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Effect of Windrow Management on Ammonia and Nitrous Oxide Emissions from Swine Manure Composting

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Abstract**—**In the era of sustainability, utilization of livestock wastes as soil amendment to provide micronutrients for crops is very economical and sustainable. It is well understood that livestock wastes are comparable, if not better, nutrient sources for crops as chemical fertilizers. However, the large concentrated volumes of animal manure produced from livestock operations and the limited amount of available nearby agricultural land areas necessitated the need for volume reduction of these animal wastes. Composting of these animal manures is a viable option for biomass and pathogenic reduction in the environment. Nevertheless, composting also increases the potential loss of available nutrients for crop production as well as unwanted emission of anthropogenic air pollutants due to the loss of ammonia and other compounds via volatilization. In this study, we examine the emission of ammonia and nitrous oxide from swine manure windrows to evaluate the benefit of biomass reduction in conjunction with the potential loss of available nutrients. The feedstock for the windrows was obtained from swine farm in Kentucky where swine manure was mixed with wood shaving as absorbent material. Static flux chambers along with photoacoustic gas analyzer were used to monitor ammonia and nitrous oxide concentrations during the composting process. The results show that ammonia and nitrous oxide fluxes were quite high during the initial composting process and after the turning of each compost pile. Over the period of roughly three months of composting, the biochemical oxygen demand (BOD) decreased by about 90%. Although composting of animal waste is quite beneficial for biomass reduction, composting may not be economically feasible from an agronomical point of view due to time, nutrient loss (N loss), and potential environmental pollution (ammonia and greenhouse gas emissions). Therefore, additional studies are needed to assess and validate the economics and environmental impact of animal (swine) manure composting (e.g., crop yield or impact on climate change).

Keywords**—**Windrow, swine manure, ammonia, nitrous oxide, fluxes, management.

I. INTRODUCTION

THE traditional practice of utilization of animal manure for fertilization of crop lands is to land applied, especially swine manure. The method of application of the liquid manure is the surface spray, in which the manure is broadcast-applied on the soil surface. This method can lead to major losses of essential nutrients for crops such as nitrogen and carbon compounds. This technique can also create a major emission problem in dispersing malodorous and other gaseous compounds in the air (i.e., ammonia and greenhouse gases such as methane, nitrous oxide, and carbon dioxide). The Intergovernmental Panel on Climate Change [1] estimates that agricultural activities, including land application of animal manures, account for about 20% of the total human induced global warming budget due to greenhouse gas (GHG) emissions. The world agricultural share of total anthropogenic emissions is approximately 50% of the anthropogenic methane, 60% of the nitrous oxide, and about 20% of the carbon dioxide in 2005 [1]. According to the USEPA [2], the agricultural sector was responsible for emissions of 454.1 teragrams of CO_2 equivalent (Tg CO_2 Eq.), or 6 percent of total U.S. greenhouse gas emissions in 2006.

In the era of sustainability, utilization of livestock wastes as soil amendment to provide micronutrients for crops is very economical and sustainable. It is well understood that livestock wastes are comparable, if not better, nutrient sources for crops as chemical fertilizers [3], [4]. However, the large concentrated volumes of animal manure produced from livestock operations and the limited amount of available nearby agricultural land areas necessitated the need for volume reduction of these animal wastes. Composting of these animal manures is a viable option for biomass and pathogenic reduction in the environment. Nevertheless, composting also increases the potential loss of available nutrients for crop production as well as unwanted emission of anthropogenic air pollutants due to the loss of ammonia and other compounds via volatilization [5]-[9].

Ammonia and nitrous oxide emissions and their subsequent deposition can be a major source of pollution, causing nitrogen enrichment, acidification of soils and surface waters, aerosol formation, photochemical air pollution, reduced visibility, ecosystem fertilization, global warming, and stratospheric ozone depletion. A number of studies have evaluated the effects of nitrogen deposition. Significant excess nitrogen deposition has occurred in the eastern coastal areas of the United States [10]. A particular area of concern is the coastal rivers and their estuaries. This excess nitrogen can result in toxic and non-toxic phytoplankton blooms, which can lead to fish kills and reductions of ‘clean water’ species [10]. Furthermore, the atmospheric deposition constitutes a large part of the overall load in these waters and is therefore an important source for fixed nitrogen [11].Soil acidification is

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another problem. Van Breeman et al. [12] identified the deposition of ammonium sulfate ($(NH_4)_2SO_4$) as the main cause of soil acidification in the Netherlands. Research conducted by Barthelmie and Pryor [13] in the Lower Fraser Valley, British Columbia, Canada showed that NH_3 and NH_4^+ species and emissions play a particularly critical role in visibility degradation. Fine particulate aerosols have also been linked to human respiratory health problems. Studies suggest that the smaller the particle the greater the potential health effect. For example, Lippmann [14] found fine particles ($PM_{2.5}$) to be more toxic than coarse particles (PM_{10}-$PM_{2.5}$). Donaldson and MacNee [15] examined ultra-fine particles (<100nm) and found that toxicity increases as particle size decreases.

Although there have been several studies that have shown the emissions of ammonia and greenhouse gases from livestock wastes [16]-[19] and their subsequent composting [5]-[9] to reduce biomass, there is a lack of knowledge about the ammonia and nitrous oxide emissions from swine waste composting since, most often time, swine slurry has less than 10% solid which make composting very difficult. Therefore, the objective of this study is to examine the various windrow management, in particular the turning frequency of the compost piles, on the ammonia and nitrous oxide emissions from the composting of swine slurry amended with woodchip absorbent materials.

II. MATERIALS AND METHODS

A. Swine Waste Mixture and Windrow

Swine waste mixed with woodchip absorbent (or bedding) materials was obtained from a high-rise slatted floor swine housing in Kentucky. During the fattening of hogs (roughly about 3000), the bedding materials were added to the underneath slatted-high-rise swine housing to absorb urine and fecal matters. These litter materials were turned every week and removed from the housing once deemed saturated. These litter materials were then used as the feedstock for the windrow composting. The feedstock consisted of roughly 60% moisture, 40% dry matter, dry organic matter of about 70%, carbon to nitrogen ratio of about 11, and pH of about 8.1. The windrows were constructed on clayey soil with about 2m by 1m by 10m (width, height, and length, respectively) as shown in Fig. 1. The composting process was carried out during the summer months of July to September with the observed ambient temperatures ranged from 20 to 30^{o}C.

B. Gas Measurement and Analysis

The fluxes (computed via concentration emissions) of ammonia and GHG (e.g., CO_2, CH_4, and N_2O) were measured using a closed-chamber technique [20]-[22]. The chambers used were made of aluminum and measured 10cm tall. At each flux measurement time the chambers were placed on fixed anchors (38cm wide and 102cm long). Each flux chamber covers a similar amount of surface area (ca. 3876 cm^2). Ammonia and GHG concentrations such as methane, nitrous oxide, and carbon dioxide were monitored using a Photoacoustic Gas Analyzer (Innova model 1412, Innova AirTech Instruments A/S, Denmark). However, only ammonia and nitrous oxide will be reported and discussed in this study. The Innova 1412 multi-gas analyzer was setup with a 1-second sampling integration time and fixed flushing time: 2 seconds for the chamber and 3 seconds for the tubing. The required time to complete one sampling cycle for ammonia, carbon dioxide, methane, nitrous oxide, and dew-point temperature measurements was approximately 70 seconds. The response time of the analyzer to step changes in gas concentrations was tested. The gas analyzer has a built-in compensation for water and cross interferences. The gas analyzer was tested using a pre-mixed standard of gases. The tested concentrations ranged from 90% to 94% of standards for all gases.

Fig. 1 Photo of swine manure compost piles

Gas fluxes were measured before and after turning of each compost pile. At least two flux chambers were utilized for each compost piles. The concentrations were measured every half hour (broken down into 10-minute periods) with half hour allocation to attain equilibrium with the atmospheric conditions between sampling periods. Three windrow management scenarios were set up using four compost piles: 1) Static condition pile, 2) turning compost pile once a week, 3) turning compost pile three times a week, and 4) turning the compost pile as needed (usually based on temperature above 55^{o}C). Gas fluxes were calculated based on Fickian diffusion as explained in the next section. Comparison of linear and non-linear regression of calculated gas fluxes was carried out using equations in the following section. Statistical analysis was performed using STATISTICA (ver. 7.0, Statsoft, Tulsa, OK). Tukey's test was used to determine the significant differences among the means of gas fluxes at the 5% significance level.

C. Computation of Gas Fluxes

The steady state of gas flux can be described by Fick's law of diffusion (1) [23]-[24]:

$$J = -D\frac{\partial c_i}{\partial x_i} \tag{1}$$

where J is the gas flux, D is the gas diffusivity constant, and $\partial c_i / \partial x_i$ is the vertical gradient of gas concentration.

In a closed chamber, gas flux at a certain point is a function of time (t) and concentration (C_d) at distance d (2).

$$J(t) = D\frac{(C_d - C(t))}{d} \tag{2}$$

where d is the distance from the emitting surface to the sampling point. Thus, the gas exchange rate estimated from a closed chamber is dependent on the chamber effective height (h) and the gas concentration (c_i) in the chamber (3).

$$J(t) = h\frac{\partial c_i}{\partial t} \tag{3}$$

By combining (2) and (3) and solving for C(t) with the assumption that gas distributes itself uniformly in the chamber where c_i is equal to C(t), the changes in gas concentrations in the chamber follow an exponential form (4):

$$C(t) = B\exp(-kt) + C_d \tag{4}$$

where B is the integration constant and k is the characteristic coefficient of the ratio of gas diffusivity constant over the effective height and distance. From (4), one can compute the normalized change (N(t)) in the gas concentration inside the chamber between initial time t and final time f. (5). Theoretically, (5) suggests that gas concentration change inside a chamber does not depend upon the initial concentration gradients, but rather on the chamber's effective height (h), diffusivity constant (D), distance (d), and time of chamber deployment (f), where $k = D/hd$.

$$N(t) = \frac{(C(t) - C(0))}{C(f) - C(0)} = \frac{\exp(-kt) - 1}{\exp(-kf) - 1} \tag{5}$$

The parameter k is determined by the effective chamber height (h) and by the surface properties relating to gas diffusivity (D) and the sampling distance (d), but not by the initial concentration gradient. Gas concentration in a chamber can also be modeled nonlinearly with few data points (6) [21].

$$J(0) = \frac{h(C(t) - C(0))^2}{0.5f(2C(t) - C(f) - C(0))}\ln[\frac{C(t) - C(0)}{C(f) - C(t)}] \tag{6}$$

where $C(0)$, $C(t)$, and $C(f)$ are the concentrations at times 0, 0.5f, and f, respectively.

For this study, we also computed the gas fluxes using the linear regression method. The instantaneous concentrations at time 0, 0.5f, and f were used to calculate gas fluxes. The slope of the concentration change was calculated from these three data points by using linear regression and then was substituted for the concentration gradient in (3).

III. Results and Discussion

Swine litter (mixture of woodchip absorbent materials and excrement) feedstock for compost piles was obtained from a fattening swine production facility in Kentucky. Windrows were constructed from this feedstock and intensive gas emissions monitoring events were carried out to examine the effect of windrow management on the ammonia and nitrous oxide fluxes. The results show that the compost pile with the most turnovers (three times per week) produce the highest ammonia flux of 5.9 ± 1.1mg per square meter per hour based on non-linear method of calculation (Fig. 2). The linear method of estimating flux resulted in smaller flux magnitude and tends not be as accurate as the non-linear method due to simple assumptions in input parameters. From here on in, the magnitudes from the non-linear method of calculation will only be mentioned and discussed (please see the figures for comparison of linear flux calculations). The ammonia fluxes range from 0.1 ± 0.1 for the static pile to 5.9 ± 1.1mg m^{-2} hr^{-1} for the thrice-per-week turning compost pile. The ammonia flux from the compost pile which was turned once a week is smaller than the compost pile that was turned "as needed" or based on temperature of usually above 55^oC ($p<0.05$). This is reasonable since the temperatures of the "as needed" compost pile were observed to reach the set temperature quite often (data not shown) at the beginning of composting, thus creating the turnover of the gases. As the compost piles were turned more often, the aerobic conditions are conducive for nitrification process to occur. Thus, higher ammonia fluxes were observed during the frequently turning of windrows as can be seen from the higher fluxes of ammonia from both thrice per week and "as needed" compost piles.

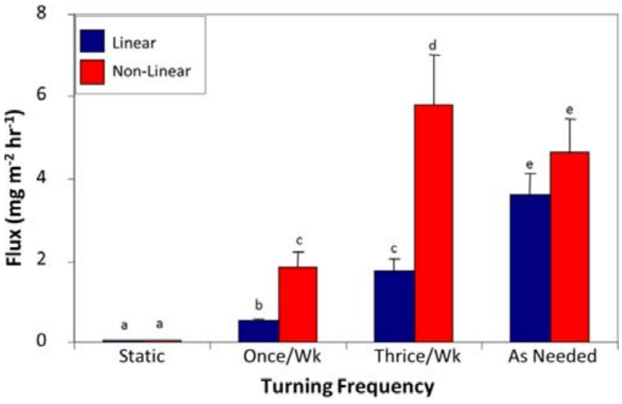

Fig. 2 Ammonia fluxes as functions of turning frequency. Linear—flux computation based on linear method. Non-Linear—flux computation based on non-linear equation. The vertical bars are standard deviations of at least 30 samples. The different letterings signify statistically different at p<0.05

For nitrous oxide, turning the compost less (once a week) appears to have the higher flux (1.1 ± 0.3mg per square meter per hour) as can be seen in Fig. 3. With the exception of static pile, it appears that the more the pile get turned the less amount of nitrous oxide flux was observed. This is understandable due to microbial activities, especially the denitrification processes. In an anoxic condition (as the inside of a windrow), nitrous oxide (one of potent greenhouse gases) can be produced from nitrite via a denitrification process. Thus, if the compost piles get turned often, there is not enough time for the anoxic conditions to prevail. Conditions are not optimum enough for denitrification to occur (less nitrous oxide can be produced) and the observed BOD (biochemical oxygen demand) was higher in this case as well (data not shown). In general, the decrease in BOD of the feedstock was observed to be more than 90% over the three months of composting. Therefore, the nitrous oxide fluxes were observed to be smaller from the compost pile with more turning (i.e., thrice per week as compared to once per week). However, the compost pile that was turned based on temperature ("as needed") should have smaller flux of nitrous oxide as well, but does not in this case. This may be explained by the fact that after the initial composting periods, the temperature of compost pile decreased quite a bit which would delay the turning of the compost pile. Hence, nitrous oxide fluxes were observed to be higher toward the end of the "as needed" compost pile (data not shown).

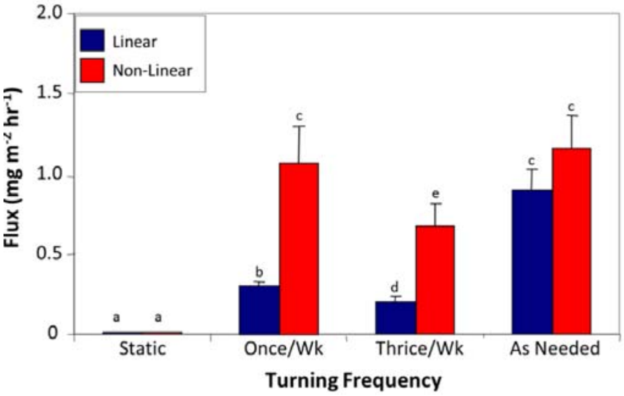

Fig. 3 Nitrous oxide fluxes as a function of turning frequency. Linear—flux computation based on linear method. Non-Linear—flux computation based on non-linear equation. The vertical bars are standard deviations of at least 30 samples. The different letterings signify statistically different at $p<0.05$.

IV. CONCLUSIONS

An experiment was carried out to examine the effect of windrow management on gas emissions, in particular ammonia and nitrous oxide, from swine manure composting. Static flux chambers and photoacoustic gas analyzer were utilized to determine the fluxes from the windrows. Results show a general trend of higher emissions of ammonia as compost piles get turned more often. On the other hand, smaller nitrous oxide fluxes were observed from the compost piles with frequent turning. This may be due to microbial activities and not necessarily due to the physical turning of the compost pile directly. Thus, further experiment is needed to elucidate the effect from biotic as well as abiotic factors on the gas fluxes from swine manure windrows as indicative by the remaining higher BOD from certain compost piles. Although composting of animal waste is quite beneficial for biomass reduction, composting may not be economically feasible from an agronomical point of view due to time, nutrient loss (N loss), and potential environmental pollution (ammonia and greenhouse gas emissions). Therefore, additional studies are needed to assess and validate the economics and environmental impact of animal (swine) manure composting (e.g., crop yield or impact on climate change).

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REFERENCES

[1] IPCC/WMO/UNEP. 2007. "Climate Change 2007: Impacts, Adaptation, and Mitigation of Climate Change: Scientific-Technical Analyses." Prepared by IPCC Working Group III. Cambridge, UK: Cambridge University Press.
[2] USEPA #430-R-07-002. 2006. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006.
[3] C.H.Burton and C. Turner. 2003. Manure management—treatment strategies for sustainable agriculture, 2nd ed. Proceedings of the MATRESA, EU accompanying measure project (2003) Silsoe Research Institute. Wrest Park, Silsoe, Bedford, UK.
[4] D.R Sloan, G. Kidder, and R.D. Jacobs. 2003. Poultry manures as a fertilizer, PS1 IFAS extension. University of Florida, Gainesville, FL, p. 241.
[5] R.T Haug. 1993. The practical handbook of compost engineering. Lewis Publishers, Boca Raton.
[6] Z Zhu, H. Dong, J. Xi, and H. Xin. 2013. Ammonia and greenhouse gas emissions from co-composting of dead hens with manure as affected by forced aeration rate. Trans ASABE. 57(1):211-217.
[7] Pagans, E., R. Barrena, X. Font, and A. Sanchez. 2006. Ammonia emissions from the composting of different organic wastes: Dependency on process temperature. Chemosphere. 62(9):1534-1542.
[8] M Mattsson. 1998. Influence of nitrogen nutrition and metabolism on ammonia volatilization in plants. NutrCyclAgroecosys. 51:35-40.
[9] C.M. Williams, J.C. Barker, and J.T. Sims. 1999. Management and utilization of poultry wastes. Rev Environ Contam. T 162:105-157.
[10] H.W Paerl. 1995. Coastal eutrophication in relation to atmpospheric nitrogen deposition: current perspectives. Ophelia. 41:237-259.
[11] L. Spokes, T. Jickells, K. Weston, B.G. Gustafsson, M. Johnsson, B. Liljebladh, D. Conley, C. Ambelas-Skjødth, J. Brandt, J. Carstensen, T. Christiansen, L. Frohn, G. Geernaert, O. Hertel, B. Jensen, C. Lundsgaard, S. Markager, W. Martinsen, B. Møller, B. Pedersen, K. Sauerberg, L.L. Sørensen, C.C. Hasager, A.M. Sempreviva, S.C. Pryor, S.W. Lund, S. Larsen, M. Tjernström, G. Svensson, and M. Žagar. 2006. MEAD: An interdisciplinary study of the marine effects of atmospheric deposition in the Kattegat. Environmental Pollution, 140 (3):453-462.
[12] N. Van Breeman, P. Burrough, E. Velthorst, H. Van Dobben, T. de Wit, T. Ridder, and H. Reijnders. 1982. Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. Nature. 299:548-550.
[13] R.J. Barthelmie, and S. Pryor. 1998. Implications of ammonia emissions for fine aerosol formation and visibility impairment—A case study from the Lower Fraser Valley, British Columbia. Atmospheric Environment. 32:345-352.

[14] M. Lippmann. 1998. The 1997 US EPA standards for particulate matter and ozone. In: Hester, R.E. and Harrison, R.M. (Eds.), Issues in Environmental Science and Technology. 10:75-79.
[15] K. Donaldson and W. MacNee. 1998. The mechanisms of lung injury caused by PM10. In: Hester, R.E. and Harrison, R.M. (Eds.), Issues in Environmental Science and Technology. 10:21-32.
[16] C.J. Dore, B.M.R. Jones, R. Scholtens, J.W.H. Huisin’t Veld, L.R. Burges, and V.R. Phillips. 2004. Measuring ammonia emission rates from livestock buildings and manure stores—Part 2: Comparative demonstrations of three methods on the farm. Atmospheric Environment. 38:3017-3024.
[17] R. Scholtens, C.J. Dore, B.M.R. Jones, D.S. Lee, and V.R. Phillips. 2004. Measuring ammonia emission rates from livestock buildings and manure stores—Part 1: Development and validation of external tracer ratio, internal tracer ratio and passive flux sampling methods. Atmospheric Environment. 38:3003-3015.
[18] J. Webb. 2001. Estimating the potential for ammonia emissions from livestock excreta and manures. Environmental Pollution. 111:395-406.
[19] N.C. Lovanh, J.G. Warren, and K.R. Sistani. 2009. Determination of Ammonia and Greenhouse Gas Emissions from Land Application of Swine Slurry: A Comparison of Three Application Methods. Bioresource Technology. 101:1662–1667.
[20] A.R. Mosier, and L. Mack. 1980. Gas chromatographic system for precise, rapid analysis of N2O. Soil Sci. Soc. Am. J. 44: 1121-1123.
[21] G.L. Hutchinson and A.R. Mosier. 1981. Improved soil cover method for field measurement of nitrous oxide fluxes. Soil Sci. Soc. Am. J. 45: 311-316.
[22] A.R. Mosier, D.S. Schimel, D.W. Valentine, K.F. Bronson, and W.J. Parton. 1991. Methane and nirous oxide fluxes in native, fertilized and cultivated grasslands. Nature 350: 330-332.
[23] R.E. Treybal. 1980. Mass-Transfer Operations, McGraw-Hill Inc.
[24] R.B. Bird, W.E. Stewart, and E.N. Lightfoot. 1960. Transport Phenomena, John Wiley & Sons, Inc.