

NITROGEN LOSS (NH₃, N₂O) PATTERNS IN BENCH-SCALE COMPOSTING

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SUMMARY: Nitrogen (N) losses during composting reduce the value of the end product as a fertilizer. Nitrogen is lost during composting mainly by ammonia (NH₃) volatilization in the thermophilic phase. We used three bench-scale aerobic bioreactors with a controlled temperature difference (CDT) system as an experimental approach to investigate the pattern of N losses during composting. N₂O peak emission occurred much earlier (7h) than NH₃ volatilization (48-60h) during the thermophilic phase (~55°C) of bench-scale composting. The NH₃ volatilization peak rate occurred following the greater biological activity (O₂ consumed/CO₂ evolved) at 40°C which could coincide with greater ammonification, but immobilization of NH₄⁺/NH₃ also occurs at this point affecting NH₃ volatilization. Differences in temperature curves and accumulated NH₃-N were related to the biological activity in each vessel. Therefore, O₂ consumed/CO₂ evolved measurements must be part of the evaluation of composting in further studies for comparisons of techniques to reduce NH₃ volatilization.

Keywords: horse manure, bioreactors, respirometric method.

INTRODUCTION

Composting of agricultural/agro-industrial wastes is a major process to produce organic and organo-mineral fertilizers, and compost is the major soil amendment for certified organic farming systems. However, the nitrogen (N) losses during composting reduce the value of the end product as a fertilizer. Nitrogen is lost during composting mainly by ammonia (NH₃) volatilization in the thermophilic stage that can account for 60 to 99% of total N losses (Liang et al., 2006), while nitrous oxide (N₂O) accounts for less than 5.0% to 22% of N losses (Fukumoto et al., 2011), depending on the composting conditions. A wide variation of total N losses might be expected in both laboratory- and full-scale composting. Many parameters affect NH₃ volatilization such as substrate composition, pH, temperature, aeration, and moisture content. Various techniques have been proposed to reduce NH₃ volatilization and enhance the value of compost as fertilizer e.g. struvite crystallization by addition of Mg and P salts (Jeong and Kim, 2001). However, little attention has been given to a comparative assessment of the efficacy of NH₃ mitigation techniques. Diverse units used by different authors make direct comparisons difficult. Moreover, erroneous conclusions could be made when biological activity is not taken in account or comparisons are made between treatments having different biological activities or ammonification rates. An appropriate experimental approach seems to be crucial to assess the composting process. Bench-scale aerobic bioreactors have been used for many proposes in composting studies and it seems to be useful for N loss comparisons. In this abstract we report the results of NH₃ volatilized and N₂O emitted from a bench-scale composting system which will be used in further studies for comparisons of techniques to reduce NH₃ volatilization during composting.

MATERIAL AND METHODS

Three bench-scale cylindrical bioreactors (3.0 L) of polypropylene equipped with insulation and electrical resistance tape were used to contain the composting process. Forced aeration was controlled by a rotometer coupled with a pressure regulator (ASA®) and monitored by a digital fluxometer (Omega®) at 150 and 50 ml min⁻¹ during the first 0-120h (0-5d) and 121-240h (6-10d), respectively. Temperature was controlled by a temperature differentials method (Magalhães et al., 1993) using Microsoll® II plus and Sitrad® software (FullGauge®) which also programmed the sampling of the exhaust air by a multi-sampler equipped with solenoid valves. Biological activity within each vessel was monitored by a respirometric method using an in-line O₂-zirconia sensor and CO₂ infra-red sensor (SST® Sensing). The air inlet was humidified prior to entry into the vessel and the air outlet was passed through an acid trap (0.5M H₂SO₄, 100ml, renewed each 6 hours) and a silica gel filter prior to gas sensing. Respirometry and flow meter data were stored in a datalogger (Campbell®).

Aerobic-thermophilic composting was carried out for 10 days. Each vessel contained approximately 1000 g wet weight with 70% moisture of a 2:1 mixture (wet basis) of horse bedding manure and hydroponic lettuce (chopped leaves). The maximum temperature was set at 55°C. Volatilized NH₃ was determined by a distillation/titration method. Gas samples were collected with syringes at 25, 30, 40, 50, 55°C for N₂O analysis by gas chromatography. Solid samples were taken at 0, 1, 5 and 10 days for further chemical analysis.

RESULTS AND DISCUSSION

The three simultaneous composting runs showed typical temperature curves, with an exponential increase of temperature reaching 56.0-57.1°C within 18 hours. Despite the similarity in temperature curves, bioreactor #1 had a faster temperature increase and a shorter thermophilic phase than the other two vessels (Fig.1A). After 10 days the organic material showed different visual and odor characteristics than the feedstock, and the lettuce leaves were totally decomposed. The loss of total dry mass was around 43.0 g (±0.7) or 14.3% (±0.3) of the initial dry mass and the greater proportion of dry mass was lost in the first 5 days. Biological activity was intense and similar among replicates, but with slight differences. O₂ consumption reached its peak at 40°C (6h) within a range of 8 to 10% (Fig. 3). O₂ consumption/CO₂ evolved data showed that the smaller biological activity coincided with the shorter thermophilic phase of bioreactor #1 (Fig.1 and Fig.2).

Nitrous oxide peak emission occurred much earlier (7h) than peak ammonia volatilization during composting (48-60h). Nitrous oxide (N₂O) emission was inversely related to O₂ consumption and initial temperature increase (20 to 40°C). The initial emission rate may be mainly related to the emission of N₂O previously formed, emission being favored by forced aeration. A rapidly increasing N₂O emission occurred at >40°C at the highest O₂ consumption rate and the peak emission rate occurred just when the temperature reached 55°C (Fig.1B). Therefore, the peak N₂O concentration was probably due to denitrification of nitrite/nitrate produced by the biodegradation of organic material and dead microbial biomass. Bioreactor #3 showed a different emission pattern (Fig.1B) for which there is presently no apparent explanation. Nitrite accumulation has been related to N₂O emissions during the mesophilic (maturation) phase (Fukumoto et al., 2011). However, this pattern of emission was not observed in our bench-scale experiment, most likely due to the aerobic conditions (aeration) or the absence of nitrite accumulation.

Ammonia volatilization curves were similar with rapidly increasing rates between 12 and 60h during the thermophilic stage (Fig.3A), except for bioreactor #1. However, the cumulative amount of NH₃ trapped was different among replicates (Fig.3B). This

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difference might be attributed to the different temperature curves (shorter thermophilic phase) and biological activity (lower O₂ consumption/CO₂ evolved), which was pronounced for bioreactor #1. Nevertheless, 50 and 90% of the NH₃ volatilized was measured around 60 and 120h for all replicates (Fig. 3B). The pH rose from 7 to 8.3-8.4 which favors NH₃ volatilization. The pH also varied consistently (7 to 7.2-7.3) during the initial thermophilic temperature increase (40-55°C).

The ammonia volatilization peak rate occurred following the greater biological activity i.e. the peak O₂ consumed/CO₂ evolved which could coincide with greater ammonification, but immobilization of NH₄⁺/NH₃ also occurs at this point affecting NH₃ volatilization (Sasaki et al., 2005). Therefore, the peak volatilization rate was at 55°C (48-60h) when pH was higher but thermophilic biological activity was less intense than the mesophilic biological activity (<40°C). We hypothesize that most of the NH₃ volatilized came from the dead microbial biomass during the mesophilic/thermophilic temperature transition. However, the effect of temperature (>50°C) on the diffusion coefficient of gases must be taken in account. The high pH drives the relatively high NH₃ volatilization during the mesophilic (maturation) phase and the reduced air flow (low O₂ demand) sharply reduced NH₃ volatilization during this stage.

CONCLUSIONS

NH₃ volatilization and N₂O emission occurred during the thermophilic phase of bench-scale composting as expected. However, an unexpectedly high variation of accumulated N losses was found among replicates. Differences in temperature curves and accumulated NH₃-N were related to the biological activity in each vessel. Therefore, O₂ consumed/CO₂ evolved measurements were a useful parameter for evaluation of the composting process, which should be part of further studies for comparisons of techniques to reduce NH₃ volatilization during composting. Furthermore, considering that NH₃ volatilization is a major fractionation process of ¹⁵N, large variations of stable isotope signatures (δ¹⁵N) are expected to be found in evolved NH₃ (Lee et al., 2011) of compost during the thermophilic phase, and δ¹⁵N values of compost could be used to estimate N losses.

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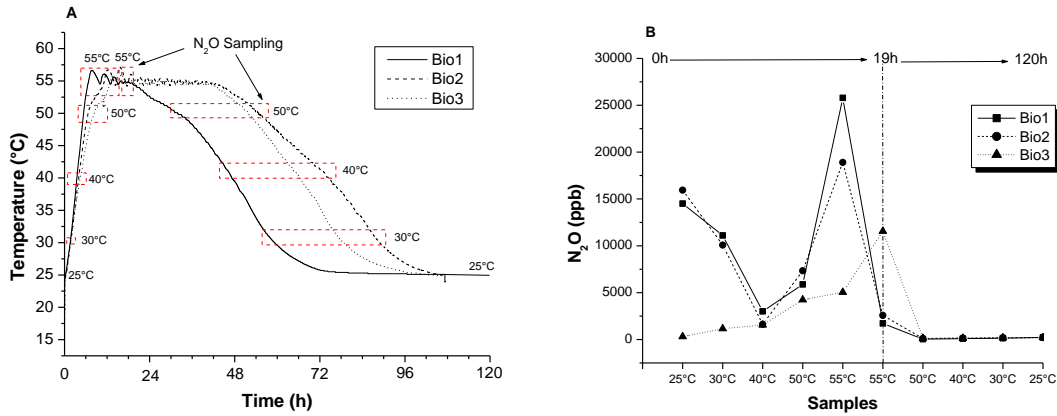


Figure 1. Temperature curves and sampling strategy of gas samples (A) and N₂O emission results (B) of bench-scale composting of horse bedding manure and lettuce leaves.

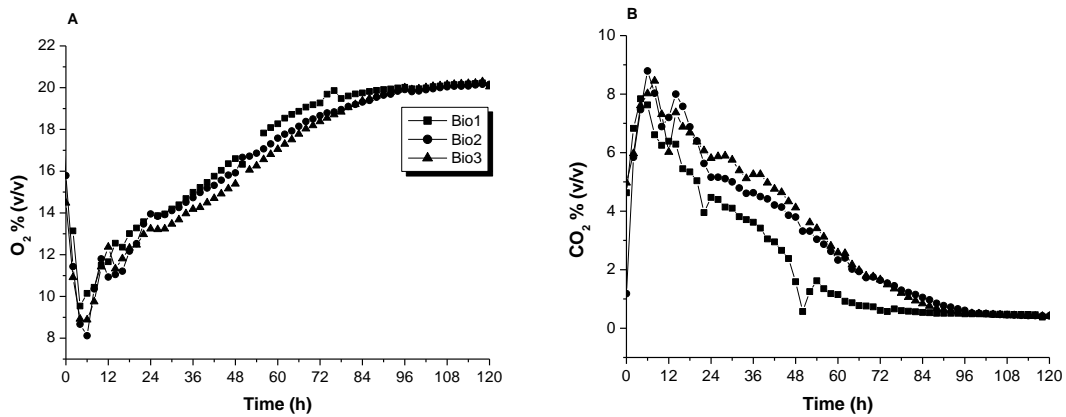


Figure 2. Biological activity of bench-scale composting of horse bedding manure and lettuce leaves. Respirometry by in-line sensor of (A) O₂ consumed and (B) CO₂ evolved.

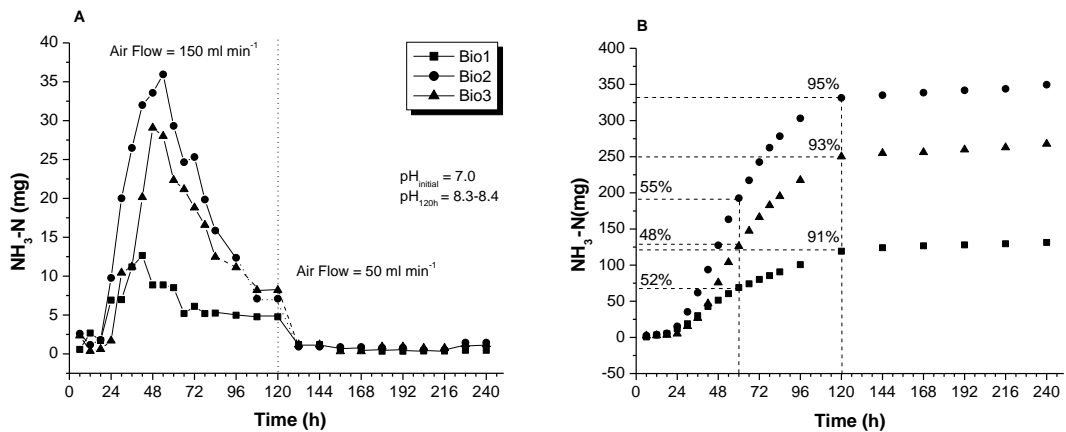


Figure 3. Ammonia volatilization in bench-scale composting of horse bedding manure and lettuce leaves. (A) NH₃-N volatilization rate (6h intervals), (B) Cumulative NH₃-N losses.