for which data from only one room was analyzed. In-vessel composting was conducted in the primary phase only, but compost identity was preserved and considered a treatment effect when compost was placed back into a room for measurements in the second phase.

[b]IVG = in-vessel system and ground carcasses, IVW = in-vessel system and whole carcasses, OSPG = open static pile and ground carcasses, and OSPW = open static pile and whole carcasses.

[c]Trt = overall treatment *P* - value; Phase = *P* - value for comparison of primary and secondary phases of composting: 1) a 20-d primary phase (d 1 to 20), and 2) a 15-d secondary phase (d 65 to 80 after initial formations of batches); Syst = *P* - value for comparison of IV and OSP systems; Carc = *P* - value for comparison of form of carcass (ground and whole).

[d, e, f]Treatment means with different superscripts in the same row (within phase) differ $P < 0.05$.

[x, y]Means having different superscript letters within cell (within treatment and comparing phases) differ $P < 0.05$.

Table 3. Budgeted annual costs for two different mortality composting systems (in-vessel and open static pile) and the low investment composting bin system as reported by Henry and Bitney (UNL-2010).

	In-vessel	**Open static pile**	**UNL-2010**
System description			
Mortality per year, lbs.	219,000	268,829	40,000
Composting system	IV unit, concrete pad, 24 x 26' open-sided pole building with monoslope roof, concrete floor, 6' high concrete walls	6 bins, each is 12' x 22' x 6', concrete floor, no roof and 25' x 75'concrete apron	bins, concrete floor and bin walls 6' high, no roof, no apron (Low investment)
Capital investment	$62,000	$7,038	$7,465
Machinery needed	Tractor loader	Tractor loader	Skid steer loader, tractor and manure spreader
Labor, hr per year	182.5	273	125.9
Carbon source	121 yd^3 @ $10.50/$yd^3$	121 yd^3 @ $10.50/$yd^3$	80 yd^3 @ $7.50/$yd^3$
Annual costs			
Fixed costs			
Composting system	$6,706.00	$936.18	$1,020.22
Tractor loader	$1,152.05	$1,152.05	$622.57
Operating costs			
Fuel and (or) electricity	$1,929.00	$2,698.00	$415.05
Custom tractor and manure spreader	$1,026.00	$1,260.00	Included above; not separated out
Labor	$2,874.00	$4,300.00	$1,888.20
Other	$1,270.50	$1,270.50	$600.00
Total annual cost	$14,957.55	$11,616.73	$4,546.04
Cost/lb. mortality	$0.068	$0.043	$0.114
Energy cost/lb. mortality	$0.0088	$0.0100	Not estimated

Figure 1. Daily maximum temperature during the primary and secondary phases of composting.

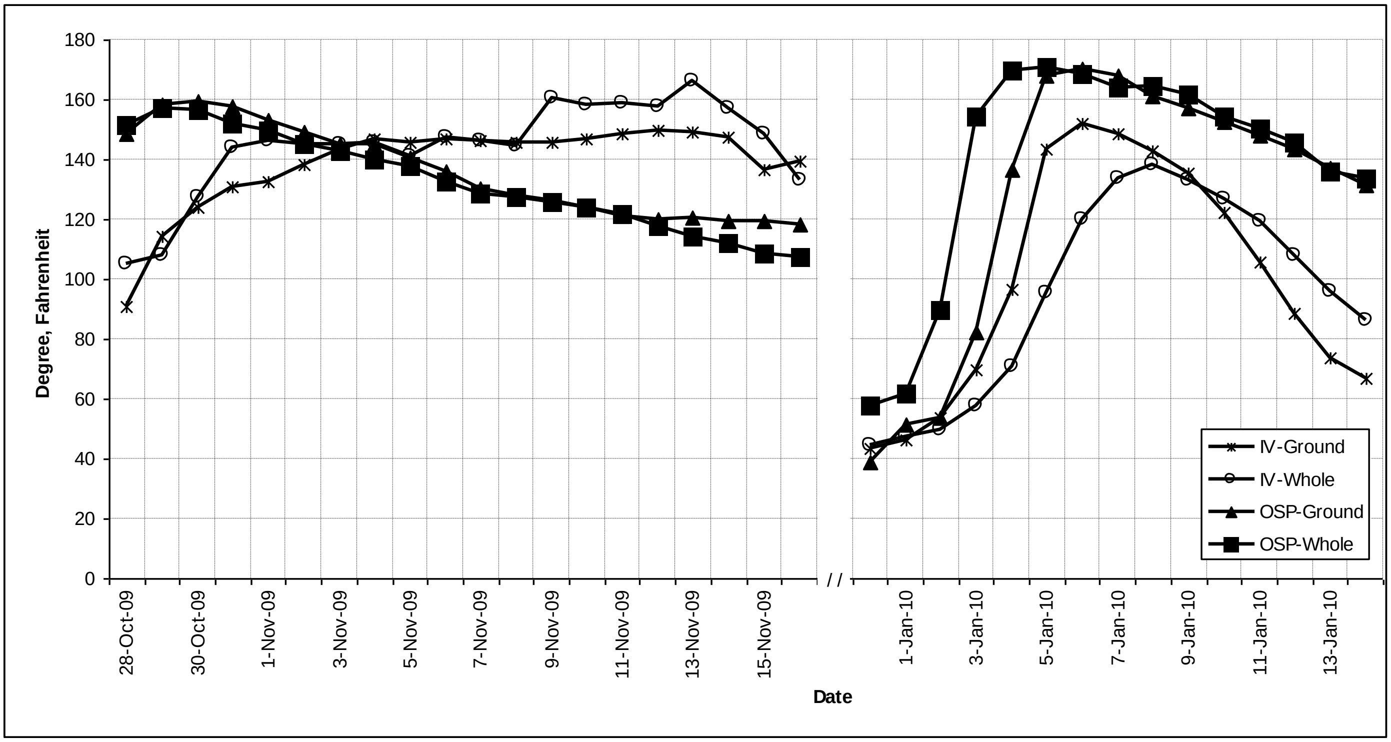


Figure 2. Temperature of compost in relation to ambient temperature after the movement of compost batches from AAQRF to Boar Test Station bins, after the secondary phase.

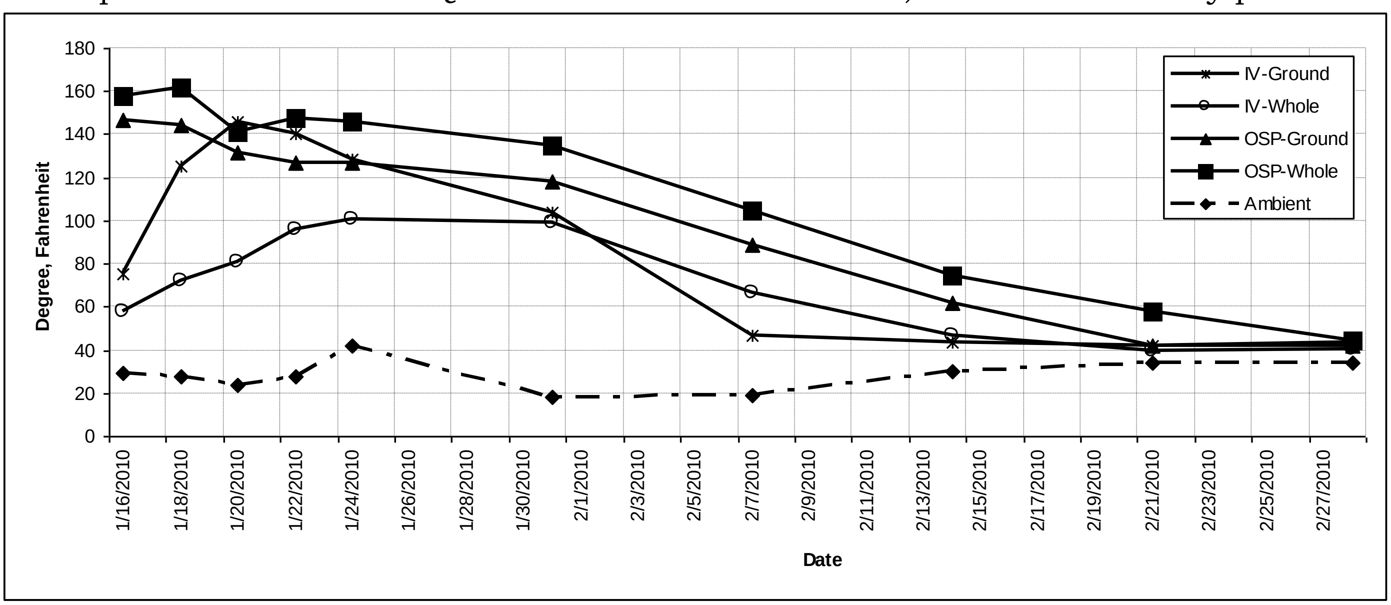


Figure 3. Oxygen consumption (average mg per min within day) during primary and secondary phases of composting.

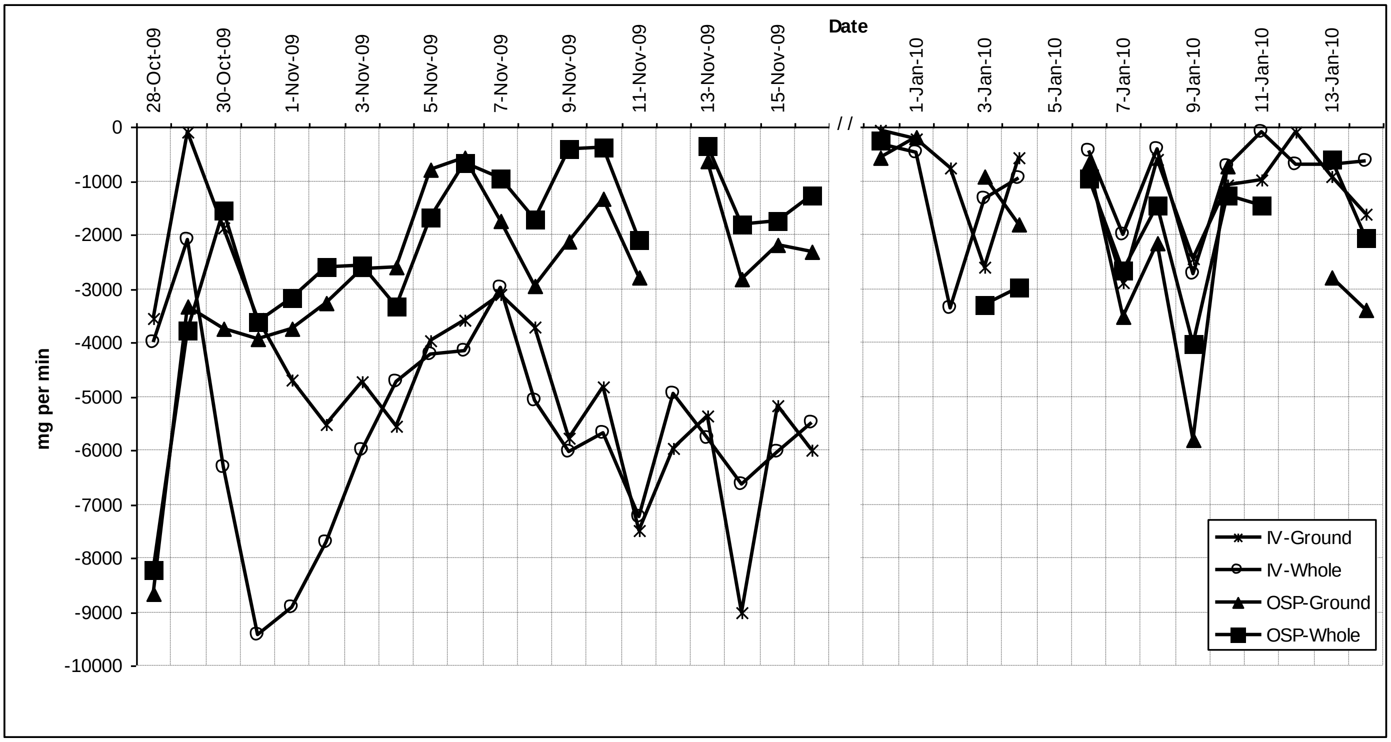


Figure 4. Emission pattern for carbon dioxide (CO_2; average mg per min within day) during primary and secondary phases of composting.

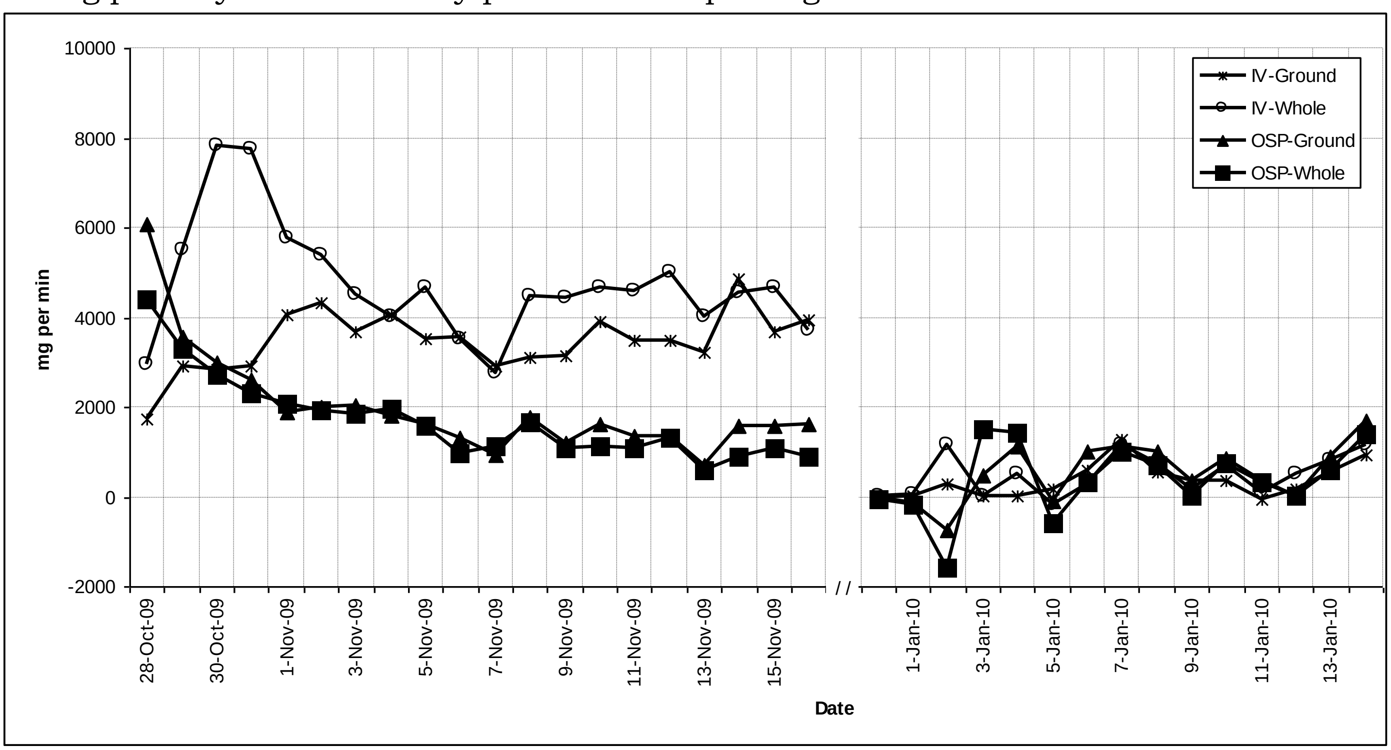


Figure 5. Emission pattern for methane (CH_4; average mg per min within day) during primary and secondary phases of composting.

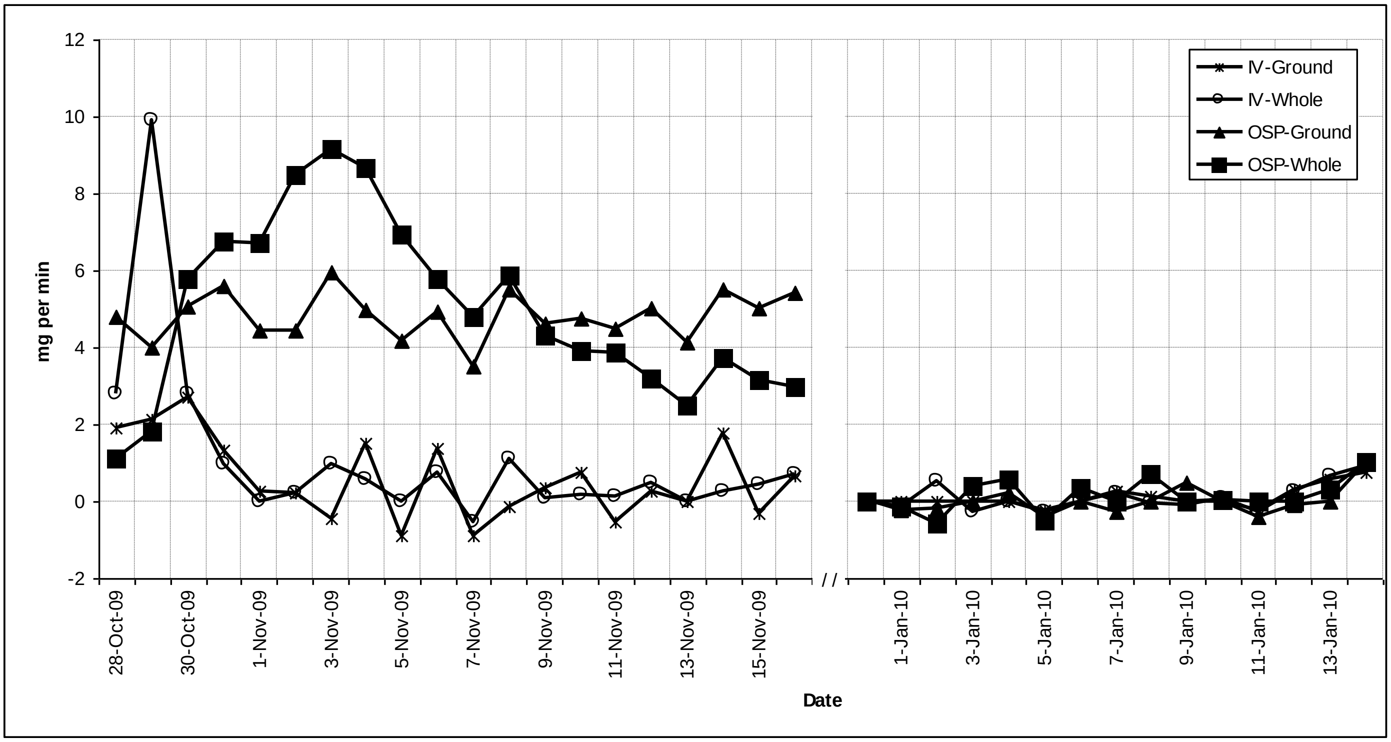


Figure 6. Emission pattern for non-methane total hydrocarbons (NMTHC; average mg per min within day) during primary and secondary phases of composting.

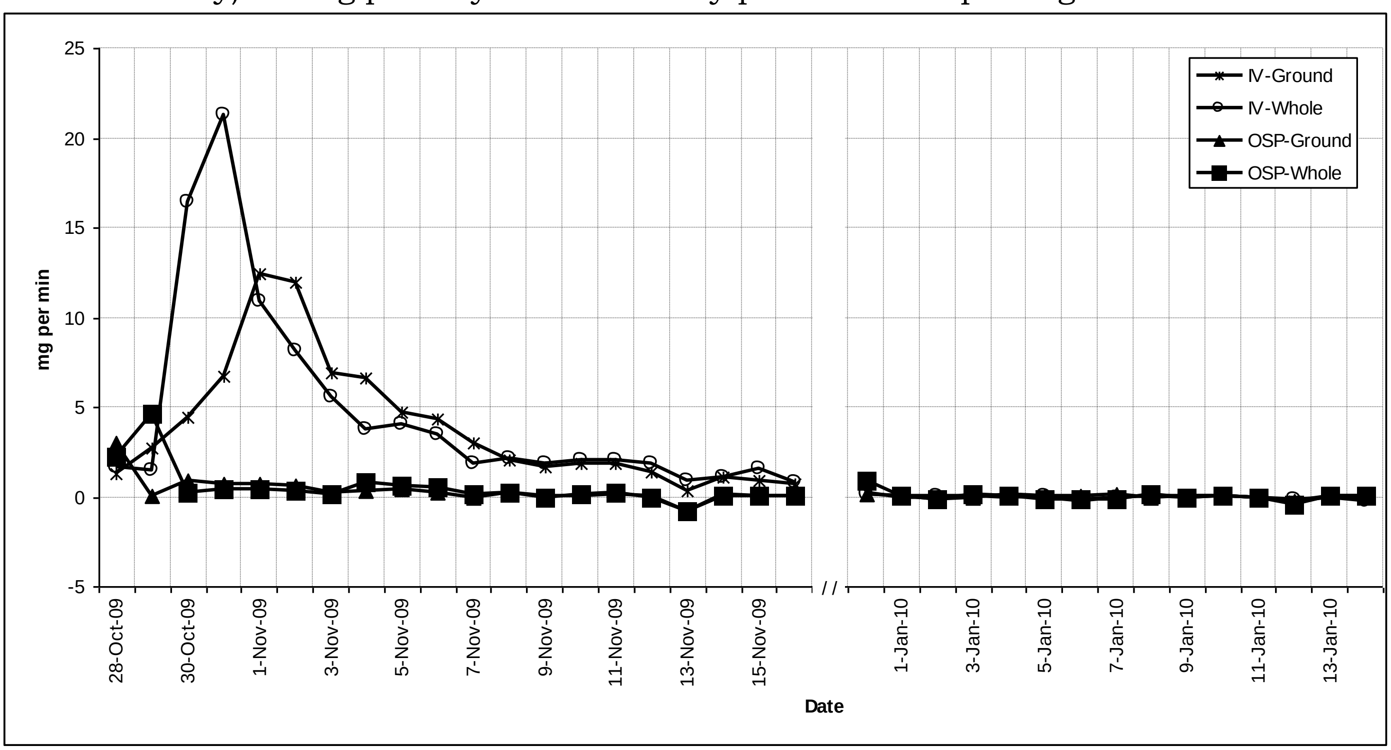


Figure 7. Emission pattern for ammonia (NH_3; average mg per min within day) during primary and secondary phases of composting.

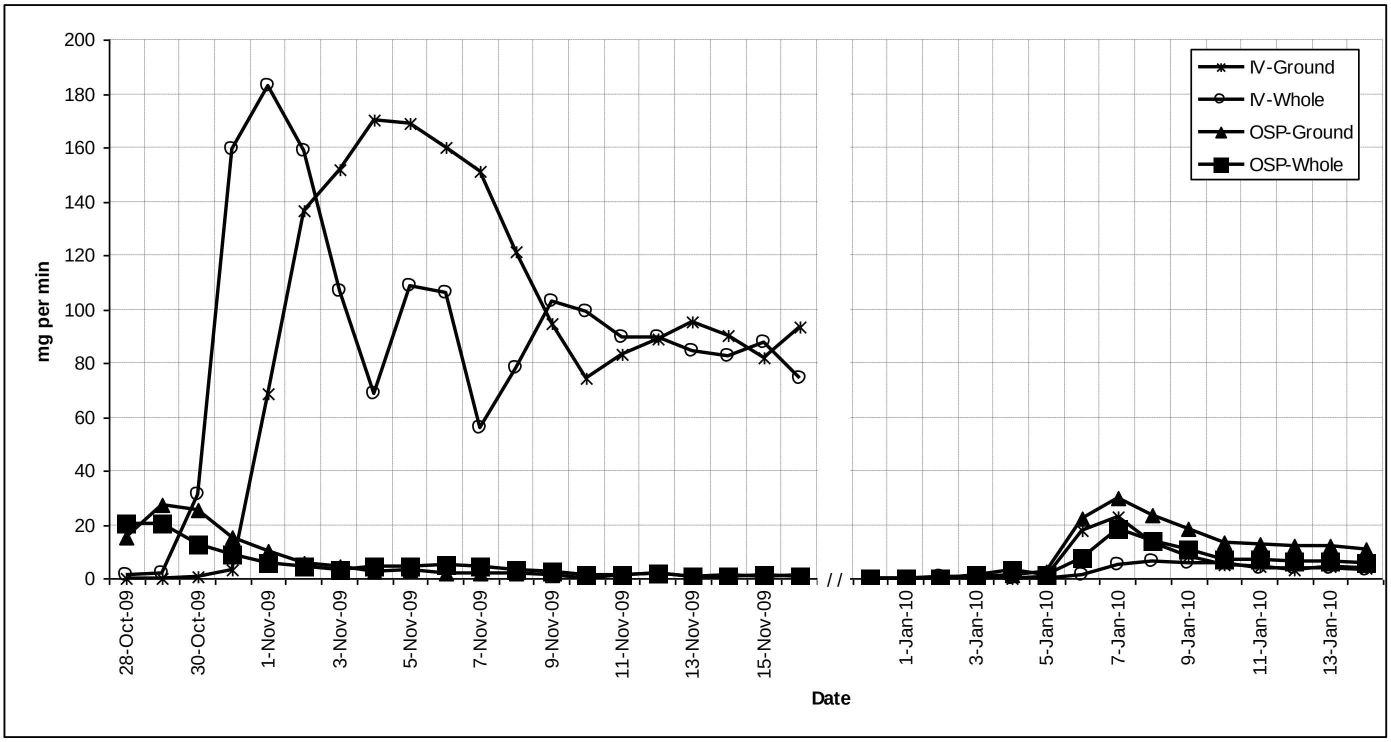


Figure 8. Emission pattern for nitric oxide (NO; average mg per min within day) during primary and secondary phases of composting.

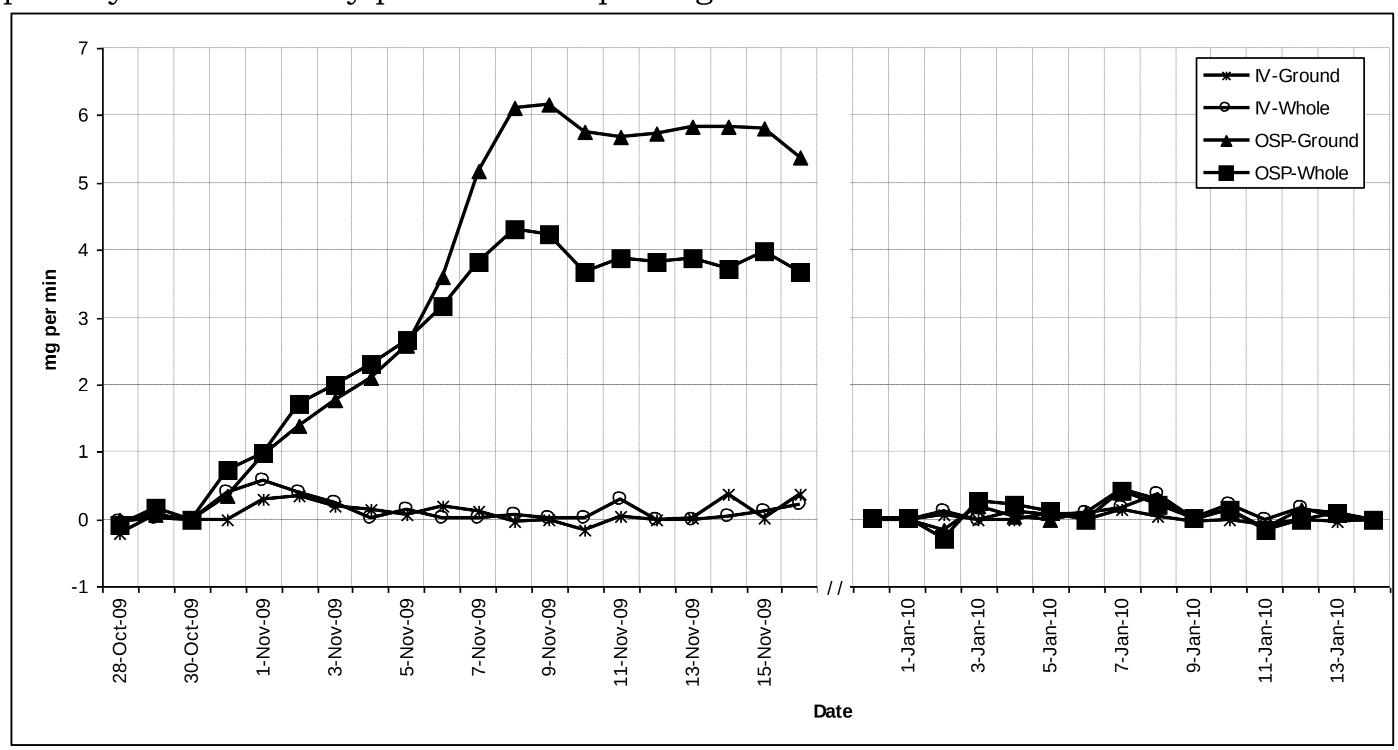


Figure 9. Emission pattern for nitrogen dioxide (NO_2; average mg per min within day) during primary and secondary phases of composting.

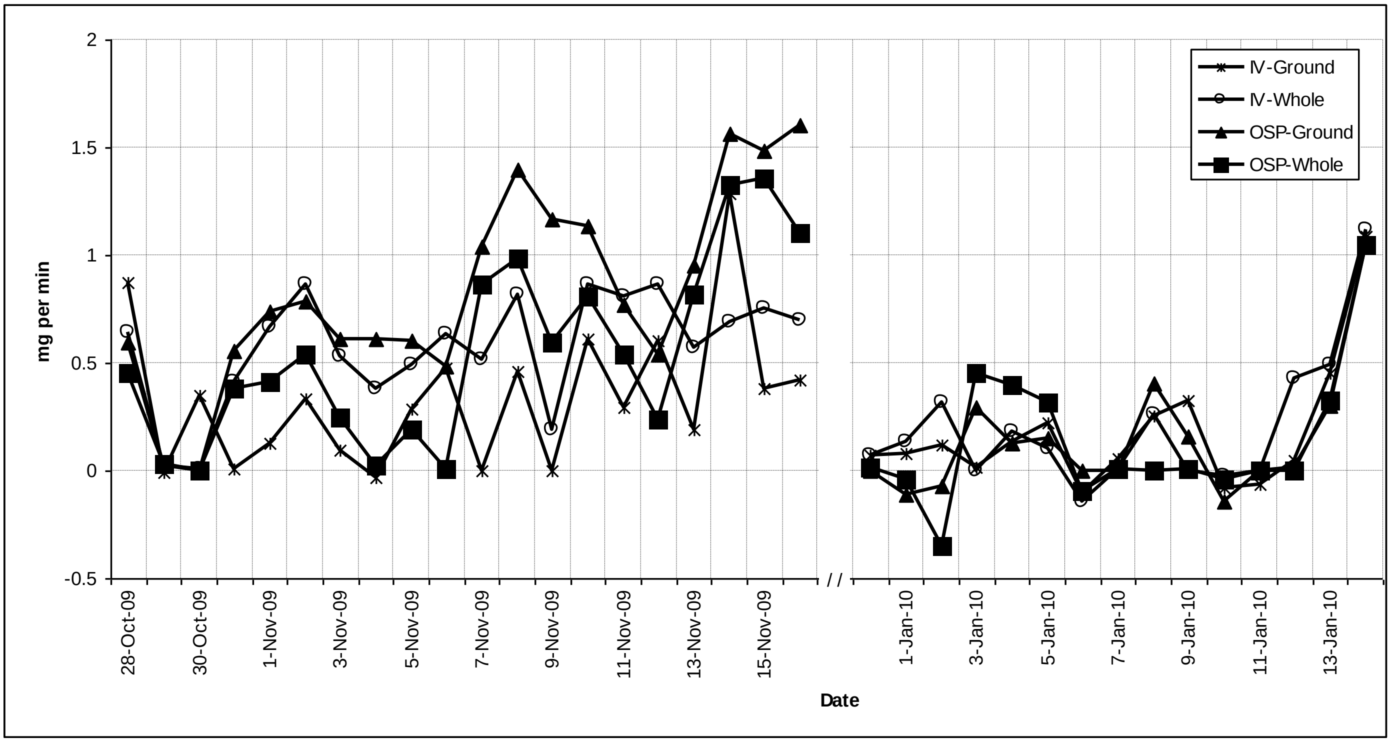


Figure 10. Emission pattern for nitrous oxide (N_2O; average mg per min within day) during primary and secondary phases of composting.

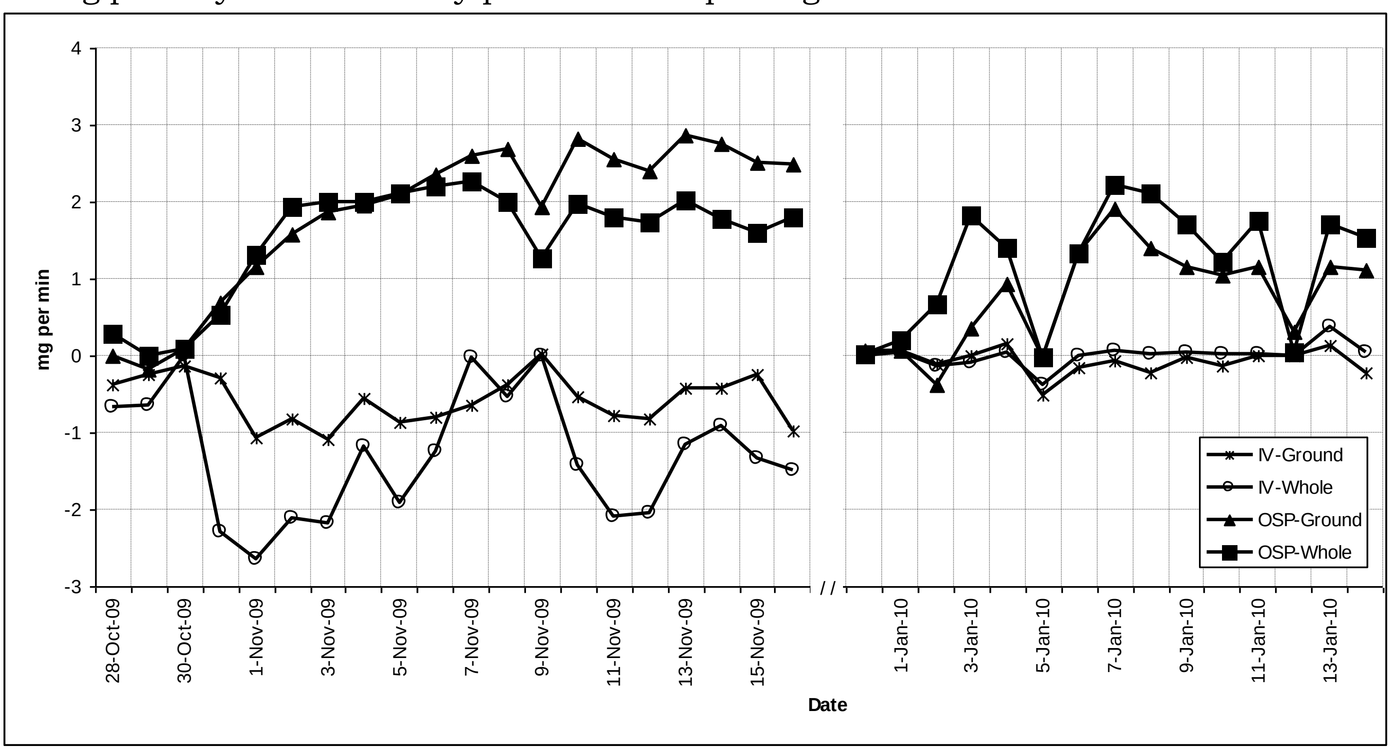


Figure 11. Emission pattern for hydrogen sulfide (H_2S; average mg per min within day) during primary and secondary phases of composting.

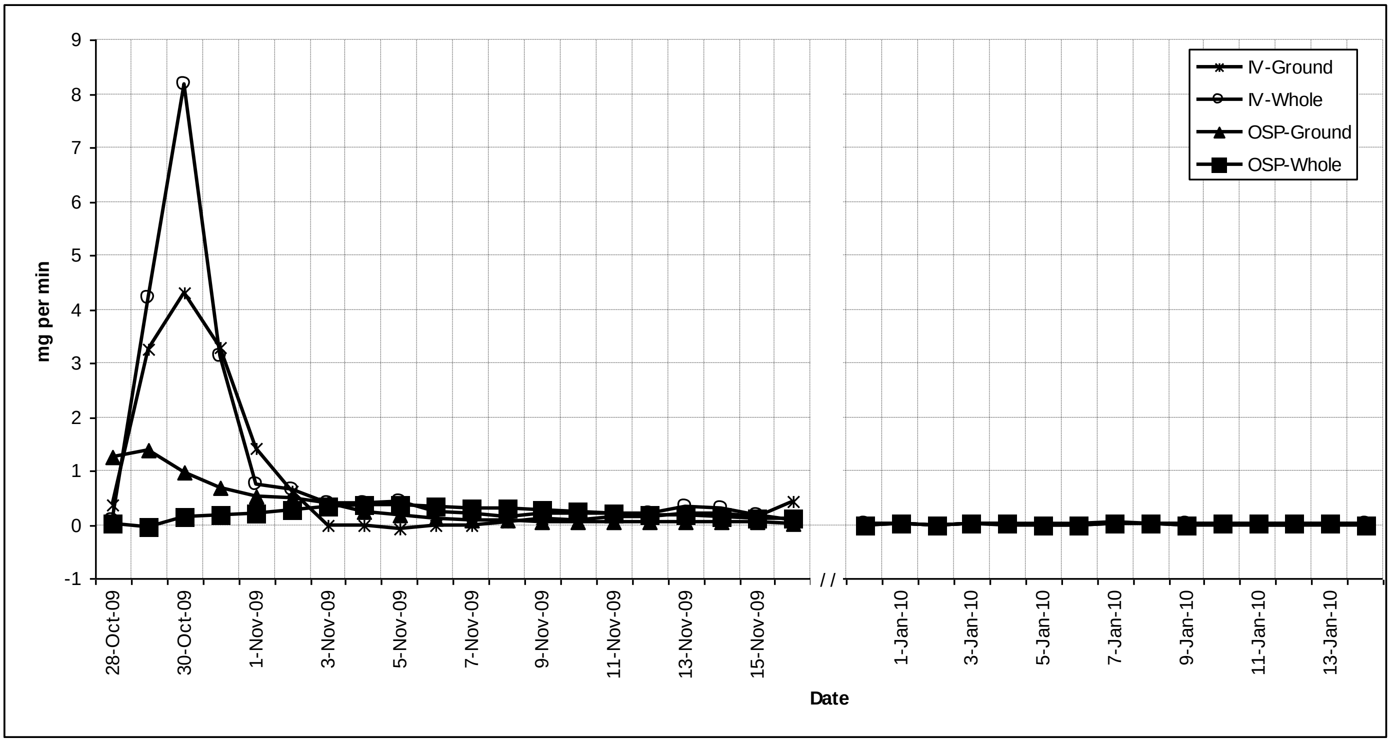
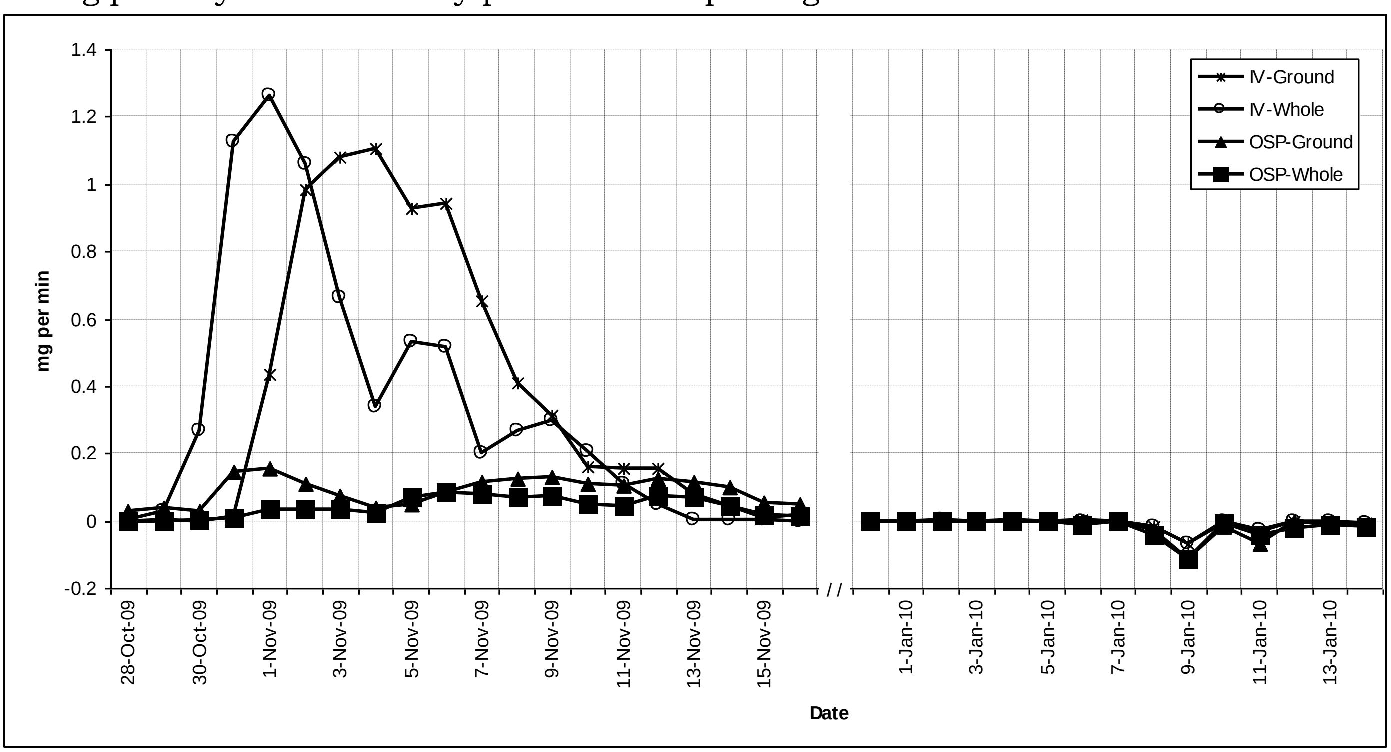


Figure 12. Emission pattern for sulfur dioxide (SO_2; average mg per min within day) during primary and secondary phases of composting.



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