Received: 26 February 2021 | Accepted: 1 October 2021 | Published online: 10 November 2021

DOI: 10.1002/jeq2.20295

Journal of Environmental Quality

REVIEWS AND ANALYSES

Nitrogen mineralization from organic fertilizers and composts: Literature survey and model fitting

Daniel Geisseler[1] | Richard Smith[2] | Mike Cahn[2] | Joji Muramoto[3]

[1] Dep. of Land, Air and Water Resources, Univ. of California, Davis, One Shields Avenue, Davis, CA 95616, USA

[2] Univ. of California Cooperative Extension Monterey County, 1432 Abbott Street, Salinas, CA 93901, USA

[3] Dep. of Environmental Studies, Univ. of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, USA

Correspondence
Daniel Geisseler, Dep. of Land, Air and Water Resources, Univ. of California, Davis, One Shields Avenue, Davis, CA 95616, USA.
Email: djgeisseler@ucdavis.edu

Assigned to Associate Editor Sanjay Shukla.

Funding information
California Department of Food and Agriculture, Fertilizer Research and Education Program (CDFA-FREP)

Abstract

Organic fertilizers and composts are valuable sources of nutrients. However, their nutrient availability is often not known and can be variable. The objective of the present study was to collect net nitrogen (N) turnover data from peer-reviewed articles and fit a model that simulates gross N mineralization and gross N immobilization to determine pool sizes and their rate constants of different common organic amendments. A total of 113 datasets were included in the study. The model predicted that 61 and 72.5% of total N in feather meal and guano, respectively, would be in the mineral form after 100 d under optimal conditions. Nitrogen availability from poultry manure and poultry manure compost was lower. On average, 16–17% of total N was present as mineral N in the materials, whereas at the end of the 100-d simulation, 39.6 and 32.7% of total N from an average poultry manure and its compost, respectively, were in the mineral form. Yard waste compost and vermicompost are stable materials, with <10% of the total N in an average material being in the mineral form at the end of the 100-d simulation. Model simulations revealed that changes in the assumed temperature sensitivity of N mineralization have a strong effect on N availability of readily available organic amendments during the first weeks after incorporation. The model performed well for guano and feather meal but was unsatisfactory for the other amendment groups. Model performance may have been hampered by different incubation protocols used in the studies included and variability in amendment properties not considered by the model. The results of this study allow estimating the release of N from a variety of organic fertilizers and composts and can be a valuable tool to improve N management of organic amendments in crop production.

Abbreviations: DR, decomposition rate; EF, model efficiency; FOM, fresh organic material; NMIN, initial mineral nitrogen; RSR, ratio of RMSE to standard deviation; SOM, soil organic matter; TFAC, temperature correction factor.

1 INTRODUCTION

Organic fertilizers and composts are valuable sources of nutrients that are extensively used in organic agriculture as well as in conventional systems. Their repeated application can increase soil fertility and soil organic matter (SOM) content (Ladha et al., 2011), which in turn helps maintain or improve soil health. The positive effect on soil health has resulted in increased interest in the use of organic amendments, especially compost, beyond organic agriculture (Norris & Congreves, 2018).

A wide range of organic fertilizers are available, including manures, slaughter products (e.g., feather or blood meal), or guano. Similarly, composts may be made from different types of green waste and manures. A challenge when applying these amendments is that their nutrient availability is often not known (Cassity-Duffey et al., 2020; Lazicki et al., 2020). Furthermore, the amount of nutrients available and the timing of when they become available may differ among materials from different suppliers and even across batches from the same supplier (Lazicki et al., 2020). This is especially true for nitrogen (N) availability. These uncertainties make it difficult to estimate the amount of amendment or supplemental mineral fertilizer needed to provide sufficient nutrients to the crops to ensure optimal yields while avoiding losses to the environment (Gordillo & Cabrera, 1997; Wortman et al., 2017).

Most of the total N in organic fertilizers and composts is in the organic form, which for the most part is not directly plant available. Nitrogen mineralization, the transformation from organic N to ammonium N, is mediated by soil microorganisms. Different factors can affect N mineralization, including temperature, water content, soil properties, as well as the properties of the organic material (Robertson & Groffman, 2007). Especially the ratio between carbon (C) and N of the material can strongly affect crop N availability. A narrow C/N ratio of less than 25:1 generally results in net N mineralization, whereas a wide C/N ratio greater than 25:1 can lead to net N immobilization (i.e., the incorporation of mineral N from soil solution into microbial biomass) (Myrold & Bottomley, 2008). However, some studies found that this threshold was between 14:1 and 19:1 for a wide range of organic amendments (Calderón et al., 2005; Gale et al., 2006; Lazicki et al., 2020). In aerated soils, ammonium is generally quickly converted to nitrate by nitrifying soil microorganisms. Nitrate, in turn, can easily be moved to deeper soil layers with rainfall or irrigation water, increasing the risk of leaching into groundwater.

Cumulative net N mineralization (N_{min}) is often estimated by fitting a one- or two-pool first-order kinetic model to the observed data (Molina et al., 1980; Stanford & Smith, 1972). The two-pool model is shown in Equation 1:

Core Ideas

- A total of 113 datasets from peer review articles were compiled for this study.
- 60–75% of N in feather meal and guano are typically available within 100 d.
- 30–40% of N are available from poultry manure and its compost after 100 d.
- Less than 10% of N in vermicompost and yard waste compost are available after 100 d.
- The results help making N management decisions with organic amendments.

$$N_{min} = N_1 \times \left(1 - e^{-k_1 t}\right) + N_2 \times \left(1 - e^{-k_2 t}\right) \quad (1)$$

where t is time since application, N_1 and N_2 are the fast and slow potentially mineralizable N pools of the added material, and k_1 and k_1 are their respective rate constants of N mineralization. These simple first-order models generally result in a good fit as long as the application of the material does not result in N immobilization. When materials are applied that may cause net N immobilization, a model that can simulate gross N mineralization and gross N immobilization is potentially better suited to estimate N availability from such materials.

The CERES-N model simulates N mineralization and immobilization from added organic matter in a relatively simple way (Godwin & Jones, 1991; Jones & Kiniry, 1986). The model divides added organic material into three pools that differ in their decomposition rate constants. The N contained in the material is uniformly distributed into the three pools. The rate constants are adjusted daily for temperature, soil water content, and N availability in the system before calculating the gross N mineralization from each pool. Nitrogen immobilization is based on microbial demand for N, which is calculated using a fixed microbial C use efficiency and biomass C/N ratio. Net N mineralized is then calculated as the difference between gross N mineralization and immobilization. The CERES-N model has been incorporated into the Decision Support System for Agrotechnology Transfer, which is a well-established model that has been extensively used to simulate cropping systems (Jones et al., 2003).

The objective of the present study was to collect net N turnover data from peer-reviewed articles and use a model adapted from CERES-N to determine pool sizes and their rate constants of different types of organic fertilizers and composts. The model results of this study shall contribute to improved simulations of N availability from organic amendments in cropping system models with daily time steps.

TABLE 1 Overview of the data used in this study

Group of amendments	Studies[a]	Amendments[b]	Datasets[c]	Observations[d]	Temp.	Duration
					˚C	d
Guano	4	4	8	44	10–28	56–84
Feather meal	7	8	14	80	10–30	56–364
Poultry manure	9	28	29	195	21–30	70–364
Poultry manure compost	4	10	16	77	5–23	70–126
Vermicompost	8	12	21	125	20–28	45–365
Yard waste compost	6	19	25	126	20–30	70–224

Note. The temperature and duration shown are the lowest and highest values for each amendment.
[a]Guano: Cabilovski et al., 2013; Hartz & Johnstone, 2006; Lazicki et al., 2020; Yousif & Abdalla, 2009. Feather meal: Cassity-Duffey et al., 2020; Dion et al., 2020; Gale et al., 2006; Hadas & Kautsky, 1994; Hartz & Johnstone, 2006; Lazicki et al., 2020; Palomino et al., 2019. Poultry manure: Abbasi & Khaliq, 2016; Cassity-Duffey et al., 2020; Castellanos & Pratt, 1981; Dion et al., 2020; Gale et al., 2006; Gordillo & Cabrera, 1997; Li & Li, 2014; Palomino et al 2019; Sims 1986. Poultry manure compost: Castellanos & Pratt, 1981; Gale et al., 2006; Lazicki et al., 2020; Whitmore, 2007 (average of three soils). Vermicompost: Cabilovski et al., 2013; Carrión-Paladines et al., 2016; Contreras-Ramos et al., 2007; Eckhardt et al., 2016; Eckhardt et al., 2018; Lazicki et al., 2020; Paradelo et al., 2011; Tognetti et al., 2005. Yard waste compost: Burgos et al., 2006; Cassity-Duffey et al., 2020; Gale et al., 2006; Hartz et al., 2000; Lazicki et al., 2020; Masunga et al., 2016. [b]Number of amendments collected from different sources. [c]Number of incubations conducted with the amendments in each group. [d]Product of the average number of measurements taken over time in each incubation and the number of datasets.

2 | MATERIALS AND METHODS

2.1 | Literature survey

We searched the online database Web of Science for peer-reviewed articles reporting results from laboratory incubations conducted under optimal soil moisture content and a constant temperature using the keywords "nitrogen," "mineral," plus the names of the different fertilizer and compost types. A total of 620 articles met these criteria and were screened for data that could be used for the present study.

The following criteria were applied to select appropriate studies: (a) At least three observations made at different times after the application of the material are reported; (b) the N mineralization data reported can be converted to mineral N from the material as a proportion of total N in the material; (c) the study reported incubation temperature, as well as application rate, mineral N, total N, and C/N ratio for the material added, or these values could be calculated based on the data provided; (d) one single application of the material was performed; (e) the material was incorporated or mixed with soil or sand; and (f) individual observations were presented in tables or figures. Studies only showing a best-fit regression line were not included.

Other data extracted from the studies were mineral N in soil (ammonium-N plus nitrate-N) as well as total soil N content. In the model used (see below), the amount of mineral N present in the soil affects N turnover from added materials that cause net N immobilization. When SOM was reported instead of total N, it was assumed that C accounts for 50% of SOM (Pribyl, 2010) and that the C/N ratio of SOM is 10, which is the average C/N ratio of SOM (Paul, 2016) and is used in the CERES-N model (Jones & Kiniry, 1986). When no SOM was reported, it was derived from Soil Survey data based on the description of the soil. When initial mineral N was not reported, it was assumed that it comprised 1% of total N.

Data for the following organic amendments were compiled in an Excel spreadsheet: feather meal, guano, poultry manure, poultry manure compost, yard waste compost, and vermicompost. Chicken and broiler manure or litter were included in poultry manure. Data reported in figures were extracted using WebPlotDigitizer (https://automeris.io/WebPlotDigitizer/).

Between four and nine studies were included for each group of amendments (Table 1). The number of individual datasets included ranged from 8 to 29, for a total of 113 datasets. A dataset is defined here as a series of data points obtained from the incubation of an amendment under specific conditions. The number of datasets was higher for some groups than the number of amendments when the same amendment was incubated at different temperatures or with different soils. The total number of observations was 647 for all datasets combined. Therefore, an average of 5.7 observations were reported per dataset over the course of the incubation.

2.2 | Model fitting

A simple N turnover model adapted from CERES Maize (Godwin & Jones, 1991; Jones & Kiniry, 1986) was used to simulate N mineralization and immobilization from SOM and the added organic materials.

The model divides added fresh organic material (FOM) into a fast, slow, and recalcitrant pool (FOM1, FOM2, and FOM3, respectively). Each pool has its own decomposition rate (FOM1DR, FOM2DR, and FOM3DR). In addition, N in SOM is mineralized. All pools were entered as mg kg^{-1} soil. The decomposition rates of SOM (SOMDR) were fixed at 0.000083 (Jones & Kiniry, 1986). The same decomposition rate was chosen for FOM3 (FOM3DR). At this rate, 3% of the organic N is mineralized in 1 yr under optimal moisture content and no temperature correction. The decomposition rates of FOM1 and FOM2 were fit to the combined datasets in each group of material but were not allowed to be lower than FOM3DR.

As the incubation temperatures varied across datasets, ranging from 5 to 30 ˚C (Table 1), a temperature correction factor (TFAC) was included in the model. The factor was calculated based on a common exponential equation:

$$\mathrm{TFAC} = Q_{10}^{\left(\frac{T-25}{10}\right)} \tag{2}$$

where the Q_{10} value is the factor by which a 10 ˚C increase in temperature (T) will increase the rate of the process. The TFAC is 1 at a temperature of 25 ˚C. The Q_{10} value was included as an unknown and determined during model fitting for each group of materials. It was constrained between 1 and 4, which is the range commonly reported in the literature for N mineralization in this temperature range (Kirschbaum, 1995). No adjustments for suboptimal soil moisture content were made, and a constant moisture correction factor (MFAC) of 1 was used for all simulations because the incubations were all carried out at optimal soil moisture contents.

The potential decomposition rate of the material (RDECR) was calculated in daily time steps as the weighted average of the three pools and their decomposition constants:

$$\mathrm{RDECR} = \left(\frac{\mathrm{FOM1} \times \mathrm{FOM1DR} + \mathrm{FOM2} \times \mathrm{FOM2DR} + \mathrm{FOM3} \times \mathrm{FOM3DR}}{\mathrm{FOM1} + \mathrm{FOM2} + \mathrm{FOM3}}\right) \tag{3}$$

The initial mineral N (NMIN) in the soil was calculated as the sum of residual soil mineral N plus mineral N in the added materials; NMIN was the sum of ammonium-N and nitrate-N. The organic N in the FOM (FONORG) was calculated by subtracting mineral N in the FOM from its total N (FON).

The C/N ratio (CNR) of the C and N available for microbial degradation was calculated as the total C in the added materials (FOC) divided by the sum of NMIN and organic N in the materials:

$$\mathrm{CNR} = \left(\frac{\mathrm{FOC}}{\mathrm{NMIN} + \mathrm{FONORG}}\right) \tag{4}$$

A C/N ratio factor (CNRF) was then calculated as described in the CERES-N model (Jones & Kiniry, 1986):

$$\mathrm{CNRF} = e^{\left[-0.693 \times \left(\frac{\mathrm{CNR}-25}{25}\right)\right]} \tag{5}$$

The CNRF was constrained between 0 and 1. The value for CNRF drops below 1 when CNR increases above 25 and then decreases with increasing CNR and slows down mineralization when N is limiting. The fraction of added material that mineralizes each day (DECR) was calculated as

$$\mathrm{DECR} = \mathrm{RDECR} \times \mathrm{CNRF} \times \mathrm{TFAC} \times \mathrm{MFAC} \tag{6}$$

For model fitting, DECR was calculated by moving TFAC from the numerator to the denominator to adjust the decomposition rate to the standard temperature of 25 ˚C and to determine the best Q_{10} value. The gross N mineralization from the added material (GMFOM) was calculated as

$$\mathrm{GMFOM} = \mathrm{FONORG} \times \mathrm{DECR} \tag{7}$$

The gross rate of N immobilization associated with the added material (GIFOM) was assumed to be the minimum of mineral N available for immobilization (NMIN) and the demand for N when FOM is decomposed by soil microorganisms

$$\mathrm{GIFOM} = \min(\mathrm{NMIN}, \mathrm{DECR} \times \mathrm{FOC} \times 0.4 \times 0.125) \tag{8}$$

where 0.4 represents the C use efficiency of the microorganisms, and 0.125 is a N/C ratio of the microbial biomass. Both were considered constants (Jones & Kiniry, 1986). Net N mineralization (NMFOM) was then calculated as

$$\mathrm{NMFOM} = \mathrm{GMFOM} - \mathrm{GIFOM} \tag{9}$$

All FOM pools were updated daily, as shown for the FOM1 pool:

$$\mathrm{FOM1}_t = \mathrm{FOM1}_{t-1} \times \mathrm{FOM1DR} \times \mathrm{TFAC} \times \mathrm{MFAC} \times \mathrm{CNRF}_{t-1} \tag{10}$$

where t refers to the current day's values, and t−1 refers to the previous day's values. FOM1DR, TFAC, and MFAC were constants and did not change during the course of the incubation. Net N mineralization from the soil organic N pool (NMSOM) was calculated as

$$\mathrm{NMSOM} = \mathrm{SON} \times \mathrm{SOMDR} \times \mathrm{TFAC} \times \mathrm{MFAC} \tag{11}$$

where SON is the soil organic N pool. The SON pool was updated daily:

$$\mathrm{SON}_t = \mathrm{SON}_{t-1} - \mathrm{NMSOM}_{t-1} \tag{12}$$

The soil mineral N pool was updated daily:

$$\mathrm{NMIN}_t = \mathrm{NMIN}_{t-1} + \mathrm{NMFOM}_{t-1} + \mathrm{NMSOM}_{t-1} \tag{13}$$

Ammonia volatilization and denitrification were not simulated for the following reasons. The studies included in our analysis were carried out at soil moisture contents that should ensure aerobic conditions (most commonly 40–60% of the soils' water holding capacity). This soil moisture content minimizes the risk of large N losses due to denitrification. Ammonia volatilization losses can be greatly reduced when materials are incorporated into the soil (Sommer & Hutchings, 2001). Furthermore, the simulation of denitrification and ammonia volatilization would require input values that were not provided in most of the studies included in this analysis, such as bulk density and water content at saturation for denitrification or rate constants for urea hydrolysis and nitrification for ammonia volatilization.

The model was run in daily time steps in Excel. Each dataset was modeled independently using the input data reported in the article, such as C/N ratio, application rate, or temperature. All materials within a particular group were assumed to share common FOM pool sizes (expressed as a fraction of FOM), decomposition rate constants of the different pools (e.g., FOM1DR), and Q_{10} values.

To describe N turnover kinetics, Excel's Solver was used to fit the model to the observed values for mineral N from the added materials. Solver uses the Generalized Reduced Gradient algorithm, which is based on work by Ladson et al. (1974). The best values for FOM1, FOM2, FOM3, FOM1DR, FOM2DR, and Q_{10} for each group of materials (e.g., feather meal) were determined by minimizing the sum of squared differences between observed and predicted values of mineral N derived from the added materials for those days where values were reported. The procedure was repeated several times with different starting values for the unknowns to ensure that the solution did not represent a local minimum. With the exception of feather meal, model fitting for the different groups of material resulted in one of the three pools having a size of or close to zero. Therefore, the model was reduced by eliminating the recalcitrant pool FOM3 with a fixed rate constant. This only slightly reduced model performance for feather meal. Because the decomposition rate constant of the slow pool was allowed to drop to the level of the recalcitrant pool, materials could still have a recalcitrant pool.

The agreement between observed and simulated values for mineral N derived from the added amendments (expressed in % of total N added) was evaluated using the bias, RMSE, and model efficiency (EF). The bias measures the average difference between measured and calculated values. If the model underpredicts, on average, the bias is positive; conversely, if the model overpredicts, on the average, the bias is negative:

$$\text{Bias} = \frac{1}{n}\Sigma_{i=1}^{n}(O_i - P_i) \tag{14}$$

where n is the total number of observations, O_i is the observed value for the ith situation, and P_i is the corresponding value predicted by the model. The RMSE is another measure for the error in the dataset:

$$\text{RMSE} = \sqrt{\frac{\Sigma_{i=1}^{n}(O_i - P_i)^2}{n}} \tag{15}$$

Furthermore, the ratio between RMSE and the standard deviation of the observations (RSR) was calculated. The RSR standardizes RMSE using the observations standard deviation (Moriasi et al., 2007).

The EF is a measure of the deviation between model predictions and observed values relative to the scattering of the observed data:

$$\text{EF} = 1 - \frac{\Sigma_{i=1}^{n}(O_i - P_i)^2}{\Sigma_{i=1}^{n}(O_i - \bar{O})^2} \tag{16}$$

where $\bar{O}$ is the average of the observed values. If the model is perfect, EF = 1. A model that gives EF = 0 has the same degree of agreement with the data as using the overall average to predict for every situation (Wallach, 2006). For the model evaluation, the initial mineral N values from Day 0 were excluded because they represented the amount of mineral N in the materials and did not differ between observed and predicted values. Model efficiency and RSR were evaluated based on guidelines by Moriasi et al. (2007).

Once the best values for the different pools and their decomposition rates were found, the model was used to simulate N turnover of materials with the minimum, average, and maximum C/N ratio in each group. For these simulations, we assumed a SOM content of 2% and an application rate of 1,000 kg ha^{-1} incorporated into the top 15 cm of the soil with a bulk density of 1,300 kg m^{-3}. The simulation was done for 100 d at optimal moisture content (MFAC = 1) and 25 ˚C (TFAC = 1). The duration of the incubations in the studies included in our analysis ranged from 45 to 365 d, with an average and medial duration of 103 and 84 d, respectively. To facilitate comparison of the different groups of amendments, a simulation duration of 100 d was chosen for all groups.

3 | RESULTS AND DISCUSSION

The protocols for the incubations differed considerably across the studies included in our analysis. Although all incubations were carried out at a constant temperature, the temperature chosen ranged from 5 to 30 ˚C (Table 1). The duration of the incubations also varied, ranging from 45 to 365 d. Both temperature and duration most likely contributed to the wide range of mineral N observed at the end of the incubations (Table 2). Differences in final mineral N contents were especially large for poultry manure, where values ranging from 3 to 75% of total N were reported. Other factors contributing to the observed variability in the final mineral N content were the C/N ratio of the materials and the proportion of total

TABLE 2 Characteristics of the amendments used in this study

Group of amendments	C/N ratio		Initial mineral N	Final mineral N
	Average	Range		
			% of total N	
Guano	2.8	1.2–3.8	2.2–55.1	50.3–87.9
Feather meal	4.0	3.3–10.0	0–16.0	55.0–77.4
Poultry manure	10.3	6.3–19.5	3.3–36.8	2.9–75.0
Poultry manure compost	7.3	5.7–9.4	12.6–25.1	24.6–54.0
Vermicompost	11.1	14.9–35.0	1.0–17.8	−38.8–8.0
Yard waste compost	16.1	9.1–22.3	0.1–8.4	−4.0–25.1

Note. The C/N ratios shown are the average and the range (lowest and highest ratio) for each amendment. The values for initial and final mineral N show the range of the observed values for each material. For references, see Table 1.

TABLE 3 Pool sizes of the organic materials (FOM1 and FOM2; expressed as a fraction of the material) and their respective decomposition rates (FOM1DR, FOM2DR; day^{-1}); temperature sensitivity factor (Q_{10}); and measures of model performance, including model efficiency (EF), bias, RMSE (expressed in % of total N in materials), and the RMSE to standard deviation ratio (RSR)

Group of amendments	FOM1	FOM2	FOM1DR	FOM2DR	Q_{10}	EF	Bias	RMSE	RSR
Guano	0.62	0.38	0.1278	0.002518	1.0	0.67	0.2	10.9	0.57
Feather meal	0.65	0.35	0.1606	0.000809	1.0	0.47	0.1	10.2	0.72
Poultry manure	0.49	0.51	0.0460	0.000083	2.0	0.07	−1.6	18.6	0.96
Poultry manure compost	0.30	0.70	0.0361	0.000083	1.0	0.18	0.2	7.8	0.90
Vermicompost	0.09	0.91	0.0775	0.000160	4.0	0.68	−0.7	5.7	0.56
Yard waste compost	1.00	–	0.0013	–	4.0	0.17	−0.6	5.1	0.91

N initially in the form of mineral N (Table 2). By using a model that takes into account the major factors affecting N turnover, the variability caused by these factors can potentially be reduced, allowing for more robust estimates of N availability from organic amendments.

3.1 | Model performance

The EF differed widely across materials (Table 3). The model was most efficient in predicting N mineralization from guano, from vermicompost, and to a lesser degree from feather meal. In the case of vermicompost, the EF could have been even higher had the model not underpredicted the strong N immobilization of one material with a C/N ratio of 35. This vermicompost was produced with waste from palo santo [*Bursera graveolens* (Kunth) Triana & Planch] fruits, which had a C/N ratio of 30:1 and a pH of 4.5 (Carrión-Paladines et al., 2016). An outlier with a C/N ratio of 10 was also among the feather meals (Gale et al., 2006). It is possible that this sample was contaminated with poultry manure. Except for these outliers, guano, vermicompost, and feather meal had a relatively narrow range in their C/N ratio, suggesting that these are generally uniform materials (see below for a more detailed discussion). Overall, the model performed well for guano and vermicompost (EF between .65 and .75) but was unsatisfactory in the case of feather meal (EF < .5). The RSR was also good for guano and vermicompost (RSR between 0.5 and 0.6) but again was unsatisfactory for feather meal (RSR > 0.7). When evaluating model efficiency, it needs to be kept in mind that the incubations were carried out with different soils by different laboratory groups each using their own protocol and setup. Soil type, as well as preparation of the samples and their handling during the incubation, can contribute considerably to the variability observed when results from different studies are included (Sradnick & Feller, 2020).

The model predictions were unsatisfactory for poultry manure, poultry manure compost, and yard waste compost. In all cases, the RSR exceeded 0.9. With EF values ranging from .07 to .18, the modeled N mineralization rates were only slightly better than simply using the average value for each material. In the case of yard waste compost, the amount of N mineralized is low, so that small differences among samples analyzed over time from the same material can have a strong effect on EF. In fact, the amount of yard waste compost N in the mineral form did not always follow a smooth pattern over the course of the incubation (e.g., Cassity-Duffey et al., 2020; Lazicki et al., 2020; Masunga et al., 2016). This is likely due to small differences across samples analyzed and is unavoidable when a different sample is analyzed for each time point

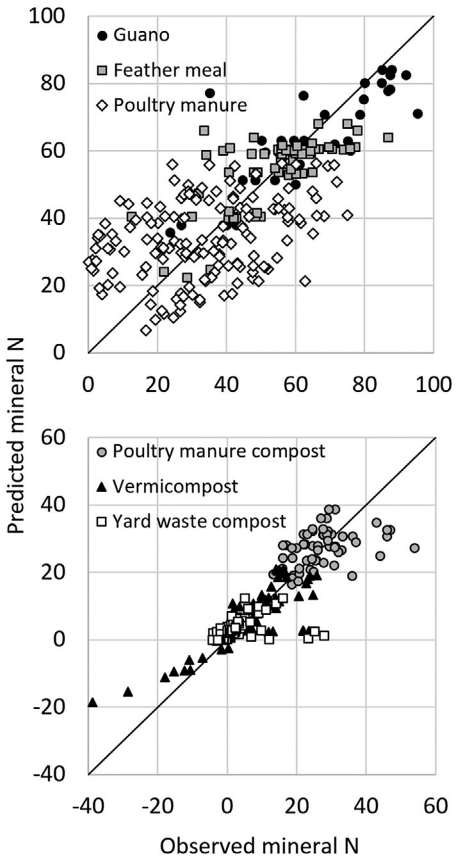

FIGURE 1 Comparison of the observed and predicted mineral N values, expressed in percentage of total N added with the materials. Negative values indicate N immobilization

during the incubation. These differences have a strong effect on model performance with materials, with very small changes in mineral N over time. To a lesser degree, this may also have contributed to the poor EF of poultry manure compost. Poultry manure was the most variable material. This variability is evident in Table 2 and likely led to the poor correlation between observed and predicted values (Figure 1). Some factors likely contributing to the variability in material characteristics are discussed below. Most studies provided little additional information about the materials beyond what is reported in Tables 1 and 2. Especially a characterization of different N or C pools may help improve model performance (see following sections). Therefore, with the data available it is not possible to correlate the FOM pool sizes or their rate constants with the measured size of C and N pools in the materials. For the more variable materials, there is clearly a need to identify properties that can be included in models to improve predictions of N mineralization.

In addition to material properties, the differences in incubation protocols used in individual studies likely contributed to the observed variability and the poor model performance. Protocols for incubations are not standardized. As an example, poultry manure was dried and sieved to pass a 1- or 2-mm screen in some studies included in this analysis (Abbasi & Khaliq, 2016; Palomino et al., 2019), whereas moist samples were incorporated into the soil in other studies (Gale et al., 2006; Gordillo & Cabrera, 1997). Other approaches included applying the manure as a slurry (Sims, 1986) or in the form of pellets (Dion et al., 2020). These pretreatments likely affect N mineralization, especially during the initial stages of the incubation.

3.2 | Guano and feather meal

Nitrogen from guano becomes rapidly plant available. This is reflected in the fact that 62% of the material was in the fast pool, which had a decomposition rate of 0.128 d^{-1} (Table 3). The slow pool had a decomposition rate of 0.0025 d^{-1}. After 100 d of simulated incubation of a material with an average C/N ratio of 2.8, t model predicted that 72.5% of the total N would be in the mineral form, half of which would be in the mineral form after only 3 d, including the initial mineral N in the material (Figure 2). Only four studies with a total of eight datasets were included in the evaluation of guano (Table 1). This may have contributed at least in part to the relatively uniform C/N ratio across materials, which ranged from 1.2 to 3.8 in the studies included in our analysis. On average, 24% of the total N in guano was already in the mineral form; however, this value ranged from 2.2 to 55.1%.

Feather meal, which is a byproduct of poultry processing plants, is a uniform material. It contains 90% protein, mainly nonsoluble keratin that is stabilized by disulfide bonds (Hadas & Kautsky, 1994). With the exception of one batch with a C/N ratio of 10.0, the C/N ratios across the other seven materials included in our analysis ranged from 3.3 to 4.0 (Table 2). Although the same material with the wide C/N ratio also had a large proportion of the total N in the mineral form (16%), the mineral N was below 1.6% of total N in all other materials. Nitrogen availability across the 14 datasets from seven individual studies was best simulated with 65% of the material being in the fast pool, mineralizing at a rate of 0.161 d^{-1} and 38% in the slow pool, with a mineralization rate of 0.00081 d^{-1} (Table 3).

For a material with an average C/N ratio, our model predicted that 61% of total N would be in the mineral form after 100 d of incubation, with half of that being in the mineral form after only 5 d of incubation (Figure 2). Therefore, feather meal is a readily available source of N.

A comparison of feather meal with guano shows that approximately two-thirds of both materials are in the fast pool. The decomposition rate of the fast pool was about 25% higher for the feather meal than for the guano, whereas the decomposition rate of the slow guano pool was more than three times higher than the one for feather meal. With both materials, a large proportion of the N is released within the first few days

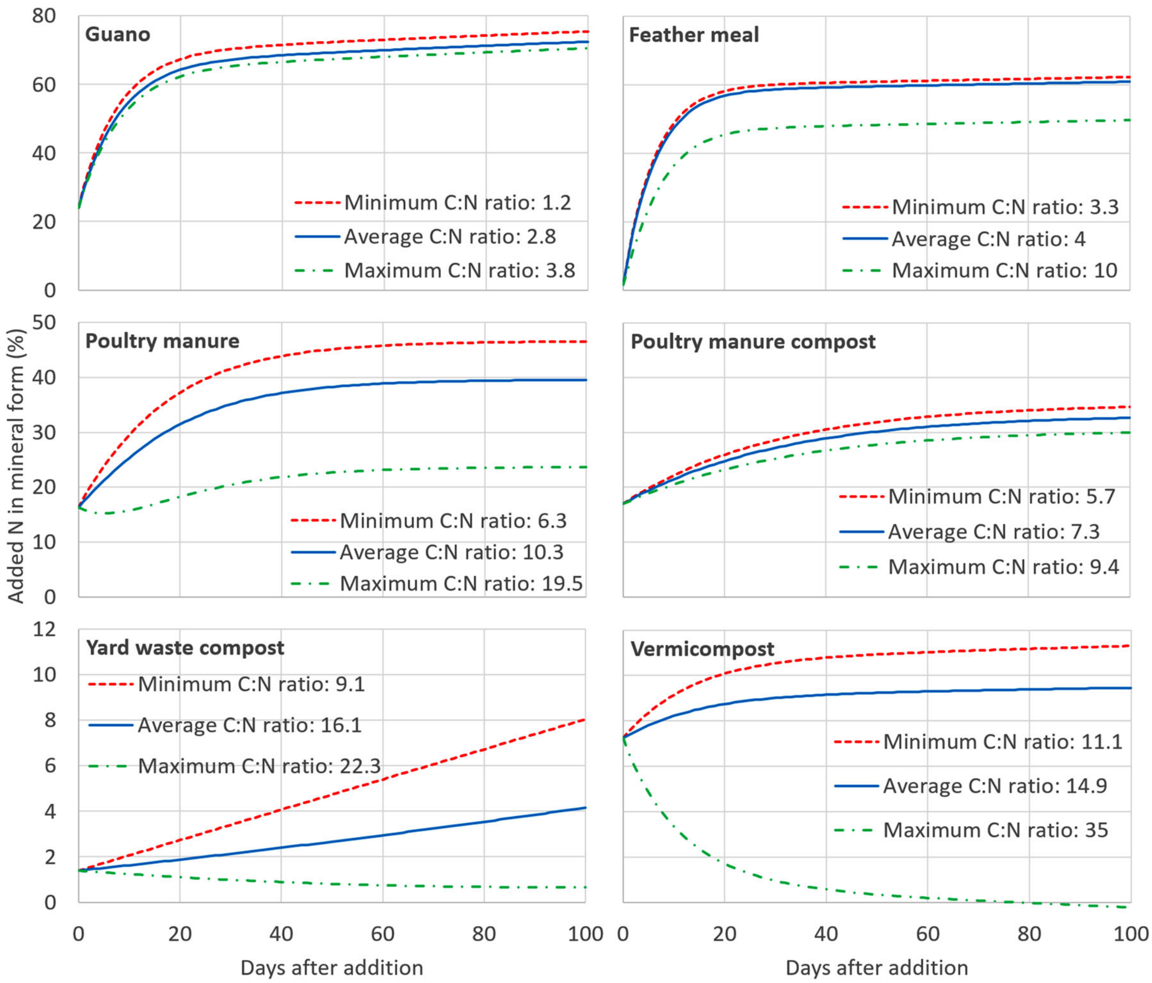

FIGURE 2 Simulated N turnover from organic fertilizers and composts based on average, minimum, and maximum C/N ratios from the literature survey. The model calculations assumed optimal moisture content and a constant temperature of 25 °C

when incorporated into warm and moist soil. The organic N fractions in feather meal and guano consist mainly of protein and uric acid, respectively (Lucassen et al., 2017; Papadopoulos, 1985), both of which are readily mineralized in soil, as our analysis shows. A slightly larger proportion of the total N in guano becomes plant available within 100 d of incorporation into warm and moist soil (70–75%) than for feather meal (50–65%). With both materials, most of the N was released within the first 20 d of the simulated incubation. The comparatively low decomposition rate of the slow feather meal pool was the reason why very little N was mineralized after 20 d of the simulated incubation. Whether this difference between the two materials is real or due to the datasets included cannot be said because the incubation conditions differed among studies. Different samples of both materials would need to be incubated under identical conditions to address this question. However, the analysis clearly shows that both materials are readily available N sources. Continuing the simulation until Day 200 would only slightly increase the amount of plant available N. For feather meal with an average C/N ratio, N availability would increase from 60.9 to 68.5% and for guano from 72.5 to 77.8%.

Net N mineralization of readily available materials, such as feather meal and guano, can also be simulated using a simple one- or two-pool kinetic model for N mineralization (Equation 1). However, entering the rate constants determined in this study into Equation 1 would result in an overestimation of net N mineralization. As an example, whereas 60.9 and 72.5% of the total N in feather meal and guano, respectively, become plant available within 100 d, using the same rate constants and pool sized in a two-pool model (Equation 1) would result in N availability of 68.5 and 77.8%, respectively. The reason for this is that the rate constants in the model used in this study are used to calculate gross N mineralization (Equation 7). Net N mineralization is then calculated by subtracting gross immobilization (Equation 9).

Studies have shown that feather meal has a very similar N mineralization pattern to fish powder (Gaskell & Smith, 2007; Hartz & Johnstone, 2006), while a slightly larger proportion of the N becomes available when blood meal is incorporated into soil. On average, studies reported that the proportion of total N mineralized is 7% higher for blood meal compared with feather meal (Cassity-Duffey et al., 2020; Dion et al., 2020; Gaskell & Smith, 2007; Hartz & Johnstone, 2006; Lazicki et al., 2020).

3.3 | Poultry manure and poultry manure compost

The properties of poultry manure can be highly variable. Factors contributing to this variability are type of bedding material used, proportion of bedding material in the manure and storage conditions (Gordillo & Cabrera, 1997). In the 29 datasets included in our analysis, the C/N ratio ranged from 6.3 to 19.5 (Table 2), while the mineral N in the manure ranged from 3.3 to 36.8% of the total N.

In our datasets, 16.3% of total N was on average present as mineral N in the material. At the end of the 100-d simulation period, 39.6% of total N from a material with an average C/N ratio of 10.3 was in the mineral form, while 23.7 and 46.6% were in the mineral form for the manure with the highest and lowest C/N ratio, respectively (Figure 2). Extending the simulation to 200 d increased the available N from an average material from 39.6 to 39.9%. In our simulation, the poultry manure with a C/N ratio of 19.5 caused net N immobilization during the first 2 d. Subsequently, net N mineralization took place, and the initial mineral N level was reached after 13 d. The model predicts net N immobilization when the C/organic N ratio in the materials exceeds 20 (Equations 7 and 8). With a mineral N content of 11.7% in this material, the threshold C/total N ratio above which N immobilization takes place was 17.7. This is in line with other studies, where the threshold was found to be between 14:1 and 19:1 for a wide range of organic amendments (Calderón et al., 2005; Gale et al., 2006; Lazicki et al., 2020). Whether net N immobilization took place in the incubation of this manure cannot be said because the first measurement was done after 30 d in the study by Palomino et al. (2019).

Even though our model took the C/N ratio and initial mineral N content into account, the model efficiency was low (Table 3). These low values reflect the fact that poultry manure as a fertilizer type is highly heterogeneous. Some of the factors contributing to this heterogeneity are amount and type of bedding material, conditions during storage, processing (e.g., pelleting) and particle size (Nahm, 2005). Properties other than C/N ratio may need to be taken into account to accurately predict net N mineralization from different poultry manures. Gordillo and Cabrera (1997) used a two-pool model (Equation 1) to describe the N mineralization pattern of 15 broiler litters. They found that uric acid N was well correlated with the size of the fast pool, whereas the C/N ratio was the best predictor for the slow pool; however, the correlation was weaker.

The poultry manure composts were a more homogeneous group than the fresh poultry manures. This may be in part due to the smaller dataset of 16 but also reflects the fact that composting generally results in the buildup of more recalcitrant material and reduced N mineralization (Castellanos & Pratt, 1981; Gale et al., 2006). Our observation is in line with Preusch et al. (2002), who found that composting yielded a more predictable and reliable source of mineralizable N than fresh litter. On average, 17% of the total N in the poultry manure composts were in the mineral form at the start of the incubations, with values ranging from 12.6 to 25.1%. At the end of the 100-d simulation, 32.7% of the total N from a material with an average C/N ratio was in the mineral form (Figure 2). For the materials with the highest and lowest C/N ratio, these values were 30.0 and 34.6%, respectively. Therefore, only a small proportion of the organic N mineralized during the simulation. Extending the simulation to 200 d increased the available N from an average material from 32.7 to 33.4%.

Both poultry manure and poultry manure compost have a recalcitrant pool. In our simulation the decomposition rate of this pool was not allowed to be lower than the decomposition rate of SOM, which results in an annual decomposition rate of 3%. The decomposition rate of the fast pool was 0.0460 d^{-1} for poultry manure and 0.036 d^{-1} for poultry manure compost (Table 3). In addition, the proportion of poultry manure in the fast pool was larger than for poultry manure compost. In poultry manure, roughly half the material was in the fast pool, whereas only one-fifth of the composted poultry manure was in the fast pool. Therefore, the difference in N mineralization between these two materials is due to both the proportion of material in the fast pool and its decomposition rate.

3.4 | Yard waste compost and vermicompost

The yard waste composts included in our analysis had a relatively wide C/N ratio, ranging from 9.1 to 22.3 (Table 2). The type of raw material used and compost maturity are major factors contributing to this variability (Campitelli & Ceppi, 2008). As an example, Brewer and Sullivan (2003) found that mature yard waste composts had a C/N ratio of 12:1. Starting with raw materials with a C/N ratio of 22:1, the C/N ratio approached 12:1 over a period of 98 d. Although the amount of mineral N in the materials included in our study ranged from 0 to 8.4% of total N, the median value across the 19 materials was only 0.6%. The model that best fit the data was a one-pool model with a decomposition rate of 0.0013 d^{-1}. Whereas the simulation of a yard waste compost with a C/N ratio of 22.3 resulted in net N immobilization during the first 100 d after incorporation, the incorporation of compost with an average C/N ratio of 16.1 resulted in net N mineralization. However, at the end of the 100-d simulation, only 4.1%

of the N in the average material was present in the mineral form. Even with a narrow C/N ratio of 9.1, the simulation predicted that only 8% of the total N would be in the mineral form after 100 d. Over the next 100 d, this value would only increase to 14.5%. Across the 25 datasets included in our analysis, the EF was low (Table 3), suggesting that the quality of the C and N pools may be more relevant than the overall C/N ratio. Although the quality of the C and N pools seems to vary considerably across different materials, a one-pool model performed as well as a two-pool model. This finding suggests that the yard waste composts included in this analysis did not contain a readily available pool that mineralized quickly and that the composting process resulted in a relatively uniform and stable material. The quality of this material, however, and therefore the N mineralization rate, can vary across different composts. Factors affecting quality include type of raw material, maturity of the compost, as well as conditions and treatments during and after composting (Amlinger et al., 2003). Therefore, a model that estimates the N mineralization potential solely on C/N ratio of yard waste composts is not adequate. With more data available, it may be possible to divide yard waste composts into more uniform groups, each with its own pool sizes and decomposition rates. However, although there is uncertainty in the amount of N mineralized from a specific yard waste compost, the proportion of the total N that becomes available for the following crop is small. In a literature review, Amlinger et al. (2003) found that the immediate N effect in the first year is <15% for biowaste and yard waste composts.

The vermicomposts included in our analysis differed in their C/N ratios, ranging from 11.1 to 35, and the proportion of mineral N initially present ranged from 1 to 17.8% of total N. These wide ranges reflect the variability in raw materials used to produce the composts. The fast pool accounted for only 9% of the material and had a rate constant of 0.078 d^{-1}. Across all materials included, 91% was in the slow pool, which had a rate constant of 0.00016 d^{-1}. This is about double the rate constant assumed for SOM. Due to the large slow pool with a low rate constant, only 9.5% of the total N was present in the mineral form when N turnover of a vermicompost with an average C/N ratio of 14.9 was simulated for 100 d. Net N mineralization was very low because 7.2% of total N was already in the mineral form when the simulation started. Only 0.3% of the total N would mineralize during the next 100-d period. Simulating a vermicompost with a C/N ratio of 35 resulted in net N immobilization throughout the 100-d simulation. Net N immobilization slightly exceeded the amount of mineral N initially present in the average material, resulting in the negative values after 85 d seen in Figure 2. In reality, immobilization of mineral N from soil solution would likely be more pronounced. The simulations shown in Figure 2 were done to illustrate the effect of different C/N ratios. For this reason, the average initial mineral N content of the materials in each group was used for the simulation of materials with average, minimum, and maximum C/N ratios. Vermicomposts with a wide C/N ratio are likely produced under N limiting conditions, and the mineral N content in these materials is likely lower than the average found in the materials included in our study. This was indeed the case with the material with the wide C/N ratio (Carrión-Paladines et al., 2016). Figure 1 suggests that the model underpredicted N immobilization. This is due to one material produced with waste from *Bursera graveolens* fruits after essential oil extraction (Carrión-Paladines et al., 2016). Due to the small sample size, it cannot be determined whether the model in general underpredicts N immobilization or whether this specific material is an outlier among vermicomposts.

Yard waste compost and vermicompost can have widely different C/N ratios, which is likely due to the raw materials used (Campitelli & Ceppi, 2008). Both are stable materials with low rate constants, resulting in low N mineralization rates during a growing season. This means that a large proportion of these materials is left in the soil, contributing to an increase in SOM content and soil fertility when applied repeatedly (Amlinger et al., 2003; Gutser et al., 2005). An important difference between the two materials is that vermicompost, in contrast to most yard waste composts, can contain mineral N, which is directly plant available when applied. Therefore, with the exception of the mineral N in vermicompost, these materials contribute little N to the following crop. Repeated application, however, can increase soil fertility in the long term.

3.5 | Temperature sensitivity

In general, Q_{10} values have been found to increase with increasing recalcitrance of the material decomposing. In an incubation study with different plant litters, Fierer et al. (2005) found that litter decomposition became more sensitive to temperature as the overall quality of the litter organic C declined, with Q_{10} values ranging from 2.1 to 3.4. Similarly, Leifeld and Fuhrer (2005) reported that SOM compounds that decomposed more slowly were more sensitive to increased temperature.

With the exception of poultry manure compost, this was also the case in our dataset (Table 3). However, the Q_{10} values found in our study need to be interpreted with care. For example, the model revealed that most of the N in feather meal and guano is made available within the first 20 d after incorporation. In our dataset, only one-third of all observations were made during the first 20 d after application. Therefore, there may not have been enough observations during the period when temperature affects the N mineralization rate most to result in a robust Q_{10} value. Furthermore, in the case of poultry manure, yard waste compost, and vermicompost, all

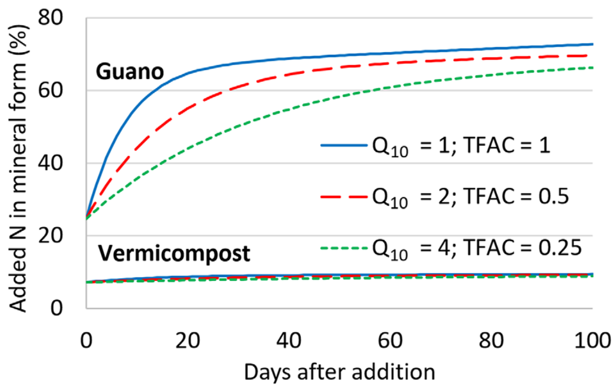

FIGURE 3 Simulation of mineral N from guano and vermicompost with an average C/N ratio at a temperature of 15 ˚C, using different Q_{10} values (factor by which a 10 ˚C increase in temperature will increase the rate of the process) for temperature adjustment. TFAC, temperature correction factor used in the model

incubations were carried out within a relatively narrow temperature range of 20–30 ˚C.

The importance of appropriate Q_{10} values was explored by simulating N mineralization from guano and vermicompost with an average C/N ratio at 15 ˚C. Three different Q_{10} values were used, namely 1, 2, and 4. With a Q_{10} value of 1, the TFAC is also 1, meaning that there is no temperature effect and that N mineralization at 15 ˚C is identical to N mineralization at 25 ˚C.

The Q_{10} value had a strong effect of the N availability from guano during the first few weeks after incorporation (Figure 3). Guano was chosen here to represent readily available amendments. After 10 d of incubation at 15 ˚C, the simulation predicted that 55.5% of the total N in guano was in the mineral form with a Q_{10} value of 1. In contrast, only 35.7% was available with a Q_{10} of 4. After 100 d, the differences were much less pronounced; 72.7 and 66.3% of the total N in guano were in the mineral form, with Q_{10} values of 1 and 4, respectively.

In the case of vermicompost, which was used to represent stable amendments, the effect of the Q_{10} value was less pronounced. After 10 d, 8.2% of the total N were in the mineral form with a Q_{10} value of 1, while 7.5% were available with a Q_{10} value of 4. After 100 d, 9.5 and 8.9% of the total N in vermicompost were in the mineral form, with Q_{10} values of 1 and 4, respectively. The small numeric differences indicate that it can be challenging to develop robust Q_{10} values for stable materials.

Figure 3 can also be used to explore the effects of soil water content. Changes in the soil moisture factor MFAC due to dry soil are treated by the model in the same way as changes in TFAC (Equations 6, 10, and 11). How much a certain decrease in gravimetric or volumetric soil water content affects N mineralization depends on soil texture. Paul et al. (2003) used different equations to simulate the effect of soil water content on N mineralization. They found a good fit (EF = .72 with 390 observations from different studies) when soil water content was expressed as relative water content. The relative water content is the difference between the measured soil water content and the water content at the permanent wilting point, divided by the difference between the water content at saturation and the water content at the permanent wilting point. In the best-fit equation, the MFAC was 1 at a relative water content was 0.7 and decreased linearly with lower water contents, reaching 0.42 at the permanent wilting point. Therefore, in Figure 3, the line for a TFAC of 1 can be considered identical to the line when samples are incubated at 25 ˚C and optimal water content (MFAC = 1), whereas the line representing a TFAC of 0.5 slightly over-predicts N availability in samples incubated at 25 ˚C and a water content at the permanent wilting point (MFAC = 0.42).

3.6 | Significance for nutrient management

The literature review revealed that N availability from organic amendments range from N immobilization to nearly 90% (Table 2), highlighting the large variability in N availability across different groups of amendments. Most of these studies investigated a limited number of locally relevant amendments. Analyses of N mineralization data across studies are rare because incubation procedures used in individual studies differ with respect to temperatures and length of incubation, making the comparisons across studies challenging. In the current study, we addressed this issue by using a model with daily time steps and a temperature correction factor.

Although there was considerable variation within some groups of amendments, the results of this analysis provide valuable estimates of the amount and timing of N availability for typical materials of each amendment group based on 113 datasets from various studies. This information can support farmers and consultants making informed management decisions.

Readily decomposable organic amendments with a narrow C/N ratio, such as guano, feather meal, and some poultry manures can contribute a considerable amount of N to the following crop. These amendments release a large proportion of that N during the first weeks after application (Figure 1). Because crop N uptake is low for several weeks after seeding, the application of these amendments can result in a buildup of nitrate in the soil profile, which is prone to leaching below the root zone with heavy rainfall or irrigation (Sims et al., 1993). Readily available amendments should therefore not be applied far in advance of seeding (Bitzer & Sims, 1988). Furthermore, careful irrigation water management is crucial during the early stages of crop growth in order to keep the nitrate in the rootzone.

In contrast, more stable amendments, such a vermicompost or yard waste compost, release N very slowly and may even cause net N immobilization, which reduces the crop-available N in the soil profile. Unless very large amounts are added, these materials may be applied some time before planting so that the N immobilization phase is complete by the time plants depend on soil N for growth. Their contribution to the N available for individual crops is relatively small. However, with repeated applications these materials can increase soil fertility and health in the long term.

4 | CONCLUSIONS

Our literature survey highlights the variability in N availability across and within groups of organic fertilizers and composts. The model used in this study simulated N availability from guano and vermicompost well across datasets from different studies. In the case of feather meal, poultry manure, poultry manure compost, and yard waste compost, the model efficiency was <0.5 and therefore needs to be considered unsatisfactory, suggesting that properties other than the C/N ratio can have a significant effect on N availability from these materials. Identifying and including these properties (e.g., uric acid in the case of poultry manure) in future models may lead to an improved accuracy of predictions. The variability observed within certain groups of organic amendments indicates where further research can help to improve N mineralization models. However, the information available for individual batches of commercial amendments is generally limited, making net N mineralization and immobilization predictions based on the C/N ratio often the best option available.

In addition to material properties, the differences in incubation protocols used in individual studies likely contributed to the observed variability and the low model performance. Standardizing incubation protocols would likely greatly reduce variability across studies. Because the protocols used often depend on the equipment available, this may be hard to achieve. Including a reference material as an additional treatment would facilitate the comparison of results from different studies. A good candidate for a reference material would be feather meal because it is a chemically uniform material, provided the batch is not contaminated with manure.

Model simulations revealed that the Q_{10} value has a strong effect on the amount of N that becomes available initially with readily available amendments, such as guano and feather meal. In contrast, the Q_{10} value has little effect on N availability of stable materials in a single season. However, accurate Q_{10} values are still required for the simulation of the long-term effects of these materials on soil fertility and soil organic matter content.

The datasets included in this analysis consisted of laboratory incubations carried out at optimal moisture content and constant temperature. Although conditions in the field can vary considerably, studies have found good correlations between N mineralization in laboratory incubations and N mineralization or crop N uptake in the field with the same soil type (Castellanos & Pratt, 1981; Gale et al., 2006; Haney et al., 2001). Therefore, with appropriate temperature and soil moisture corrections, the results of this study can help in estimating the amount and timing of N availability for typical amendments in the field. The model used in our analysis is relatively simple and can be adapted to local conditions and used as stand-alone application or incorporated into more comprehensive tools to provide guidelines for nutrient management. Combined with soil and plant tissue testing, the model used in this analysis can be a valuable tool to improve N management of organic amendments in crop production.

ACKNOWLEDGMENTS

We thank two anonymous reviewers and the Associate Editor for their valuable comments and suggestions. This work was funded by the California Department of Food and Agriculture, Fertilizer Research and Education Program (CDFA–FREP).

AUTHOR CONTRIBUTIONS

Daniel Geisseler: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing-original draft; Writing-review & editing. Mike Cahn: Conceptualization; Data curation; Investigation; Methodology; Writing-review & editing. Richard Smith: Conceptualization; Data curation; Investigation; Methodology; Writing-review & editing. Joji Muramoto: Conceptualization; Data curation; Funding acquisition; Investigation; Methodology; Project administration; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

ORCID

Daniel Geisseler https://orcid.org/0000-0002-5483-9982

REFERENCES

Abbasi, M. K., & Khaliq, A. (2016). Nitrogen mineralization of a loam soil supplemented with organic–inorganic amendments under laboratory incubation. *Frontiers in Plant Science*, *7*, 1038. https://doi.org/10.3389/fpls.2016.01038

Amlinger, F., Götz, B., Dreher, P., Geszti, J., & Weissteiner, C. (2003). Nitrogen in biowaste and yard waste compost: Dynamics of mobilisation and availability—a review. *European Journal of Soil Biology*, *39*, 107–116. https://doi.org/10.1016/S1164-5563(03)00026-8

Bitzer, C. C., & Sims, J. T. (1988). Estimating the availability of nitrogen in poultry manure through laboratory and field studies. *Journal of Environmental Quality*, *17*, 47–54. https://doi.org/10.2134/jeq1988.00472425001700010007x

Brewer, L. J., & Sullivan, D. M. (2003). Maturity and stability evaluation of composted yard trimmings. *Compost Science & Utilization*, *11*, 96–112. https://doi.org/10.1080/1065657X.2003.10702117

Burgos, P., Madejón, E., & Cabrera, F. (2006). Nitrogen mineralization and nitrate leaching of a sandy soil amended with different organic wastes. *Waste Management & Research*, *24*, 175–182. https://doi.org/10.1177/0734242X06062876

Cabilovski, R., Manojlovic, M., Bogdanovic, D., Cupina, B., Krstic, D., & Mikic, A. (2013). Estimation of potentially mineralizable N from fertilizers in organic agriculture. In E. Saljnikov (Ed.), *Proceedings of the 1st International Congress on Soil Science* (pp. 208–221). Soil Science Society of Serbia.

Calderón, F. J., McCarty, G. W., & Reeves, J. B. (2005). Analysis of manure and soil nitrogen mineralization during incubation. *Biology & Fertility of Soils*, *41*, 328–336. https://doi.org/10.1007/s00374-005-0843-x

Carrión-Paladines, V., Fries, A., Gómez-Muñoz, B., & García-Ruiz, R. (2016). Agrochemical characterization of vermicomposts produced from residues of Palo Santo (*Bursera graveolens*) essential oil extraction. *Waste Management*, *58*, 135–143. https://doi.org/10.1016/j.wasman.2016.09.002

Cassity-Duffey, K., Cabrera, M., Gaskin, J., Franklin, D., Kissel, D., & Saha, U. (2020). Nitrogen mineralization from organic materials and fertilizers: Predicting N release. *Soil Science Society of America Journal*, *84*, 522–533. https://doi.org/10.1002/saj2.20037

Castellanos, J. Z., & Pratt, P. F. (1981). Mineralization of manure nitrogen: Correlation with laboratory indexes. *Soil Science Society of America Journal*, *45*, 354–357. https://doi.org/10.2136/sssaj1981.03615995004500020025x

Campitelli, P., & Ceppi, S. (2008). Chemical, physical and biological compost and vermicompost characterization: A chemometric study. *Chemometrics & Intelligent Laboratory Systems*, *90*, 64–71. https://doi.org/10.1016/j.chemolab.2007.08.001

Contreras-Ramos, S. M., Álvarez-Bernal, D., & Dendooven, L. (2007). Dynamics of nitrogen in a PAHs contaminated soil amended with biosolid or vermicompost in the presence of earthworms. *Chemosphere*, *67*, 2072–2081. https://doi.org/10.1016/j.chemosphere.2006.10.069

Dion, P., Jeanne, T., Thériault, M., Hogue, R., Pepin, S., & Dorais, M. (2020). Nitrogen release from five organic fertilizers commonly used in greenhouse organic horticulture with contrasting effects on bacterial communities. *Canadian Journal of Soil Science*, *100*, 120–135. https://doi.org/10.1139/cjss-2019-0056

Eckhardt, D. P., Redin, M., Jacques, R. J. S., Lorensini, F., Santos, M. L. S., Weiler, D. A., & Antoniolli, Z. I. (2016). Mineralization and efficiency index of nitrogen in cattle manure fertilizers on the soil. *Ciência Rural*, *46*, 472–477. https://doi.org/10.1590/0103-8478cr20140958

Eckhardt, D. P., Redin, M., Santana, N. A., Conti, L., Dominguez, J., Jacques, R. J. S., & Antoniolli, Z. I. (2018). Cattle manure bioconversion effect on the availability of nitrogen, phosphorus, and potassium in soil. *Revista Brasileira de Ciência de Solo*, *42*, e0170327. https://doi.org/10.1590/18069657rbcs20170327

Fierer, N., Craine, J. M., McLauchlan, K., & Schimel, J. P. (2005). Litter quality and the temperature sensitivity of decomposition. *Ecology*, *86*, 320–326. https://doi.org/10.1890/04-1254

Gale, E. S., Sullivan, D. M., Cogger, C. G., Bary, A. I., Hemphill, D. D., & Myhre, E. A. (2006). Estimating plant-available nitrogen release from manures, composts, and specialty products. *Journal of Environmental Quality*, *35*, 2321–2332. https://doi.org/10.2134/jeq2006.0062

Gaskell, M., & Smith, R. (2007). Nitrogen sources for organic vegetable crops. *HortTechnology*, *17*, 431–441. https://doi.org/10.21273/HORTTECH.17.4.431

Godwin, D. C., & Jones, C. A. (1991). Nitrogen dynamics in soil-plant systems. In J. Hanks & J. T. Ritchie (Eds.), *Modeling plant and soil systems* (pp. 287–321). ASA, CSSA, and SSSA.

Gordillo, R. M., & Cabrera, M. L. (1997). Mineralizable nitrogen in broiler litter: II. Effect of selected soil characteristics. *Journal of Environmental Quality*, *26*, 1679–1686. https://doi.org/10.2134/jeq1997.00472425002600060031x

Gutser, R., Ebertseder, T., Weber, A., Schraml, M., & Schmidhalter, U. (2005). Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. *Zeitschrift für. Pflanzenernährung und Bodenkunde*, *168*, 439–446. https://doi.org/10.1002/jpln.200520510

Hadas, A., & Kautsky, L. (1994). Feather meal, a semi-slow-release nitrogen fertilizer for organic farming. *Fertilizer Research*, *38*, 165–170. https://doi.org/10.1007/BF00748776

Haney, R. L., Hons, F. M., Sanderson, M. A., & Franzluebbers, A. J. (2001). A rapid procedure for estimating nitrogen mineralization in manured soil. *Biology & Fertility of Soils*, *33*, 100–104. https://doi.org/10.1007/s003740000294

Hartz, T. K., & Johnstone, P. R. (2006). Nitrogen availability from high nitrogen-containing organic fertilizers. *HortTechnology*, *16*, 39–42. https://doi.org/10.21273/HORTTECH.16.1.0039

Hartz, T. K., Mitchell, J. P., & Giannini, C. (2000). Nitrogen and carbon mineralization dynamics of manures and composts. *HortScience*, *35*, 209–212. https://doi.org/10.21273/HORTSCI.35.2.209

Jones, C. A., & Kiniry, J. R. (1986). *CERES-Maize: A simulation model of maize growth and development*. Texas A&M University Press.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J., & Ritchie, J. T. (2003). The DSSAT cropping system model. *European Journal of Agronomy*, *18*, 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7

Kirschbaum, M. U. F. (1995). The temperature-dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. *Soil Biology & Biochemistry*, *27*, 753–760. https://doi.org/10.1016/0038-0717(94)00242-S

Ladha, J. K., Reddy, C. K., Padre, A. T., & van Kessel, C. (2011). Role of nitrogen fertilization in sustaining organic matter in cultivated soils. *Journal of Environmental Quality*, *40*, 1756–1766. https://doi.org/10.2134/jeq2011.0064

Lasdon, L. S., Fox, R. L., & Ratner, M. W. (1974). Nonlinear optimization using the generalized reduced gradient method. *Revue Française d'Automatique, Informatique, Recherche Opérationnelle*, *8*(V-3), 73–103.

Lazicki, P., Geisseler, D., & Lloyd, M. (2020). Nitrogen mineralization from organic amendments is variable but predictable. *Journal of Environmental Quality*, *49*, 483–495. https://doi.org/10.1002/jeq2.20030

Leifeld, J., & Fuhrer, J. (2005). The temperature response of CO_2 production from bulk soils and soil fractions is related to soil organic matter quality. *Biogeochemistry*, *75*, 433–453. https://doi.org/10.1007/s10533-005-2237-4

Li, L. L., & Li, S. T. (2014). Nitrogen mineralization from animal manures and its relation to organic N fractions. *Journal of Integrative Agriculture*, *13*, 2040–2048. https://doi.org/10.1016/S2095-3119(14)60769-3

Lucassen, F., Pritzkow, W., Rosner, M., Sepúlveda, F., Vásquez, P., Wilke, H., & Kasemann, S. A. (2017). The stable isotope composition of nitrogen and carbon and elemental contents in modern and fossil seabird guano from Northern Chile: Marine sources and diagenetic effects. *PLOS ONE*, *12*(6), e0179440. https://doi.org/10.1371/journal.pone.0179440

Masunga, R. H., Nwakaego Uzokwe, V., Deusdedit Mlay, P., Odeh, I., Singh, A., Buchan, D., & De Neve, S. (2016). Nitrogen mineralization dynamics of different valuable organic amendments commonly used in agriculture. *Applied Soil Ecology*, *101*, 185–193. https://doi.org/10.1016/j.apsoil.2016.01.006

Molina, J. A. E., Clapp, C. E., & Larson, W. E. (1980). Potentially mineralizable nitrogen in soil: The simple exponential model does not apply for the first 12 weeks of incubation. *Soil Science Society of America Journal*, *44*, 442–443. https://doi.org/10.2136/sssaj1980.03615995004400020054x

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, *50*, 885–900. https://doi.org/10.13031/2013.23153

Myrold, D. D., & Bottomley, P. J. (2008). Nitrogen mineralization and immobilization. In W. Raun & J. S. Schepers (Eds.), *Nitrogen in agricultural soils* (pp. 157–172). ASA.

Nahm, K. H. (2005). Factors influencing nitrogen mineralization during poultry litter composting and calculations for available nitrogen. *World's Poultry Science Journal*, *61*, 238–255. https://doi.org/10.1079/WPS200455

Norris, C. E., & Congreves, K. A. (2018). Alternative management practices improve soil health indices in intensive vegetable cropping systems: A review. *Frontiers in Environmental Science*, *6*, 50. https://doi.org/10.3389/fenvs.2018.00050

Palomino, L., Vega, R., Lara, C., Gomero, L., & García, S. (2019). Evaluación de cinco residuos avícolas como fuentes de nitrógeno mineral disponible. *Idesia (Arica)*, *37*(3), 121–129. https://doi.org/10.4067/S0718-34292019000300121

Papadopoulos, M. C. (1985). Processed chicken feathers as feedstuff for poultry and swine: A review. *Agricultural Wastes*, *14*, 275–290. https://doi.org/10.1016/S0141-4607(85)80009-3

Paradelo, R., Moldes, A. B., & Barral, M. T. (2011). Carbon and nitrogen mineralization in a vineyard soil amended with grape marc vermicompost. *Waste Management & Research*, *29*, 1177–1184. https://doi.org/10.1177/0734242X10380117

Paul, E. A. (2016). The nature and dynamics of soil organic matter: Plant inputs, microbial transformations, and organic matter stabilization. *Soil Biology & Biochemistry*, *98*, 109–126. https://doi.org/10.1016/j.soilbio.2016.04.001

Paul, K. I., Polglase, P. J., O'Connell, A. M., Carlyle, J. C., Smethurst, P. J., & Khanna, P. K. (2003). Defining the relation between soil water content and net nitrogen mineralization. *European Journal of Soil Science*, *54*, 39–48.

Preusch, P. L., Adler, P. R., Sikora, L. J., & Tworkoski, T. J. (2002). Nitrogen and phosphorus availability in composted and uncomposted poultry litter. *Journal of Environmental Quality*, *31*, 2051–2057. https://doi.org/10.2134/jeq2002.2051

Pribyl, D. W. (2010). A critical review of the conventional SOC to SOM conversion factor. *Geoderma*, *156*, 75–83. https://doi.org/10.1016/j.geoderma.2010.02.003

Robertson, G. P., & Groffman, P. M. (2007). Nitrogen transformations. In E. A. Paul (Ed.), *Soil microbiology, ecology, and biochemistry* (3rd ed., pp. 341–364). Academic Press.

Sims, J. T. (1986). Nitrogen transformations in a poultry manure amended soil: Temperature and moisture effects. *Journal of Environmental Quality*, *15*, 59–63. https://doi.org/10.2134/jeq1986.00472425001500010014x

Sims, J. T., Murphy, D. W., & Handwerker, T. S. (1993). Composting of poultry wastes: Implications for dead poultry disposal and manure management. *Journal of Sustainable Agriculture*, *12*, 67–82. https://doi.org/10.1300/J064v02n04_07

Sommer, S. G., & Hutchings, N. J. (2001). Ammonia emission from field applied manure and its reduction—invited paper. *European Journal of Agronomy*, *15*, 1–15. https://doi.org/10.1016/S1161-0301(01)00112-5

Sradnick, A., & Feller, C. (2020). A typological concept to predict the nitrogen release from organic fertilizers in farming systems. *Agronomy*, *10*, 1448. https://doi.org/10.3390/agronomy10091448

Stanford, G., & Smith, S. J. (1972). Nitrogen mineralization potentials of soils. *Soil Science Society of America Proceedings*, *36*, 465–472. https://doi.org/10.2136/sssaj1972.03615995003600030029x

Tognetti, C., Laos, F., Mazzarino, M. J., & Hernández, M. T. (2005). Composting vs. vermicomposting: A comparison of end product quality. *Compost Science & Utilization*, *13*, 6–13. https://doi.org/10.1080/1065657X.2005.10702212

Wallach, D. (2006). Evaluating crop models. In D. Wallach, D. Makowski, & J. W. Jones (Eds.), *Working with dynamic crop models* (pp. 11–53). Elsevier.

Whitmore, A. P. (2007). Determination of the mineralization of nitrogen from composted chicken manure as affected by temperature. *Nutrient Cycling in Agroecosystems*, *77*, 225–232. https://doi.org/10.1007/s10705-006-9059-1

Wortman, S. E., Holmes, A. A., Miernicki, E., Knoche, K., & Pittelkow, C. M. (2017). First-season crop yield response to organic soil amendments: A meta-analysis. *Agronomy Journal*, *109*, 1210–1217. https://doi.org/10.2134/agronj2016.10.0627

Yousif, A. M., & Mubarak, A. R. (2009). Variations in nitrogen mineralization from different manures in semi-arid tropics of Sudan with reference to salt-affected soils. *International Journal of Agriculture and Biology*, *11*, 515–520.

How to cite this article: Geisseler, D., Smith, R., Cahn, M., & Muramoto, J. (2021). Nitrogen mineralization from organic fertilizers and composts: Literature survey and model fitting. *J Environ Qual*. *50*:1325–1338. https://doi.org/10.1002/jeq2.20295