

Effect of soil texture on nitrogen mineralization from organic fertilizers in four common southeastern soils

Kate Cassity-Duffey  | Miguel Cabrera | Dory Franklin | Julia Gaskin | David Kissel

University of Georgia, Crop and Soil Sciences, 3111 Miller Plant Sciences Building, Athens, GA 30602

Correspondence

Kate Cassity-Duffey, University of Georgia, Crop and Soil Sciences, 3111 Miller Plant Sciences Building, Athens, GA 30602.
Email: katecass123@gmail.com

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Abstract

Previous studies have indicated that soil properties and texture could lead to differences in N mineralization from applied organic materials. We conducted a 100-day (d) incubation study to measure net N mineralized from feather meal (14–0.1–0.1) and pellet mix (10–1–6) at 150 mg N kg soil⁻¹ (approximately 72 kg N ha⁻¹) incorporated into four common southeastern soils: Cecil 1, Cecil 2, Greenville, and Tifton. A second 23-d study was conducted to determine pH dynamics and the potential for ammonia volatilization from the same soils and materials. There were no differences in net N mineralized from pellet mix among soils, but net N mineralized from feather meal was lower in Greenville soil, which had the greatest clay content. Analysis of the first-order dynamics of N mineralization indicated that even in soils that differ in clay content it may be possible to describe N mineralization from feather meal and pellet mix with a single model. Our results also suggest that the effect of pH on the N mineralization dynamics of these fertilizers may be more important than the effect of clay content. No ammonia loss was observed regardless of soil texture, soil pH buffering capacity, or initial soil pH.

1 | INTRODUCTION

Organic farmers are reliant on a wide range of organic fertilizers to provide supplemental fertility to growing crops; this is especially true for supplying in-season nitrogen (N). These fertilizers are made from a variety of animal or plant byproducts that can be highly processed (hydrolyzed, ground, or mixed) or packaged “as is”. Nitrogen in these products is predominately in the organic form (National Organic Program, 2019) and must undergo microbially mediated N mineralization to become plant available ammonium (NH₄-N) and nitrate (NO₃-N). To address on-farm N needs and the lack of synchronization of plant demand with nutrient availability often observed in organic farming (Berry et al., 2002; Pang & Letey, 2000), we must be able to accurately predict N mineralization from these materials.

With such a variety of products, there are inherent differences in the initial N (1–15% total N), the pool of potentially mineralizable N, and the rate of mineralization (Gale et al., 2006; Gaskell & Smith, 2007; Hartz & Johnstone, 2006). Depending on individual chemical characteristics, these products have been shown to release anywhere from 20–93% of the total N applied as plant available in laboratory and field studies (unpublished data; Gale et al., 2006; Hadas & Kautsky, 1994; Hartz & Johnstone, 2006). Further complicating the difficulty in predicting mineralization, environmental conditions have the potential to alter N mineralization when these products are used in the field. Temperature and soil water content will affect microbial activity and directly impact the rate of N mineralization (Agehara & Warncke, 2005; Hartz & Johnstone, 2006). Also, previous studies have suggested that soil properties have the potential to

alter the mineralization of organic materials through the physical/chemical protection of organic matter, variations in aeration, and limitations due to pH and pH buffering capacity (Feller & Beare, 1997; Gordillo & Cabrera, 1997; Hassink, Bouwman, Zwart, Bloem, & Brussaard, 1993; Mowrer, Kissel, Cabrera, & Hassan, 2014). These different soil properties not only directly affect the microbial and enzymatic communities necessary for mineralization, but also impact the potential for loss of N through mechanisms, like ammonia volatilization.

Previous research determining the effect of soil texture from organic materials (primarily manures and crop residues) and from soil organic matter have generally come to the consensus that fine-textured soils tend to result in less net N mineralization whereas sandy/course-textured soils tend to favor N mineralization. Fine texture soils, particularly those with high clay contents can lead to the physical/chemical protection of organic matter or reduce substrate movement or availability, making it inaccessible to microorganisms and enzymes (Hassink et al., 1993). Additionally, researchers have observed increased N immobilization with increasing clay contents (Sorensen & Hensen, 1995), leading to less available N in fine texture or clayey soils. Hadas, Bar-Yosef, Davidov, and Sofer (1983) determined no significant differences in net N mineralization between a sandy soil and clay soil incubated with dairy and poultry manures (ground or pellets), but did observe differences in the distribution of the inorganic N fractions ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) in the soils. The group observed smaller $\text{NH}_4\text{-N}$ levels in the clay soil than in the sandy soil and attributed it to potential immobilization in the clay soil. Gordillo and Cabrera (1997) working with nine different soils that received broiler litter found that the pool of mineralizable N was related to the ratio of the percent sand and water content at field capacity of the soils, a ratio that indicates higher aeration and less silt or clay. Few studies have been conducted looking at specialty organic fertilizers products. Stadler, con Tucher, Schmidhalter, Gutser, and Heuwinkel (2006) determined N mineralization from three different organic fertilizers (produced from commercial byproducts) on four different soils (designated molic and hortic soil horizons). The group did not determine statistical differences between soils properties, but noted differences in mineralization patterns, particularly the tendency for immobilization to occur early in two of the hortic soils. The relationship between ammonia volatilization and soil characteristics such as cation exchange capacity, soil organic matter, initial pH, and pH buffering capacity, has long been established for inorganic N fertilizers (Ferguson, Kissel, Koelliker, & Basel, 1983; Zhenghu & Honglang, 2000). Cation exchange capacity and soil organic matter can bind free $\text{NH}_4\text{-N}$ and reduce losses, while the initial pH and pH buffering capacity moderated the $\text{NH}_4\text{-N}$ and $\text{NH}_3\text{-N}$ equilibrium in the soil solution. Ammonification of organic matter causes an increase in soil pH through the consumption of H^+ ions followed by a decrease in pH as

Core Ideas

- Nitrogen mineralization from organic fertilizers may vary based on soil texture
- The amount of N mineralized was affected by increasing clay content for feather meal but not for pellet mix
- Particle size of organic materials may determine the protection effect of clays

nitrification occurs (production of two H^+ for each mole of $\text{NO}_3\text{-N}$). Therefore, early after the application of an organic material, when ammonification dominates, there is potential for an elevated soil pH coupled with high concentrations of $\text{NH}_4\text{-N}$ (Hadas et al., 1983; Hartz & Johnstone, 2006). Depending on the soil texture and other characteristics, there is potential for ammonia volatilization from these materials.

To better understand the rate of N release so as to synchronize plant available N from these products, it is necessary to determine the effect of soil texture on N mineralization, pH dynamics, and the potential for ammonia volatilization. Therefore, the objectives of this experiment were to (1) determine N mineralized and analyze mineralization kinetics from two organic fertilizers applied to four soils commonly found in the southeastern United States through a long-term incubation study; and (2) determine the effect of soil type on pH and ammonia volatilization in a short-term incubation study of the same materials and soils.

2 | MATERIALS AND METHODS

2.1 | Initial characteristics

Four different soils were collected (upper 20 cm) from across the state of Georgia: two different Cecil soils (Fine, kaolinitic, thermic Typic Kanhapludults), a Tifton soil (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults), and a Greenville soil (Fine, kaolinitic, thermic Rhodic Kandiudults). These soils were chosen to be representative of typical agricultural areas of the state and had a range of soil textures and initial chemical characteristics (Table 1). After collection, soils were air-dried to reduce mineralization during storage, passed through a 2-mm screen, and stored at room temperature until use (23°C). The maximum gravimetric water holding capacity was estimated through saturation and draining over a sand bath (Priha & Smolander, 1999). Briefly, soils were packed lightly by tapping into a plastic cylinder (3.5 i.d., 15 cm height) with 60- μm mesh at the bottom. Cylinders were placed in a water bath and saturated through capillary

TABLE 1 Initial soil characteristics

Soil	Sand	Clay	Silt	50% water holding capacity	Total N	Total C	Initial inorganic N	pH (1:1; 0.01 mol L ⁻¹ CaCl ₂)	pH buffering capacity
	g kg ⁻¹				g kg ⁻¹ soil		mg kg ⁻¹ soil		mmol H ⁺ kg ⁻¹ soil pH ⁻¹
Cecil 1	860	65	78	150	1.3	19.7	70.8	5.8	15.3
Cecil 2	812	81	107	230	1.4	15.8	66.4	5.4	14.0
Greenville	703	198	98	190	0.8	11.1	21.0	6.3	18.3
Tifton	931	32	37	100	0.2	5.9	15.0	6.1	6.2

action. Samples were then placed on a sand bath and allowed to freely drain for 4 h, following which gravimetric water content was determined by drying (48 h at 105°C). This gave an estimation of the maximum water holding capacity of the sieved soil used in the incubation. Particle-size distribution was determined using the hydrometer method with four replications per soil (Gee & Or, 2002) and soil pH was measured at 1:1 ratio in 0.01 mol L⁻¹ CaCl₂ (Miller & Kissel, 2010). Soil pH buffering capacity (pHBC mmol H⁺ kg⁻¹ soil pH⁻¹) was measured with titration (Kissel, Sonon, & Cabrera, 2012) and total C and N were determined by dry combustion (Kirsten, 1979). Initial inorganic N of the soil was measured using 1 mol L⁻¹ KCl extraction (5 g soil to 40 ml KCl; Mulvaney, 1996), followed by colorimetric determination (Crooke & Simpson, 1971; Keeney & Nelson, 1982).

Two organic fertilizers were used in the N mineralization study: feather meal and a pelleted fertilizer blend (pellet mix, proprietary mix of animal meals and sulfate of potash) (Table 2). The organic fertilizers (one replication per fertilizer) underwent routine analysis for total Ca, K, Mg, Mn, Fe, Al, B, Cu, Zn, Na, S, and P (USEPA, 1996, 2007a, 2007b). Total N and C were determined by dry combustion (Kirsten, 1979). Fertilizer gravimetric water content was determined by drying at 65°C for 48 h (3 replications per fertilizer). Initial inorganic N was determined on fresh materials in 1 mol L⁻¹ KCl (1:200 ratio, 3 replications per fertilizer). Samples were shaken for 30 min, centrifuged for 20 min, and then passed through a 0.45-μm filter over vacuum. Filtrates were analyzed colorimetrically for determination for NO₃-N and NH₄-N (Crooke & Simpson, 1971; Keeney & Nelson, 1982).

2.2 | Long term N mineralization: 100-d incubation

A 100-d study was conducted to determine the rate of N mineralization and the pool of mineralizable N from the soils and organic fertilizer treatments. Soil was rewetted to 50% maximum water holding capacity (Table 1) and preincubated for five weeks to avoid the initial flush of mineralization observed through soil rewetting and reestablishment of the microbial community (Cabrera, 1993). Soil water content was determined (48 h at 105°C) and 300 g dry equivalent of soil was added to 0.9-L screw-top jars. In replicates of three, fertilizers were incorporated “as is” (no grinding or drying) to supply 150 mg kg⁻¹ total N (assuming approximately 50% of the total N applied would become available over the 100-d incubation; Gale et al., 2006). There were four soil treatments: Cecil 1, Cecil 2, Greenville, and Tifton soils; with three fertilizer sub-treatments: no fertilizer (control), feather meal, and pellet mix. Experimental units were placed in an incubator at 30°C and were aerated and adjusted for water content (gravimetrically) every few days. To determine inorganic N release,

TABLE 2 Selected characteristics of fertilizers used in the incubation study. One replication per fertilizer for total N, P, K, and C with three for inorganic N determination. Standard deviations are presented in parenthesis

Fertilizer	Total N	P	K	Total C	C to N ratio	Initial NH ₄ -N	Initial NO ₃ -N
	g kg ⁻¹ dry material					mg kg ⁻¹ dry material	
Feather meal	143	1.4	1.0	552	3.9	1085 (22)	5 (1)
Pellet mix	102	10.8	62.3	417	4.1	455 (140)	56 (3)

5-g (weight basis) subsamples were taken at 1, 3, 6, 14, 28, 42, 65, and 100 d and analyzed for inorganic N (Franklin, Bender-Ozenc, Ozenc, & Cabrera, 2015). Subsamples were extracted with 40 ml of 1 mol L⁻¹ KCl, shaken for 30 min, and passed through a #42 Whatman filter and inorganic N (NH₄-N and NO₃-N) was determined colorimetrically (Crooke & Simpson, 1971; Keeney & Nelson, 1982). Samples were mixed during water content adjustments and just prior to soil subsampling. Gravimetric water content was determined at 100 d. Inorganic N was calculated on a dry weight basis using the water content determined at the end of the study.

2.3 | Ammonia volatilization and soil pH: 23-d incubation

To determine the potential for ammonia volatilization from organic fertilizers, a short-term study was conducted to measure ammonia loss, inorganic N, and soil pH. The experiment was prepared similarly to the long-term experiment above: four soils each with three fertilizer treatments (no amendment, feather meal, pellet mix). The soils were preincubated at 50% max water holding capacity for five weeks, 300 g dry equivalent of soil was added to 0.9-L screw-top jars (two replications per treatment), and fertilizers were incorporated “as is” to supply 150 mg kg⁻¹ total N. Water content was maintained by mass and soils were aerated every few days. To capture ammonia volatilization from the soil and materials, 40 ml of 0.05 mol L⁻¹ H₂SO₄ traps were placed in each screw-top jar (Cabrera & Chiang, 1993). Traps were changed at 3, 8, 14, and 23 d to allow for the accumulation of NH₃-N (background was measured in jars with no soil or fertilizer in replications of three). After removal, traps were brought up to their original volume with deionized water, and analyzed colorimetrically for NH₄-N (Crooke & Simpson, 1971; Keeney & Nelson, 1982). As above, N and pH dynamics, a 5-g (weight basis) subsample was taken when each NH₃-N trap was changed. Soil pH and inorganic N analysis were performed on the same 5-g subsample. First, 10 ml of deionized water was added and soil pH was measured (1:2 soil/water). Then, 10 ml of deionized water and 20 ml of 2 mol L⁻¹ KCl were added and inorganic N concentrations were determined as described above. Due to interference with the colorimetric method, CaCl₂ solution could not be used to measure soil pH in the ammonia volatilization trial.

2.4 | Nitrogen mineralization kinetics and statistical analysis

Cumulative Net N mineralized was calculated for both the control soils (unamended) and for the two fertilizer sources where

Cumulative Control Net N min.

$$= \text{Inorg. N}_{(t)} - \text{Inorg. N control}_{(t=0)} \quad (1)$$

Cumulative Fertilizer Net N min.

$$= \text{Fert. Inorg. N}_{(t)} - \text{Fert. Inorg. N control}_{(t=0)} - \text{Inorg. N}_{(t=0)} \quad (2)$$

where t is the sampling day, “Inorg N_(t=0)” is the initial inorganic N of the soil, and “Fert. Inorg. N_(t=0)” is the initial inorganic N of the fertilizer. Net N mineralized was expressed by mass (mg N kg⁻¹ dry soil, g N kg⁻¹ applied material) and as the percentage (%) of total N applied with the fertilizers.

Similar to Cabrera (1993), net N mineralized from the control soils followed a linear relationship (zero-order kinetics), so individual soils were fit using PROC REG (SAS, 2016) to the model:

Cumulative Control Net N Min. (mg kg⁻¹ dry soil)

$$= k_{\text{linear}} \times t \quad (3)$$

where k_{linear} (mg kg⁻¹ d⁻¹) is the rate coefficient of mineralization, and t is time in days. Goodness of fit was determined using the adjusted R² and significant differences ($p < .05$) between the intercepts and fitted slopes of the soils were determined with contrasts in PROC GLM (SAS, 2016).

Cumulative net N mineralized from the fertilizers was fit to a first-order kinetics model:

Cumulative Fertilizer Net N Min. (g N kg⁻¹ dry material)

$$= N_0 \times (1 - e^{-kt}) \quad (4)$$

where N_0 is the potential pool of mineralizable N (g N kg⁻¹ dry material), t is time in days, and k is the rate constant of

TABLE 3 Cumulative net N mineralized in 100 d from control soils and from feather meal and pellet mix fertilizers

Soil	No fertilizer (Control)	Feather meal	Pellet mix
	mg kg ⁻¹ dry soil	g kg ⁻¹ dry material (% TN applied) ^a	
Cecil 1	54 ± 1 a ^b	109 ± 6 (71)a	57 ± 3 (53)a
Cecil 2	76 ± 6 b	109 ± 4 (71)a	62 ± 7 (58)a
Greenville	37 ± 3 c	85 ± 7 (56)b	59 ± 8 (55)a
Tifton	9 ± 0.5 d	102 ± 5 (67)a	62 ± 2 (58)a

^aValues in parenthesis are percent of total N applied.^bMeans not followed by a common letter are significantly different according to Fisher's LSD at $p < .05$.

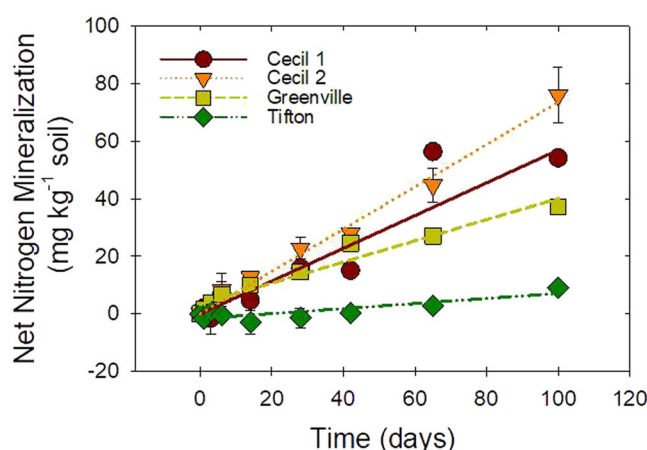
mineralization (d⁻¹). Proc NLIN in SAS was used to fit the model individually to each of the organic fertilizers in each soil to determine their individual N₀ and k values. Pseudo R² for the first-order models were calculated as 1 – (residual sum of squares/corrected sum of squares). To determine significant differences among the models, a residual sum of squares of analysis (Miliken & Debruin, 1978) was used. For example, to determine if the k values were different for feather meal mineralizing in two given soils (H₀: k values are the same), the first-order model was fit using their individual N₀ values but a single k value. The sum of squares residual of that model constituted the sum of squares residual under H₀ (SSresH₀). The addition of the sum of squares residuals for the models fit to each of the two soils individually constituted the sums of squares residual for the option of using individual models with different N₀ and k values (SSres). The sum of squares residual due to deviations from H₀ was calculated as SSdevH₀ = SSresH₀ – SSres. Subsequently, an F value was computed as: $F = (SSdevH_0/df)/(SSres/df)$, where df refers to the corresponding degrees of freedom. If the computed $F > F(df \text{ numerator}, df \text{ denominator}, 0.05)$ from the F table, H₀ was rejected, which meant that k values were not the same. A similar analysis was carried out to determine if N₀ values were the same between two given soils. All possible pairwise analysis of residual sum of squares for the four soils were conducted for each organic fertilizer.

Significant differences for net N mineralized by day were determined using PROC MIXED (SAS, 2016) for the control soils and applied fertilizers with least squares means of fixed effects treatment means separated at $p = 0.05$. Day 100 data were analyzed using PROC GLM for the analysis of variance, and treatment means were separated using Fisher's Protected LSD at $p = 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Soil and fertilizer characteristics

A range of initial soil characteristics were measured in the four soils (Table 1). The Tifton soil, with the greatest sand content, had the lowest total N, total C, and initial inorganic N of all soils, whereas the Greenville soil had the greatest clay

**FIGURE 1** Net nitrogen mineralization (mg kg⁻¹ soil) from the four different control soils incubated for 100 d and associated linear regressions (error bars indicated standard deviation)

content (198 g kg⁻¹ soil). Cecil 1 and Cecil 2 were characterized as loamy fine sands, and had been previously managed to meet organic certification, which included a history of cover cropping and additions of organic amendments. All soils, with the exception of Cecil 2, had pH > 5.5, with pH buffering capacities ranging from 6.2 to 18.3 mmol H⁺ kg⁻¹ soil pH⁻¹. Feather meal had a total N of 143 g kg⁻¹, a C to N ratio of 3.9, and an initial inorganic N content of 1090 mg N kg⁻¹ (Table 2). The pellet mix had a total N of 102 g kg⁻¹, a C to N of 4.1, and initial inorganic N of 501 mg N kg⁻¹.

3.2 | Effect of soil texture on N mineralization

The cumulative amount of net N mineralized in 100 d from control soils ranged from 9 to 76 mg N kg⁻¹ with significant differences between means ($p < .0001$) (Table 3; Figure 1). Cecil 2 had the largest amount of net N mineralized even though it had the lowest pH. Data fit well to a linear model (Table 4) without intercept with R² greater than 0.92 for all soils but the Tifton soil, which had a R² = 0.50. The lower R² observed for this soil is likely due to the low mineralization rate (near and around zero). All slopes (linear/zero-order constants) were significantly different from each other at $p < .05$. These results show that N mineralization from soil organic

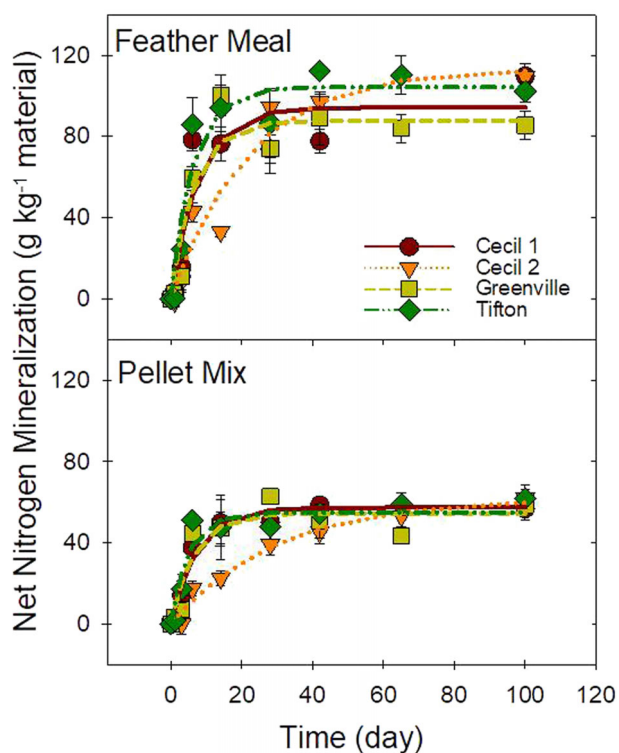
TABLE 4 Fit parameters for net N mineralized from control soils (zero-order kinetics) and from feather meal and pellet mix (first-order kinetics)

Soil	Control (Unamended) ^a		Feather meal ^b			Pellet mix ^b		
	k_{linear} $\text{mg kg}^{-1} \text{d}^{-1}$	R^2	k d^{-1}	N0 $\text{g kg}^{-1} \text{material}$	R^2	k d^{-1}	N0 $\text{g kg}^{-1} \text{material}$	R^2
Cecil 1	0.57 b	0.95	0.142 a	89 b	0.86	0.136 a	57 a	0.92
Cecil 2	0.73 a	0.96	0.046 b	113 a	0.93	0.034 b	62 a	0.95
Greenville	0.49 c	0.92	0.153 a	88 b	0.87	0.154 a	55 a	0.86
Tifton	0.06 d	0.50	0.163 a	104 ab	0.90	0.199 a	55 a	0.86
Full model ^c	—	—	0.152	95	0.86	0.171	53	0.82

^aFor control soils, k_{linear} values followed by different letters are significantly different at $p < .05$ according to contrasts using Proc GLM in SAS.

^bFor feather meal and pellet mix, k and N0 values followed by different letters are significantly different at $p < .05$ according to pairwise residual sum of squares analyses (Milliken & Debruin, 1978).

^cThe full model is the fit using all four unamended soils (Controls) and using Cecil 1, Greenville, and Tifton soils for feather meal and pellet mix.

**FIGURE 2** Net nitrogen mineralization ($\text{g kg}^{-1} \text{material}$) from the feather meal and pellet mix incubated for 100 d in four different soils and associated first order regressions (error bars indicated standard deviation)

matter may provide significant amounts of plant-available N in soils like Cecil and Greenville, whereas it is not likely to provide much N in soils like Tifton.

Rapid mineralization was observed from feather meal and pellet mix, with the majority of mineralization occurring within the first two weeks (Figure 2). By 14 d, the amount of N mineralized ranged from 56–72% of the applied N for feather meal, and from 53–58% of the applied N for the pellet mix in the four soils. Similar rapid N mineralization values have

been previously reported for commercially available organic fertilizers. Hadas and Kautsky (1994) observed a rapid release of inorganic N from hydrolyzed feather meal with about 65% of the applied N available after 56 d. Hartz and Johnston (2006) found that 64% and 70% of the organic N applied became available for feather and blood meal respectively, and Mondini et al. (2008) observed 30–58% of the applied N to be available from different meat bone meals (average initial total N of ~8%). With the pellet mix containing a variety of mixture of animal byproducts, the amount of N mineralized would be a composite of these different materials.

For feather meal, no significant differences were found in net N mineralized in 100 d for Cecil 1, Cecil 2, and Tifton soils, with an average amount of net N mineralized of 107 g N kg^{-1} (70% of applied total N; Figure 2). Although the net mineralized from feather meal was the same for the three soils, a delay in N mineralization was observed in the Cecil 2 soil from the 6-d sampling till the 42-d sampling (Figure 2). This delay may result in N deficiencies if N availability is delayed with respect to crop demand. The delay observed in Cecil 2 when compared to the other three soils may have been due to its lower pH (5.4 in $0.01 \text{ mol L}^{-1} \text{CaCl}_2$), which could have delayed the growth of zymogenous microbial biomass. The zymogenous microbial biomass is thought to be the opportunistic biomass that grows as a result of the addition of organic materials to soil (Langer, Böhme, & Böhme, 2004). In soils that have not received recent additions of organic materials, the zymogenous biomass may exist at a basal level that will grow upon subsequent addition of organic materials. Such growth may be limited when conditions are not favorable. It should be noted, however, that Cecil 2 had the largest amount of net N mineralized from the soil organic matter, which is usually decomposed by the autochthonous microbial biomass (Langer et al., 2004). It is evident from the dynamics of net N mineralization from soil organic matter in Cecil 2 that the autochthonous biomass was well adapted to the conditions in that soil.

The amount of net N mineralized from feather meal in Greenville soil was 79% of that mineralized from the other three soils (85 versus 107 g N kg⁻¹, Table 3). The lower mineralization in Greenville soil may have been due to its greater clay content (Table 1), although the difference observed was not as large as that found in a study by Gordillo and Cabrera (1997) in which net N mineralized in 112 d from broiler litter in Greenville soil was 62% of that mineralized from Pacolet soil (similar to Cecil soil; 484 vs 784 g N kg⁻¹ organic N). Thus, the effect of clay in these soils may not be as large for feather meal as for broiler litter.

The N mineralization data for feather meal fit well to first-order kinetics with pseudo R^2 varying from 0.86 to 0.93. The pairwise residual sums of squares analysis for the four soils indicated that k and N_0 values were not different for Cecil 1, Greenville, and Tifton soils (Table 4). Thus, the dynamics of N mineralization in these three soils could be described by a single first-order model ($N_0 = 94$ g N kg⁻¹, $k = 0.153$ d⁻¹; pseudo $R^2 = 0.86$). In contrast, a separate model was needed for Cecil 2 soil due to its greater N_0 value and smaller k (Table 4).

For the pellet mix there were no significant differences in the amount of net N mineralized in 100 d among all four soils, with an average of 60 g N kg⁻¹ (56% of applied total N; Table 3). The observed lack of differences in net N mineralized from pellet mix contrasts with the results for feather meal, in which the soil with greatest clay content (Greenville) showed significantly less N mineralized (Table 3). An explanation for this difference may be found in the particle size of the two organic fertilizers. Whereas feather meal had particles smaller than 1 mm, the pellet mix had particles sizes varying between 2 and 5 mm. If clay can offer protection to organic particles through physicochemical binding (Six, Paul, & Paustian, 2002), it would seem that smaller particle sizes would be more likely to interact with clays than larger particle sizes.

Similarly to feather meal results, a lag in N mineralization from the pellet mix was observed in Cecil 2 (Figure 2), which suggests a slow growth of the microbial population involved. As in the case of feather meal, the pairwise residual sum of squares analysis indicated that the dynamics of N mineralization in Cecil 1, Greenville, and Tifton soils could be described by a single model because there were no differences in k and N_0 values (Table 4). Also, as in the case of feather meal, a separate model was needed for Cecil 2 due to its lower first-order rate constant of mineralization (k).

The overall results of the 100-d study indicated that although the total amount of N mineralized from feather meal was smaller in Greenville soil (with 19.8% clay) than in the other three soils (with clay contents ranging from 3.2–8.5%), an analysis of the dynamics of N mineralization according to first-order kinetics showed no differences among Greenville, Cecil 1 (8.5% clay) and Tifton (3.2% clay) soils. A regression

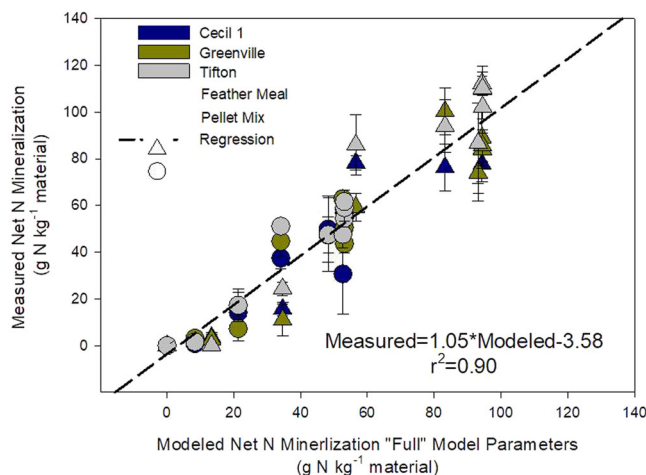


FIGURE 3 Modeled versus measured net N mineralization from the feather meal and pellet mix using parameters determined from the model fit to Cecil 1, Greenville, and Tifton soil (error bars indicated standard deviation)

of measured versus predicted N mineralized from feather meal or pellet mix using the single model fit to Greenville, Cecil and Tifton soils had an $R^2 = 0.90$ with intercept not significantly different from zero and slope not significantly different from 1 (Figure 3).

3.3 | Ammonia volatilization and soil pH

During the short-term incubation, no detectable ammonia volatilization was measured from any of the materials or soil combinations. Some losses were expected given relatively high pH and $\text{NH}_4\text{-N}$ concentrations observed in Tifton soil (Figure 4). The pH measurements reported in the short-term incubation were higher than those measured in CaCl_2 for the 100-d incubation study as the measurement of pH in water versus CaCl_2 leads to larger pH values (Kissel, Sonon, Vendrell, & Isaac, 2009). For all treatment combinations, pH and $\text{NO}_3\text{-N}/\text{NH}_4\text{-N}$ dynamics followed expected trends: a rise in pH was observed with the increase in $\text{NH}_4\text{-N}$ but pH rapidly decreased coinciding with $\text{NO}_3\text{-N}$ production.

While it was expected to see low losses of $\text{NH}_3\text{-N}$ from organic fertilizers incorporated into the fine-textured soils (Meisinger & Jokela, 2000), we were anticipating some losses from the feather meal applied to the Tifton soil due to a low pH buffering capacity, low organic matter, and high sand content (Hargrove, 1988; Wang & Alva, 2000). As shown in Figure 4, pH rapidly climbed to 8.6 in the Tifton soil after the application of the feather meal coupled with $\text{NH}_4\text{-N}$ concentrations of 69 mg kg⁻¹ soil. The low pH buffering capacity of this soil is reflected in the rapid changes in soil pH depending on inorganic N speciation.

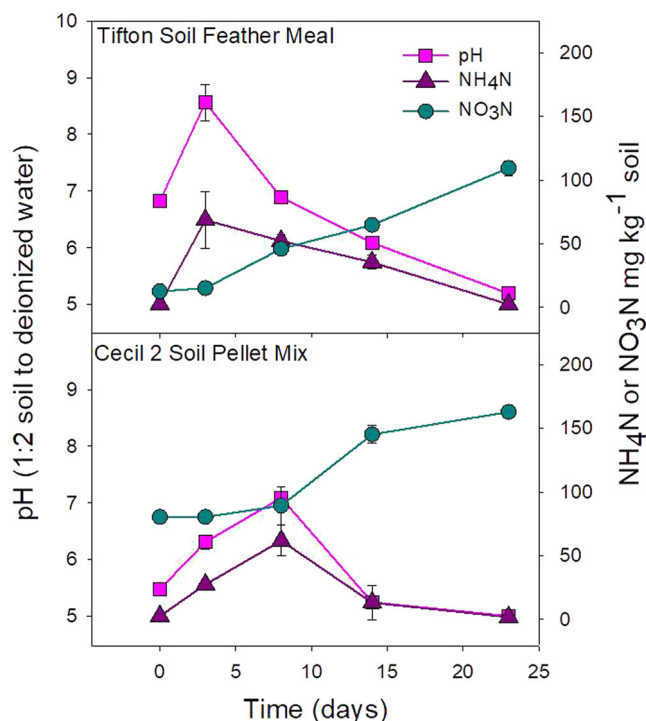


FIGURE 4 Ammonium and nitrate concentrations measured and 1:2 soil/water pH during 23-d incubation (error bars indicated standard deviation)


As suggested in the 100-d study, mineralization in Cecil 2 soil seemed to be limited by the initial soil pH. In the short-term study, the maximum pH was reached by 3 d for both the pellet mix and feather meal, with the exception of Cecil 2 soil for which the maximum pH was reached at 8 d (Figure 4). The addition of the pellet mix to the Cecil 2 soil led to delayed ammonification compared to other soil treatments and $\text{NO}_3\text{-N}$ levels were stagnant until soil pH increased to near 7 at 8 d. It would seem that the dynamics of ammonium/nitrate and soil pH played a role in the rate of mineralization from these materials.

4 | CONCLUSIONS

Potential N mineralization from the four control soils used in this study varied from 9 to 76 mg inorganic N kg^{-1} soil in 100 d, which depending on soil properties and previous management, may represent a large source of plant-available N. While the amount of N mineralized from feather meal in 100 d was smaller in Greenville soil (19.8% clay) than in the other three soils (2.5–8.5% clay), such effect of clay was not observed with pellet mix, which had larger particle sizes. Thus, additional research should be conducted to determine if the particle size of the added organic materials plays a role in the protecting role of clay on organic material mineralization kinetics. Our analysis of the dynamics of N mineralization

suggests that even in soils that differ in clay content it may be possible to describe N mineralization from feather meal and pellet mix with a single model. Our results also suggest that the effect of pH on the N mineralization dynamics of these fertilizers may be more important than the effect of clay content in the soils used for this study. Additional research on the effect of pH would thus be warranted.

ORCID

Kate Cassity-Duffey 

<https://orcid.org/0000-0002-9672-223X>

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