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Compost mineralization in soil as a function of composting process conditions

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Keywords
compost decomposition, mineralization, organic substrates, denitrification

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Compost mineralization in soil as a function of composting process conditions

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Abstract

Compost has been shown to have a range of positive impacts on soil quality and can provide an important source of nutrients for plants. While these benefits have been documented for many finished composts, there is presently little understanding of the impact of composting process conditions and the extent of compost decomposition on soil C and N mineralization after compost incorporation. This study evaluated the impact of composting process conditions and the extent of compost decomposition on soil C and N mineralization after compost incorporation. Dried, ground composts were blended with equal parts of quartz sand and soil and incubated aerobically for 28 d at 30 °C. Cumulative respired CO_2–C and net mineralized N were quantified. Results indicate that (1) organic substrates that did not degrade due to sub-optimal conditions during the composting process can readily mineralize after incorporation in soil; (2) C and N cycling dynamics in soil after compost incorporation can be affected by compost feedstock, processing conditions, and time; and (3) denitrification after compost incorporation in soil can limit N availability from compost.

1. Introduction

Environmental, economic and socio-political pressures on the swine industry are forcing many producers to re-evaluate their manure management systems and consider alternative technologies. Deep-bedded manure management systems, and especially hoop structures [8], have seen tremendous growth in the last 5 years in North America. Hoop systems allow economically competitive swine production with greatly reduced capital investment, and appear to also provide reductions in odor emissions and water quality risks [14]. Typical management of hoop systems produces a manure/bedding mixture which is ideally suited for composting, with incidental composting even occurring within the hoop bedded pack and whenever the mixture is stored in piles of moderate size prior to spreading on the field [21].

While composting offers several advantages for subsequent manure management [20], the effect on nitrogen quantities and availability is less certain. Composting results in the loss of manure nitrogen through ammonia volatilization, denitrification, and leaching [5,9,13], all of which hinder efficient nutrient recycling.

In addition to affecting the quantity of nitrogen lost, the composting process also affects the availability of nitrogen and other nutrients when the compost is applied to the field. While nitrogen dynamics during the composting process have been investigated by a number of researchers [2,10,22,26], relatively few studies have evaluated the continuing dynamics of nitrogen after the compost is incorporated in soil [7].

Mineralization of composted manure C and N in soil can be described by first-order reaction kinetics. Nitrogen mineralization generally occurs in two phases, a rapid exponential immobilization or mineralization phase, followed by a slow linear mineralization phase [1,3,6,25]. Mineralization of composted manure C is coupled with these processes in soil. The C:N ratio of the composted manure determines whether

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immobilization or mineralization will dominate in the early stages of decomposition.

The rate of inorganic N release to the soil from composted manure depends on the rate of decomposition of the manure organic matter and on subsequent turnover of the decomposed C and N in soil [6]. Manure inorganic N has traditionally been used as an indicator of plant-available N in the first growing season after application. Fresh manure has higher inorganic N concentrations and, in one previous study, higher net N mineralization rates than composted manure, and as a result, N recovery by plants in the first growing season was found to be higher from fresh manure than from composted manure [19]. Release of plant-available N from manure in the soil is controlled by the balance of N immobilization and mineralization, which in turn, is controlled, to a large extent, by the C/N ratio of the decomposing organic material.

There are relatively few studies in the literature that evaluate the impact of composting process conditions and the extent of compost decomposition on soil C and N mineralization after compost incorporation. This study evaluated post-incorporation effects, using composts from experiments that examined the effects of moisture, C/N ratio, and two alternative strategies on N conservation during the composting process. The alternative strategies examined were (1) incorporation of moderate-to-high cation exchange capacity soil in the compost mixture and (2) use of a layer of stabilized compost on the surface of the pile as a passive "biofilter" to trap ammonia as it exits the pile [23]. These strategies are applicable for simple on-farm windrow composting technology and can be accomplished using readily available materials.

2. Materials and methods

2.1. Compost production

Each of the three trials reported in this paper consisted of four treatments of swine manure-straw mixtures from deep-bedded swine hoop structures. Hoop structures can use a variety of bedding materials and have been adapted to various phases of swine production. The manure used in these trials came from structures designed for raising finishing pigs for market and used corn stover (dry stalks, baled after grain harvest) for bedding. The first trial examined the effect of moisture by adding water to the mixture, the second trial varied the C/N ratio by adding additional corn stover, and the third trial evaluated two nitrogen-conserving strategies on N conservation during the composting process. These strategies included (1) blending in 20% topsoil (dry basis) to the mix, and (2) covering the compost with a 0.15 m layer of mature compost as a biofilter cover. Bedded manure was collected from hoop structures immediately after the animals were marketed, when the bedded pack is normally removed and windrow composting would begin on-farms. Since the trials were done in series, the bedded manure used as an initial feedstock came from different hoop structures at different times of the year. To assess the resulting variability in feedstock among trials, one treatment in each trial was always a control of unadjusted feedstock. Details on the treatments in each trial, along with bioreactor identification, and chemical characterization of the compost throughout the trials are indicated in Tables 1 (trial I), 2 (trial II) and 3 (trial III).

For each trial, three replicates of each treatment were composted for 6 weeks in a set of twelve 90 l insulated bioreactors. The bioreactors were unloaded and mixed manually each week, at which time a 650 g composite of five sub-samples was collected after mixing. Samples were refrigerated immediately after collection and homogenized within 3 h in a commercial food processor. Compost water content of homogenized sub-samples was determined gravimetrically after oven-drying at 75 °C. Additional sub-samples of the homogenized compost were removed for inorganic N ((NO_2 + NO_3) + NH_4) analysis, laboratory incubation studies, and total C and N analysis.

2.2. Laboratory methods

Bulk compost samples for inorganic N analysis were extracted immediately or frozen until 3 h prior to extraction. Five replicate sub-samples were removed from each respective bulk sample, extracted with 2 M KCl (1:80 compost:solution ratio), and the filtrates were frozen prior to analysis. Inorganic N ((NO_2 + NO_3) + NH_4) in the filtrates was quantified colorimetrically [12] using flow injection technology (Lachat Instruments, Milwaukee, WI, USA). The optimal compost to solution ratio was determined empirically in preliminary experiments.

Compost sub-samples were acidified prior to the preparation for total C and N analysis in order to arrest microbiological activity and prevent N loss. We added 200 ml of 0.5 N HCl to 100 g of homogenized compost and stirred the mixture with a stainless steel spoon until all of the compost was submerged. The acidified samples were dried in a fume hood for 4–5 d or until the samples were dry. The dried samples were pushed through an 8–mm sieve to break up the dried clumps of compost, and then ground in a Retsch centrifugal mill (Brinkman Instruments, Westbury, NY, USA). Total organic C (after removal of carbonates with 1 N H_2SO_4) and total N were measured in triplicate using dry combustion methods in a Carlo-Erba NA1500 NCS elemental analyzer (Haake Buchler Instruments, Paterson, NJ, USA). The ground and dried compost water content was determined gravimetrically after drying over-night at 105 °C and was used to express all data relative to the mass of dried compost.

Compost sub-samples for laboratory incubation studies were processed exactly the same way as those for total C and N analysis except they were not acidified prior to drying. Incubations were done in triplicate for each reactor, so that there were a total of nine incubations for each treatment at four extents of decomposition (0, 2, 4, and 6 weeks). For each incubation a 0.6 g sample of the dried, ground compost was placed in a small glass vial and mixed with 10 g of acid-

Table 1
Bedded manure treatments during compost trials in 90 l bioreactors: Trial I (Moisture—increased with added water)

Trial and treatments	Week	A: Control	B: Medium	C: High	D: Very High
Moisture content (%)	0	50.7 ± 3.35 a	53.3 ± 2.10 a	54.1 ± 1.71 a	60.2 ± 2.98 b
	2	63.2 ± 1.80 a	65.9 ± 1.81 a	64.9 ± 3.33 a	66.9 ± 4.54 a
	4	65.9 ± 1.25 a	68.6 ± 0.63 a	65.7 ± 12.24 a	71.6 ± 0.47 a
	6	59.8 ± 2.16 a	65.2 ± 2.44 a	64.7 ± 10.71 a	68.7 ± 0.98 a
pH	0	8.09 ± 0.06 a	8.06 ± 0.05 a,b	8.02 ± 0.02 b	8.07 ± 0.05 a
	2	8.69 ± 0.09 a	8.44 ± 0.09 b	8.42 ± 0.15 b	8.31 ± 0.14 c
	4	8.54 ± 0.09 a	8.28 ± 0.09 b	8.15 ± 0.19 c	8.19 ± 0.12b c
	6	8.32 ± 0.11 a	8.20 ± 0.05 a	8.05 ± 0.23 b	7.94 ± 0.11 b
C/N ratio	0	13.5 ± 0.2 a	13.5 ± 0.1 a	14.3 ± 0.3 b	13.7 ± 0.3 a
	2	11.9 ± 0.2 a	12.3 ± 0.9 a,b	12.4 ± 0.1 a,b	12.9 ± 0.4 b
	4	10.4 ± 0.9 a	10.9 ± 0.9 a	11.7 ± 0.7 a	12.2 ± 2.0 a
	6	9.5 ± 0.8 a	9.6 ± 1.2 a	9.3 ± 0.9 a	9.4 ± 0.5 a
Total carbon (%)	0	38.74 ± 0.41 a	38.74 ± 0.18 a,b	39.39 ± 0.24 b,c	39.51 ± 0.47 c
	2	36.61 ± 0.40 a	35.98 ± 1.99 a	35.09 ± 1.64 a	39.58 ± 0.27 b
	4	35.58 ± 1.32 a	36.52 ± 0.59 a	37.04 ± 1.27 a	37.16 ± 1.47 a
	6	34.89 ± 3.31 a	34.10 ± 3.53 a	33.12 ± 0.71 a	31.15 ± 1.23 a
Total nitrogen (%)	0	2.86 ± 0.02 a	2.88 ± 0.02 a	2.76 ± 0.07 b	2.88 ± 0.06 a
	2	3.08 ± 0.03 a	2.93 ± 0.08 a,b	2.84 ± 0.11 b	3.06 ± 0.09 a
	4	3.45 ± 0.21 a	3.35 ± 0.29 a	3.21 ± 0.21 a	3.08 ± 0.42 a
	6	3.67 ± 0.06 a	3.57 ± 0.14 a,b	3.58 ± 0.28 a,b	3.32 ± 0.07 b
(NH_4–N + NO_3–N) (mg/kg)	0	1567 ± 129 a	1693 ± 53 a	1716 ± 29 a	2018 ± 135 b
	2	3933 ± 252 a	4227 ± 352 a	4340 ± 150 a	4274 ± 474 a
	4	3906 ± 246 a	3845 ± 146 a	3408 ± 1038 a	3086 ± 649 a
	6	3301 ± 180 a	2842 ± 186 a	1945 ± 340 b	1988 ± 277 b

Means in the same row with different letters are significantly different ($P < 0.05$).

washed quartz sand and 10 g of 2–mm sieved air-dried soil (Clarion loam [fine-loamy, mixed, mesic Typic Hapludoll]). This ratio of compost to soil is equivalent to incorporating about 80 dry Mg of compost per hectare to a depth of 0.1 m. Baseline inorganic N was determined for the soil–compost–sand mixtures (hereafter referred to as compost mixtures) after extraction in 2 M KCl (1:5 soil:solution ratio). The compost mixtures were slowly moistened with water to 60% water-filled pore space (WFPS) and the incubation vials were placed in 4–l glass canning jars with self-sealing lids. Another small glass vial containing 3 ml of 2.5 N NaOH was placed in the glass jar to trap respired CO_2. The samples were incubated aerobically in the dark at 30 °C for 28 d. The NaOH base traps were changed at day 1, 3, 7, 14, 22 and 28 and mineralized C was quantified by back-titration using HCl after addition of $BaCl_2$ to precipitate the CO_3. The carbon mineralization measured includes CO_2–C evolved from microbial decomposition and respiration but does not include CH_4 mineralized by anaerobic processes. The CO_2–C evolved from the dissolution of carbonates in the (soil + compost + sand) mixture would also be included in the carbon mineralization estimates, but this reaction is favored only under acidic conditions. The pH of the (soil + compost + sand) mixtures was close to neutral at the start of the incubation (data not shown).

After 28 d, the entire 20.6 g sample was extracted with 2 M KCl (1:5 soil:solution ratio) and inorganic N in the filtrates was quantified using flow injection technology.

2.3. Statistical analysis

The experimental design for each reactor trial was a randomized complete block with four treatments and three replicates. We used ANOVA to determine treatment significance for each trial and Fisher's LSD mean separation to test for differences among the means. Data analysis was performed using SAS procedures [24] and curve fitting was performed with Microsoft Excel 97 (Redmond, VA).

3. Results

3.1. Bioreactor trial I

There was no significant difference in the amount of cumulative C mineralized after 28 d from the freshest or the

Table 2
Bedded manure treatments during compost trials in 90 l bioreactors: Trial II (C/N Ratio—increased with corn stover)

Trial and treatments	Week	A: Control	B: Medium	C: High	D: Very High
Moisture content (%)	0	61.6 ± 7.13 [a]	60.5 ± 3.17 [a,b]	66.0 ± 2.24 [a,b]	71.3 ± 1.94 [b]
	2	87.0 ± 5.86 [a]	94.1 ± 1.65 [a]	92.0 ± 2.10 [a]	92.6 ± 0.67 [a]
	4	65.3 ± 0.78 [a]	74.0 ± 1.37 [b]	74.3 ± 2.32 [b]	74.0 ± 2.29 [b]
	6	64.2 ± 2.26 [a]	72.0 ± 3.49 [a]	66.5 ± 7.93 [a]	73.0 ± 0.72 [a]
pH	0	8.49 ± 0.02 [a]	8.29 ± 0.19 [b]	8.21 ± 0.09 [b]	8.05 ± 0.14 [c]
	2	8.77 ± 0.11 [a]	8.15 ± 0.05 [b]	8.28 ± 0.11 [c]	8.33 ± 0.07 [c]
	4	8.57 ± 0.14 [a]	8.22 ± 0.06 [b]	8.19 ± 0.11 [b]	8.40 ± 0.16 [c]
	6	8.26 ± 0.16 [a]	8.45 ± 0.12 [b]	8.49 ± 0.29 [b]	8.69 ± 0.06 [c]
C/N ratio	0	15.3 ± 0.2 [a]	22.6 ± 5.4 [a]	38.0 ± 6.4 [b]	36.4 ± 7.1 [b]
	2	11.9 ± 0.5 [a]	22.2 ± 1.5 [b]	27.8 ± 1.1 [c]	35.7 ± 2.9 [d]
	4	10.5 ± 0.6 [a]	14.0 ± 1.2 [a]	22.4 ± 3.1 [b]	32.0 ± 4.2 [c]
	6	10.1 ± 0.6 [a]	13.1 ± 0.4 [a]	19.4 ± 2.3 [b]	28.8 ± 4.2 [c]
Total carbon (%)	0	37.22 ± 2.42 [a]	40.79 ± 2.63 [a]	45.54 ± 0.47 [b]	44.46 ± 1.34 [b]
	2	29.91 ± 1.86 [a]	40.20 ± 0.43 [b]	41.80 ± 3.52 [b]	43.97 ± 0.74 [b]
	4	28.24 ± 1.51 [a]	35.24 ± 2.21 [b]	41.51 ± 2.51 [c]	41.11 ± 3.22 [c]
	6	26.07 ± 0.53 [a]	32.67 ± 1.98 [b]	38.97 ± 1.87 [c]	43.40 ± 1.89 [d]
Total nitrogen (%)	0	2.43 ± 0.18 [a]	1.85 ± 0.29 [b]	1.19 ± 0.15 [c]	1.25 ± 0.23 [c]
	2	2.50 ± 0.38 [a]	1.82 ± 0.13 [b]	1.51 ± 0.16 [b,c]	1.23 ± 0.09 [c]
	4	2.70 ± 0.03 [a]	2.52 ± 0.06 [b]	1.87 ± 0.15 [c]	1.29 ± 0.07 [d]
	6	2.59 ± 0.16 [a]	2.49 ± 0.11 [a]	2.01 ± 0.03 [b]	1.52 ± 0.17 [c]
(NH_4–N + NO_3–N) (mg/kg)	0	4537 ± 942 [a]	3613 ± 849 [a]	1571 ± 136 [b]	622 ± 73 [b]
	2	2375 ± 686 [a]	365.33 ± 112 [b]	353 ± 39 [b]	263 ± 77 [b]
	4	372 ± 207 [a]	323.67 ± 123 [b]	340 ± 35 [b]	350 ± 81 [b]
	6	149 ± 45 [a,b]	190.33 ± 31 [a]	85 ± 31 [b]	107 ± 30 [b]

Means in the same row with different letters are significantly different ($P < 0.05$).

oldest compost mixtures for the low (control), medium, high, and very high moisture levels (A, B, C, and D, respectively). After 2–4 weeks of composting, the driest compost mixtures (A) mineralized more C compared to the other moisture levels, except for the wettest compost mixtures (D) after 4 weeks of composting (Fig. 1a).

All of the compost mixtures immobilized between 4% and 6% of the total N during the first half of the incubation. After 4 weeks, about 2% of the total N had mineralized in the low moisture compost mixture (A), but N was still being immobilized in the very high moisture treatment (D). Net N immobilization dominated in all the compost mixtures after 6 weeks of composting (Fig. 1b).

3.2. Bioreactor trial II

The lowest C/N ratio compost mixture (A) mineralized significantly less C than the other three treatments regardless of the composting time, and the medium C/N ratio mixture (B) mineralized significantly less C than the two higher C/N ratio treatments (C and D), except when the compost mixture was very young (Fig. 2a).

Note that although the initial C/N ratios reported in Table 2 for the C and D reactors are the reverse of the labeled descriptors, this was due to a high total N analysis for the original composite sample from one of the D reactors, probably due to the sampling error in this heterogeneous feedstock. This relatively high N sample resulted in a lower initial C/N ratio in the corresponding soil incubation as well. Subsequent weekly and final analysis of these reactors confirmed that the D bioreactors had the highest C/N ratios (Table 2).

All of the compost mixtures immobilized between 2% and 5% of the total N during the first half of the incubation except for the very young 15:1 C/N ratio compost (A). After 4 weeks, about 1–2% of the total N had mineralized in the two highest C/N ratio compost mixtures (C and D), but net N immobilization still dominated in the two lowest C/N ratio mixtures (A and B). Net N immobilization dominated in all the compost mixtures after 6 weeks of composting, except in the lowest C/N ratio treatment (A) (Fig. 2b).

3.3. Bioreactor trial III

The control (A) C mineralization patterns closely tracked those of the biofilter treatment (C) for the duration of the

Table 3
Bedded manure treatments during compost trials in 90 l bioreactors: Trial III (+N—Conserving Treatments)

Trial and treatments	Week	A: Control	B: Soil	C: Biofilter	D: Stover
Moisture content (%)	0	68.9 ± 3.31 [a]	63.5 ± 1.24 [b]	66.8 ± 0.61 [a,b]	64.6 ± 1.48 [b]
	2	72.2 ± 1.38 [a,b]	68.8 ± 0.91 [a]	70.2 ± 3.83 [a,b]	74.0 ± 3.07 [b]
	4	73.7 ± 0.42 [a]	69.6 ± 0.84 [b]	71.7 ± 1.13 [a,b]	73.2 ± 2.56 [a]
	6	73.2 ± 0.50 [a]	69.0 ± 1.10 [b]	72.0± 0.87 [a]	73.0 ± 2.45 [a]
pH	0	8.96 ± 0.07 [a]	8.68 ± 0.05 [b]	8.89 ± 0.03 [c]	8.72 ±0.04 [b]
	2	8.68 ± 0.05 [a]	8.64 ± 0.07 [a]	8.69 ± 0.04 [a]	7.86 ± 0.15 [b]
	4	7.56 ± 0.11 [a]	7.57 ± 0.17 [a]	7.75 ± 0.06 [b]	7.56 ± 0.02 [a]
	6	7.73 ± 0.13 [a,b]	7.63 ± 0.26 [a]	7.69 ± 0.04 [a,b]	7.82 ± 0.16 [b]
C/N ratio	0	13.6 ± 0.5 [a]	13.9 ± 0.3 [a]	14.7 ± 0.3 [a]	25.8 ± 2.9 [b]
	2	12.67 ± 0.9 [a]	12.7 ± 0.8 [a]	12.7 ± 0.4 [a]	16.7 ± 1.1 [b]
	4	13.5 ± 0.4 [a]	12.5 ± 0.7 [a]	13.9 ± 1.5 [a,b]	16.6 ± 0.0 [b]
	6	12.8 ± 0.6 [a,b]	12.4 ± 0.4 [a]	13.4 ± 0.4 [b]	14.9 ± 0.2 [c]
Total carbon (%)	0	39.28 ± 4.41 [a]	34.65 ± 0.14 [b]	37.83 ± 0.48 [a,b]	40.67 ± 0.95 [a]
	2	37.63 ± 2.34 [a]	30.02 ± 0.91 [b]	36.39 ± 0.81 [a]	41.52 ± 1.51 [c]
	4	33.39 ± 0.66 [a]	26.19 ± 1.65 [b]	32.65 ± 1.79 [a]	41.99 ± 2.34 [c]
	6	32.92 ± 1.38 [a]	26.21 ± 1.04 [b]	34.38 ± 1.26 [a]	39.80 ± 0.47 [c]
Total nitrogen (%)	0	2.88 ± 0.23 [a]	2.48 ± 0.03 [b]	2.57 ± 0.09 [b]	1.59 ± 0.15 [c]
	2	2.98 ± 0.33 [a]	2.38 ± 0.14 [b]	2.86 ± 0.07 [a]	2.48 ± 0.10 [b]
	4	2.48 ± 0.13 [a]	2.09 ± 0.05 [b]	2.35 ± 0.15 [a]	2.56 ± 0.17 [a]
	6	2.57 ± 0.02 [a]	2.12 ± 0.09 [b]	2.57 ± 0.14 [a]	2.66 ± 0.02 [a]
(NH_4–N + NO_3–N) (mg/kg)	0	4408 ± 423 [a]	3844 ± 153 [b]	4243 ± 35 [a,b]	4201 ± 85 [a,b]
	2	4602 ± 679 [a]	3609.33 ± 166 [b]	4066.33 ± 235 [a,b]	723 ± 101 [c]
	4	3508 ± 2306 [a]	1328.67 ± 739 [a]	1607.67 ± 887 [a]	2212 ± 1180 [a]
	6	699 ± 190 [a]	633.67 ± 225 [a]	409.33 ± 60 [a]	511 ± 338 [a]

Means in the same row with different letters are significantly different ($P < 0.05$).

composting process. The compost mixed with corn stalks generally mineralized the most C throughout the incubation and the soil treatment (B) generally mineralized the least C throughout the incubation. The biofilter treatment (C) and the compost mixed with corn stover treatment (D) mineralized significantly more C than the other two treatments when the compost mixtures were very young or stabilized. The 2–week old corn stover/compost mixture mineralized significantly more C than the other three treatments and the biofilter treatment mineralized relatively low amounts of C regardless of the age of the compost mixture. (Fig. 3a).

All of the compost mixtures immobilized between 1% and 3% of the total N for 2 and 4 weeks composting except for the very young corn stover/compost mixture (D). After 6 weeks, about 2–3% of the total N was mineralized in all of the compost mixtures. Bioreactor trial III was the only trial where net N mineralization dominated in all the compost mixtures after 6 weeks of composting (Fig. 3b).

Carbon and N mineralization patterns varied among the three-bioreactor trials throughout the 28 d of aerobic incubation, although there were several similarities noted for the three trials. Differences between trials may have been related to differences in the initial substrate, as previously described. In general, the maximum amounts of mineralized C were produced from the freshest manure mixtures (0 weeks of composting) and potentially mineralizable C values stabilized at about 30–50% of the maximum value after 2–4 weeks of composting. Similarly, the percentage of total C mineralized was greatest (20–25%) for the fresh manure mixtures and dropped to 10–15% after 2–4 weeks of composting (Figs. 1a, 2a and 3a).

Carbon mineralization patterns followed first-order rate kinetics. The relationship between cumulative mineralized C and incubation time for the compost mixtures was curve–linear and exhibited two phases, a rapid rate phase from about 1 to 15 d and a slower rate phase from 15 to 28 d (Fig. 4).

Nitrogen mineralization data for bioreactor Trials I and II were similar, with net N immobilization exceeding net N mineralization until the manure mixtures had composted for 4 weeks. Nitrogen mineralization exceeded or equaled N immobilization after about 4 weeks of composting, but after 6 weeks of composting, N immobilization again exceeded N mineralization (Figs. 1b and 2b). A different pattern emerged during Bioreactor trial III, where N immobilization exceeded N mineralization until the sixth week of composting after

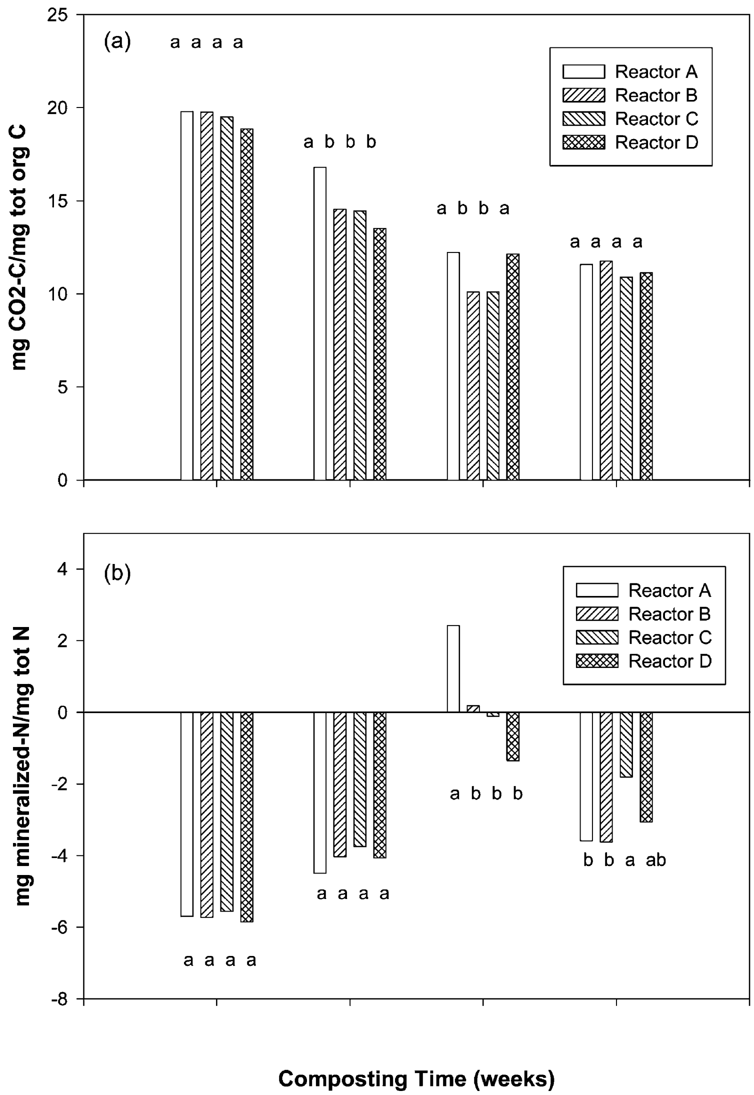

Fig. 1. Normalized cumulative C (a) and N (b) mineralization after 28 d incubation for Bioreactor trial I.

which net N mineralization exceeded net N immobilization (Fig. 3b). The return to negative net N mineralization during week six of trials I and II did not correlate with increasing NH_4–N levels nor NO_3–N levels in the original composts, as both of these were decreasing between weeks four and six (Fig. 5), with the exception of a small increase in NO_3–N level in trial I, which was still less than 0.5% of total N. Similarly, we found no relationship between net N mineralization and C/N ratio (Fig. 6) or cumulative C mineralization (Fig. 7) of the (soil + compost + sand) mixtures in any of the three bioreactor trials.

4. Discussion

4.1. Carbon mineralization

Carbon mineralization rates for the 4–week old compost mixtures taken from the lowest and highest moisture bioreactors (A and D) were greater than the other moisture treatments in bioreactor trial I. This observation is consistent with previous studies indicating that compost decomposition can be limited by low or high moisture in the bioreactors [11,15], resulting in a less stable compost product relative to the other treatments. Mineralization rates for the most stabilized compost mixtures taken after 6 weeks in the bioreactors in trial I were similar for all the moisture treatments, suggesting that increased composting times can compensate for the effects of moisture limitations on the quality of the compost product.

We hypothesized that cumulative C mineralization would be positively related to the C/N ratio of the compost feedstock, with the highest C/N ratio material leading to the highest amount of C mineralized. Predicted effects of C/N ratio on cumulative C mineralization were evident in the lowest C/N ratio treatment (A) for the young, 2–week, and 4–week old composts in bioreactor trial II.

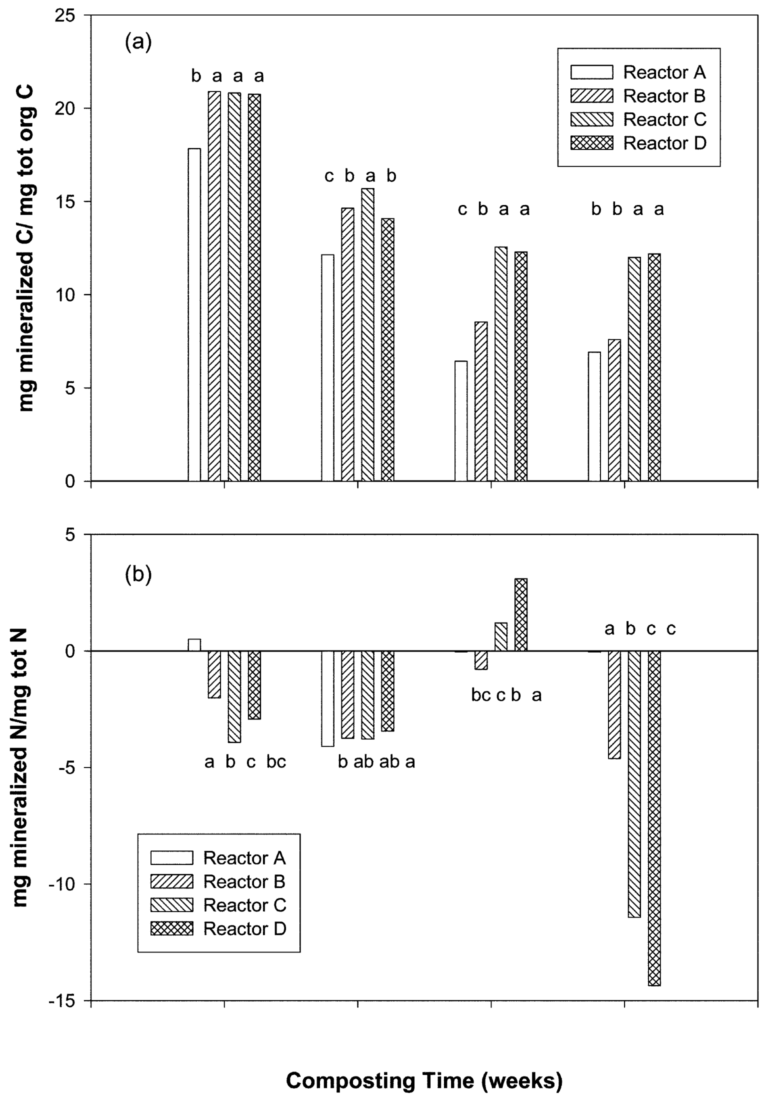

Fig. 2. Normalized cumulative C (a) and N (b) mineralization after 28 d incubation for Bioreactor trial II.

Blending soil into the compost resulted in the lowest amounts of mineralized C (except for the 2 week old compost) in bioreactor trial III. In particular, the addition of soil to the compost apparently resulted in a more stable compost product compared with the unmodified hoop manure control. Cumulative C mineralization patterns in the biofilter cover treatment (C) were similar to those for the unmodified hoop manure treatment, which suggests the biofilter cover did not affect the quality of the compost product. This observation is significant, since the only purpose of the filter is to prevent gaseous N loss during the composting process.

4.2. Nitrogen mineralization

Net cumulative mineralized N was obtained by subtracting baseline inorganic N from the final inorganic N values. Net cumulative mineralized N is thus the difference between gains to the mineral N pool through degradation of organic N, and losses from the mineral N pool through assimilation into microbial biomass (immobilization), NH_3 volatilization, or denitrification to N_2O and N_2.

The decomposition of agricultural crop residues with a C/N ratio of 25:1 will usually result in no net N mineralization or immobilization. The net effect of the sum of the processes is zero, even though both processes can be occurring at significant rates [18]. Net N immobilization is commonly expected when high C/N ratio substrates (>25:1) are added to soil. Inorganic N is removed from the soil solution to meet the N requirements of soil microorganisms as they utilize the available substrate carbon [18]. In this study, the C/N ratios of the (soil + compost + sand) mixtures during the 28–d laboratory incubations were relatively low, ranging from 10:1 to 18:1, and never exceeding 25:1. The compost treatments that were amended with corn stover to relatively

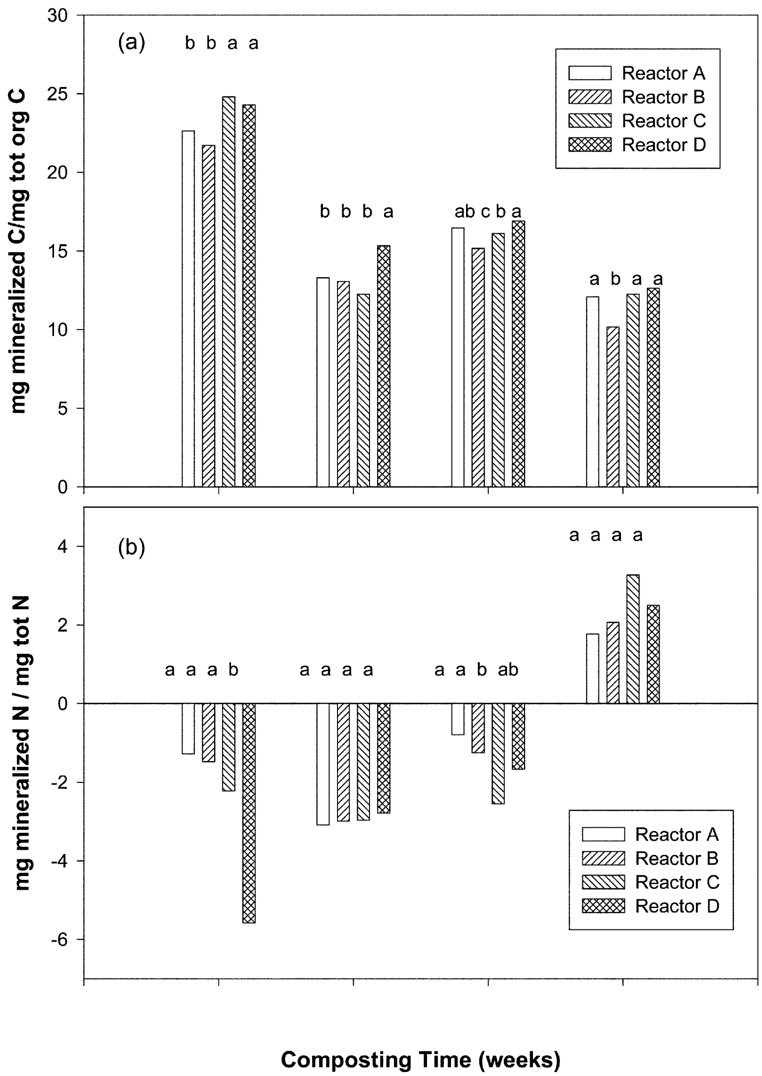

Fig. 3. Normalized cumulative C (a) and N (b) mineralization after 28 d incubation for Bioreactor trial III.

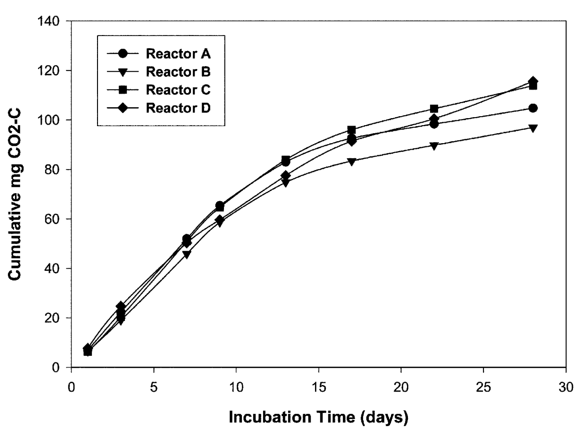

Fig. 4. Cumulative mineralized CO2–C for Bioreactor trial III.

high C/N ratios (C and D reactors in trial II, and D reactors in trial III), immobilized more N than the other treatments, but this effect was not consistent, occurring only at week zero in trial III and at weeks zero and six in trial II. Overall, there was no significant relationship between net N mineralization and the C/N ratio of the (soil + compost + sand) mixtures for any treatment combination in the three trials (Fig. 6).

The rarity of positive net N mineralization was a particularly important result in these trials. If we assume that immobilization of soil mineral N into microbial biomass was the primary explanation for the observed negative net N mineralization rates, we might expect a relationship between microbial biomass activity, represented by C mineralization, and net N mineralization. In fact, there is no relationship between C and N mineralization in these experiments (Fig. 7). Apparent net N immobilization occurred across the full range of C mineralization rates, and net N immobiliza-

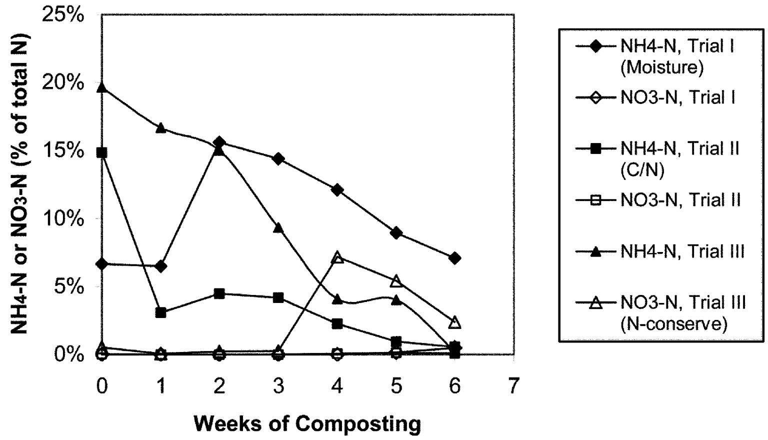

Fig. 5. Ammonium and nitrate levels in the fresh manure and compost (before drying) as a percentage of total N. Mean values for each trial are shown.

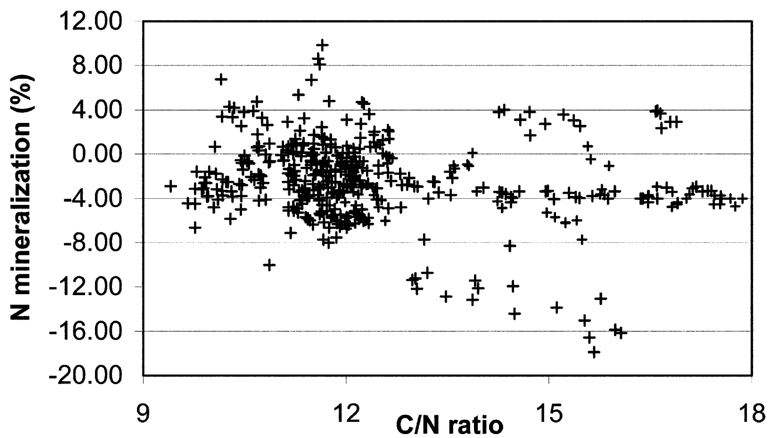

Fig. 6. Net nitrogen mineralization vs. C/N ratio for all replicates of all treatments in all trials.

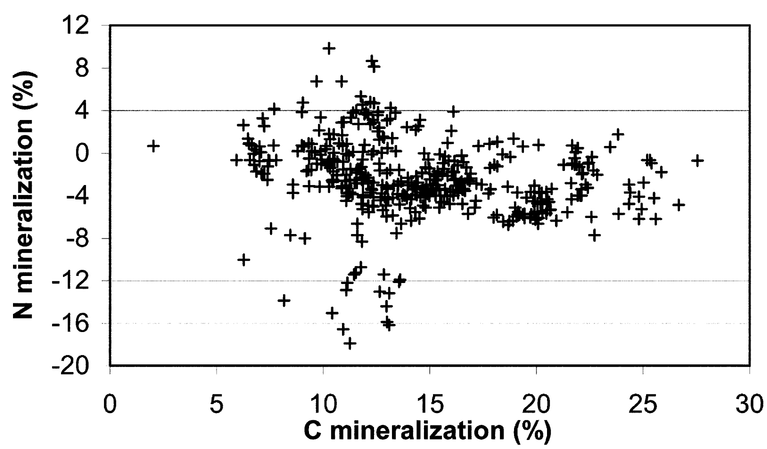

Fig. 7. Net nitrogen mineralization vs. carbon mineralization for all replicates of all treatments in all trials.

tion was greatest after 6 weeks of composting, when C mineralization rates were relatively low.

No significant correlations were found between net N mineralization and (soil + compost + sand) mixture C/N ratio or carbon mineralization, as illustrated in Figs. 6 and 7, respectively. The lack of correlation with these often cited indicators of N limitation (the C/N ratio) or C availability (C mineralization) [1,3,6] suggests the observed predominance

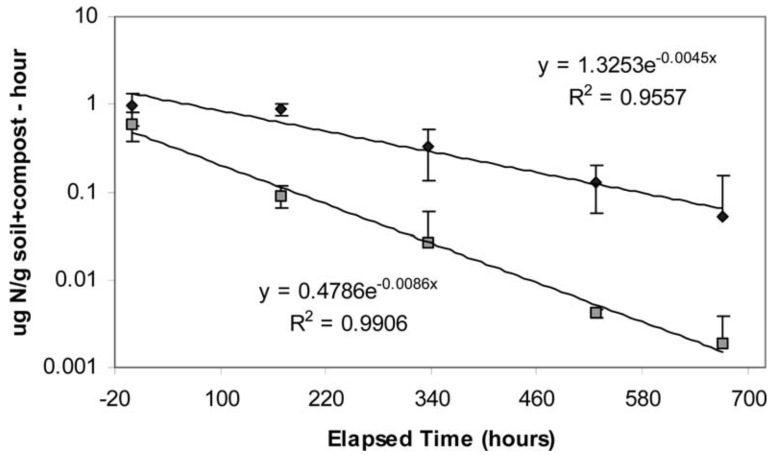

Fig. 8. Denitrification rates for fresh hoop manure (♦) and hoop manure that has been composted in windrows for 16 weeks (■), blended with soil and incubated for 28 d. Results are plotted on a logarithmic scale, and fit to a first-order decay function as indicated.

of negative net N mineralization has a more complex explanation.

Ammonia volatilization could be a major sink for mineral N, particularly for fresh manure or compost at 2 weeks, when NH_4^+ levels in the fresh compost were relatively high. However, this is unlikely to fully explain the persistence of negative net N mineralization in samples composted for 4 and especially 6 weeks, when NH_4^+ levels were decreasing to 7% of total N in trial I, and less than 1% of total N in Trials II and III (Fig. 5).

Another possible explanation is that nitrate-N was being lost through denitrification faster than it was being produced through nitrification in the laboratory incubations. Simultaneous nitrification–denitrification has previously been shown to occur in microsites within soil systems [4,17], and similar aerobic/anoxic/anaerobic microsites have recently been implicated in composting systems as well [9].

We empirically tested this hypothesis by incubating two different (soil + compost + sand) mixtures in the laboratory. We estimated potential denitrification rates every week for 4 weeks using an acetylene block technique [16]. Gas samples were analyzed for N_2O with an electron-capture-detector gas chromatograph. One treatment contained soil plus fresh hoop manure and the second treatment contained soil plus hoop manure that had been composted in windrows for 16 weeks. The data indicated that denitrification could be an important mechanism for N loss in this system (Fig. 8). Integrating the first-order decay function for the 28–d incubation predicts cumulative denitrification of 280 and 55 μg N/g soil + compost + sand for fresh manure and composted manure, respectively. This is equivalent to 10% (fresh manure) and 2% (mature compost) of the total average N in our (soil + compost + sand) incubation mixtures, and thus could drive net N mineralization from positive values to the negative values we observed.

A return to net negative N mineralization in week six samples for trials one and two after being positive in week four, may also have important ramifications for compost utilization. While greater compost maturity, with corresponding reductions in C/N ratio and C availability, is generally thought to reduce the possibility of net negative N mineralization [1,3,6], this study suggests that the dynamics of substrate availability and microbial activity can counteract this trend, at least temporarily. Existing indicators of compost maturity may not be adequate to predict the optimum timing of compost application, particularly where nutrient availability is a primary concern.

5. Conclusions

The impact of composting process conditions and the extent of compost decomposition on soil C and N mineralization after compost incorporation is poorly understood. This study evaluated post-incorporation effects, using composts from experiments that examined the effects of moisture, C/N ratio, and two alternative strategies on N conservation during the composting process. We have summarized below the major conclusions that can be drawn from this work.

1. Organic substrates that did not degrade because of sub-optimal conditions during the composting process may readily mineralize after compost incorporation in soil, where moisture or C/N ratio constraints are reduced. Therefore, cumulative carbon mineralization in compost-amended soils can be increased relative to similar-aged composts following sub-optimal compost conditions.
2. Compost produced after several weeks of intensive composting under near-optimum conditions may not result in net N mineralization after soil incorporation. The dynamics of mineralization, nitrification, denitrification, ammonia volatilization and N cycling through the microbial biomass are complex in soil systems, and can be affected by compost feedstock, processing conditions, and time.

3. Denitrification may severely limit N availability from compost when the compost is applied to agricultural soils.

The composts used in this study were significantly altered through drying and grinding relative to moist heterogeneous composts typically used in agronomic settings. These alterations were necessary to allow homogeneous application in small quantities for laboratory incubations, providing better relative understanding of the differences related to compost feedstock and processing, but doubtless also affecting the magnitude of the results. Further studies with unaltered composts in larger scale systems are needed to better understand the nature and implications of C and N dynamics in compost amended soil.

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References

[1] M.P. Bernal, H. Kirchmann, Carbon and nitrogen mineralization and ammonia volatilization from fresh, aerobically and anaerobically treated pig manure during incubation with soil, Biol. Fertil. Soils 13 (1992) 135–141.

[2] V. Chanyasak, M. Hirai, H. Kubota, Changes of chemical components and nitrogen transformation in water extracts during composting of garbage, J. Ferment. Technol. 60 (5) (1982) 439–446.

[3] T.H. DeLuca, D.K. DeLuca, Composting for feedlot manure management and soil quality, J. Prod. Agric. 10 (2) (1997) 235–241.

[4] L.L. Goodroad, D.R. Keeney, Nitrous oxide production in soil, Soil Biol. Biochem. 16 (1) (1984) 39–43.

[5] C.M. Groenestein, H.G. Van Faassen, Volatilization of ammonia, nitrous oxide and nitric oxide in deep-litter systems for fattening pigs, J. Agric. Eng. Res 65 (1996) 269–274.

[6] A. Hadas, R. Portnoy, Nitrogen and carbon mineralization rates of composted manures incubated in soil, J. Environ. Qual. 23 (1994) 1184–1189.

[7] A. Hadas, R. Portnoy, Rates of decomposition in soil and release of available nitrogen from cattle manure and municipal waste composts, Compost Sci. Util. 5 (3) (1997) 48–54.

[8] J.D. Harmon, M.S. Honeyman, D.C. Lay, J.B. Kliebenstein, T.L. Richard, Hoop Structures Internet Homepage, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, 2000. Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, 2000. http://www.ae.iastate.edu/hoop_structures/home.htm.

[9] Y. He, Y. Inamori, M. Mizuochi, H. Kong, N. Iwami, T. Sun, Measurements of N_2O and CH_4 from the aerated composting of food waste, Sci. Total Env. 254 (2000) 65–74.

[10] M.D. Jawson, L.F. Elliott, R.I. Papendick, G.S. Campbell, The decomposition of ^{14}C–labeled wheat straw and ^{15}N–labeled microbial material, Soil Biol. Biochem. 21 (3) (1989) 417–422.

[11] J.S. Jeris, R.W. Regan, Controlling environmental parameters for optimum composting II: Moisture, free air space and recycle, Compost Science 14 (2) (1973) 8–15.

[12] D.R. Keeney, D.W. Nelson, Nitrogen-inorganic forms, second ed, in: A.L. Page, et al. (Eds.), Methods of Soil Analysis, ASA and SSSA, Madison, WI, 1982, pp. 643–698 Part 2 Agron. Mongr. 9.

[13] U. Krogmann, H. Woyczechowski, Selected characteristics of leachate, condensate and runoff released during composting of biogenic waste, Waste Manage. Res. 18 (2000) 235–248.

[14] MidWest Plan Service (MWPS), Hoop structures for grow-finish swine, AED-41, MidWest Plan Service, Iowa State University, Ames, IA, 1997, pp. 16.

[15] K. Nakasaki, N. Aoki, H. Kubota, Accelerated composting of grass clippings by controlling moisture level, Waste Manage. Res. 12 (1994) 13–20.

[16] T.B. Parkin, J.A. Robinson, Stochastic models of soil denitrification, Appl. Environ. Microbiol. 22 (1989) 409–477.

[17] T.B. Parkin, J.L. Starr, J.J. Meisinger, Influence of sample size on measurement of soil denitrification, Soil Sci. Soc.Am. J. 51 (1987) 1492–1501.

[18] E.A. Paul, F.E. Clark, Soil Microbiology and Biochemistry, Academic Press Inc., San Diego, CA, 1989, pp. 137.

[19] J.W. Paul, E.G. Beauchamp, Short-term nitrogen dynamics in soil amended with fresh and composted cattle manures, Can. J. Soil Sci. 74 (1994) 147–155.

[20] T.L. Richard, H.L. Choi, Eliminating waste: strategies for sustainable manure management, Asian-Aus. J. Anim. Sci. 12 (7) (1999) 1162–1169.

[21] T.L. Richard, S.M. Tiquia, In-Barn composting system plus a warm bed for pigs, BioCycle 40 (10) (1999) 44.

[22] R. Riffaldi, R. Levi-Minzi, A. Pera, M. de Bertoldi, Evaluation of compost maturity by means of chemical and microbial analysis, Waste Manage. Res. 4 (1986) 387–396.

[23] R. Rynk, T.L. Richard, Commercial composting production systems, in: P.J. Stoffella, B.A. Kahn (Eds.), Compost Utilization in Horticultural Cropping Systems, CRC Press, Boca Raton, Florida, USA, 2001.

[24] S.A.S. Institute, SAS procedures guide, SAS Inst., Cary, NC, 1989 Version 6.07 Ed.

[25] P. Sorensen, E.S. Jensen, Mineralization of carbon and nitrogen from fresh and anaerobically stored sheep manure in soils at different texture, Biol. Fertil. Soils 19 (1995) 29–35.

[26] E. van Bochove, D. Couillard, M.C. Nolin, Caractérisation des phases du processus de compostage par une approche multidimensionelle: application au cycle de l'azote, Environ. Technol. 16 (10) (1995) 929–941.