

2 Potential Nitrogen Mineralization: Laboratory and Field Evaluation

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Nitrogen fertilizer rates are currently estimated without considering field to field variability in N mineralization. The use of average N rates in fields with different N mineralization often leads to inadequate as well as excessive N applications. Therefore, the capability to adjust N fertilizer rates according to N mineralization potential is required for efficient N use and for prevention of groundwater pollution with NO_3^- .

The adjustment of N rates for N mineralization can be made with the budget or balance-sheet method (Neeteson, 1990):

$$N_{\text{rec}} = Y_{\text{exp}} \times b - N_{\text{up}} - N_{\text{ini}} - N_{\text{add}} - M_s - M_r - M_m + N_{\text{im}} + N_{\text{ich}} + N_{\text{gas}} + N_{\text{inf}} \quad [1]$$

where N_{rec} is the recommended N rate, Y_{exp} is the expected grain yield, b is the total N uptake per unit of grain yield (including vegetative parts and roots), N_{up} is the amount of N already absorbed by the crop at the time of fertilizer application, N_{ini} is the initial amount of inorganic soil N (at the time of fertilizer application), N_{add} represents N additions through rain and N fixation, M_s , M_r , and M_m are the amounts of net N mineralized (between the time of fertilizer application and the time at which net N uptake is complete) from soil organic matter, residue, and manure, respectively, N_{im} is fertilizer N immobilized, N_{ich} and N_{gas} are leaching and gaseous N losses, and N_{inf} is the amount of inorganic N at the end of the season. Thus, knowledge of several variables is needed for calculating correct N rates; however, the only variables that can be known accurately at the time of fertilizer application are inorganic N (N_{ini}) and N accumulated by the crop up to that time (N_{up}). All other variables, including N mineralized from soil organic matter (M_s) and from crop residues (M_r), must be estimated.

The adjustment of N rates for N mineralization can also be made with simulation models that take into account plant growth, nutrient uptake, and soil N transformations (Osmond et al., 1992). Simulation models also use an N balance approach, but in addition require a quantitative understanding of the biological processes involved. Consequently, the modeling approach can provide a finer resolution of the fertilizer N required for economically and environmentally sound crop production. Operationally, to calculate optimum fertilizer rates with simulation models, the user would need to simulate crop yield at several N fertilizer rates, fit the resulting yields to an equation of the form: Yield = $f(N \text{ applied})$ and then compute the economic optimum N rate in the traditional manner (Heady, 1956).

While the balance-sheet method requires estimates of N mineralized from soil organic matter, crop residues, and manures, simulation models require estimates of the sizes and rates of N mineralization of those N pools (Willigen & Neeteson, 1985; Wolf et al., 1989). In this chapter, we review research on estimating sizes and rates of N mineralization of soil organic matter pools, as well as amounts of N mineralized from soil organic matter and crop residues.

NITROGEN MINERALIZATION FROM SOIL ORGANIC MATTER

Magnitude

The amount of N mineralized from soil organic matter depends on soil type and environmental conditions. Some estimates of net N mineralized during the corn (*Zea mays* L.) growing season range from 13 to 131 kg N ha⁻¹ in Nebraska (Saint-Fort et al., 1990) and from 50 to 123 kg N ha⁻¹ in Japan (Saito & Ishii, 1987). Field studies conducted for 2 yr in Kansas (Cabrera & Kissel, 1988a) showed that N mineralized during the sorghum [*Sorghum bicolor* (L.) Moench] growing season varied from 31 to 51 kg N ha⁻¹ in three soils. In the same study, N mineralized during ~3 mo in two fallowed soils ranged from 75 to 107 kg N ha⁻¹ due to the higher water content of fallowed than cropped soils. Campbell et al. (1988) reported that N mineralized from a Canadian soil during 92 d was 52, 81, and 86 kg N ha⁻¹ under dryland cropped, irrigated cropped, and summer fallow treatments, respectively. These results show a large variability in N mineralization and indicate that in many cases N mineralized from soil organic matter is a significant proportion of the amount of N needed by a crop.

Estimation of Potentially Mineralizable Nitrogen with Laboratory Incubations

Potentially mineralizable N (N_0) refers to an active fraction of soil N that is mainly responsible for the release of inorganic N through microbial activity. Stanford and Smith (1972) proposed a method for estimating N_0 that involves incubating a soil-sand mixture under optimum temperature and moisture conditions. The soil-sand mixture is leached periodically (0.01 M CaCl₂) to remove inorganic N, and cumulative N mineralized with time (excluding the first 2 wk) is fitted to a single exponential model of the form: $N_{\min} = N_0(1 - e^{-kt})$, where N_{\min} is cumulative N mineralized in time t , N_0 is an initial estimate of potentially mineralizable N, and k is its rate constant of mineralization. The final value for N_0 is

calculated by adding the amount of N mineralized during the first 2 wk to the value of N_0 estimated with the model. Stanford and Smith (1972) used this procedure to estimate N_0 because the single exponential model could not adequately describe the initial flush of N mineralization observed in many soils. Later, other workers suggested modifying the single exponential model to include a constant amount of N that mineralizes immediately after starting incubation (Jones, 1984), or after a fixed period of time (Beauchamp et al., 1986). These models provided a better fit to mineralization data that show an initial flush.

In an attempt to find better models to describe N mineralized, Molina et al. (1980) and Deans et al. (1986) used two first-order equations (double exponential model) to represent two pools of mineralizable N, one of them decomposing much faster than the other and accounting for the initial flush of N mineralization observed in many soils. Deans et al. (1986) showed that this model was better than the single exponential model for describing data obtained in several laboratory studies.

Several authors (Juma et al., 1984; Ellert & Bettany, 1988; Bonde & Lindberg, 1988; White & Marinakis, 1991) reviewed other regression models for describing N mineralization, some of which can adequately describe the lag that occurs when the mineralization rate depends not only on substrate concentration, but also on the size of the microbial population. Houot et al. (1989) also proposed quantifying N_0 by adjusting a simulation model to reproduce experimental results and using as N_0 the initial N content of some of the organic N pools. Nevertheless, the single and double exponential models are the most used ones.

Several factors affect the size and rate constant of mineralization of pools identified with the single and double exponential models of N mineralization. Among them are the regression procedure used, length of incubation, date of soil sampling, and soil depth.

Effect of Regression Procedure

Stanford and Smith (1972) estimated N_0 and k using an iterative procedure to fit their data to a logarithmic transformation of the single exponential model. Their fitting method has the drawback of weighting the largest values of cumulative N mineralized more than the smallest numbers. Smith et al. (1980) compared the procedure used by Stanford and Smith (1972) to a nonlinear regression technique and concluded that when the errors are uncorrelated with sampling time, the nonlinear technique had lower root mean square values than the linear method of Stanford and Smith (1972). Similarly, Talpaz et al. (1981) compared linear regression after log transformation to a nonlinear regression procedure for estimating N_0 and k for the 39 soils used by Stanford and Smith (1972). They found that for all soils, N_0 was smaller, k was greater, and the sum of squares of the error was smaller with the nonlinear technique than with the linear procedure.

Ellert and Bettany (1988) showed that fitting a nonlinear model to incremental data from each incubation interval is better than fitting the model to cumulative data obtained by summing incremental observations. Some of the advantages of using an incremental model are that the interdependence of observation errors is decreased and that it is possible to use data with missing observations. Thus, the use of nonlinear regression procedures, such as PROC NLIN in SAS

(SAS Institute, 1985), to fit incremental models may provide the most simple and precise approach to estimate parameter values for the single and double exponential models of N mineralization.

Effect of Length of Incubation Time

Paustian and Bonde (1987) observed that mineralization curves with different values of N_0 and k can appear very similar for short incubations, and noted that parameters N_0 and k could change as incubation time increased. Similarly, Cabrera and Kissel (1988b) observed that as incubation time increased (from 140 to 252 d), the size of the mineralizable N pools estimated with the double exponential model increased whereas the corresponding rate constants decreased. These results emphasize (i) the importance of standardizing incubation times so that comparison of pool sizes and rates can be made without the confounding effect of time, and (ii) the need to consider both N_0 and k as indicators of the mineralizing capacity of soils.

Effect of Date of Sample Collection

Few studies have evaluated the effect of date of sampling on N_0 and k . El-Haris et al. (1983) determined N_0 and k in spring and fall samples taken from a long-term crop rotation-tillage experiment. They found that the average N_0 was 72 mg N kg⁻¹ in the spring and 131 mg N kg⁻¹ in the fall, whereas the respective average k were 0.349 and 0.096 wk⁻¹. Bonde and Rosswall (1987) measured N mineralized in samples taken from four cropping systems in April, June, August, and October. They observed that the N mineralized in a 13-wk incubation decreased from April through August and increased from August to October. The increase observed after August was attributed to the addition of crop residues, which probably enhanced N immobilization and increased the amount of N in dead cells and microbial metabolites. Although there is no direct evidence indicating that these forms of N may constitute a significant proportion of mineralizable N in soils, a close association was found between mineralizable N and microbial biomass (Bonde et al., 1988).

In a recent unpublished study, we measured N_0 (by the method of Gianello & Bremner, 1986a), microbial biomass, inorganic N, and water content in soil samples collected monthly (for 18 mo) from the upper layer (0–2.5, 2.5–5, 5–10, and 10–15 cm) of plots under conventional and no-till management on a Cecil sandy clay loam (clayey, kaolinitic, thermic Typic Kanhapludult) in Georgia. Seasonal changes in N_0 were very evident in the 0 to 2.5 cm of no-till plots, and were highly correlated with changes in microbial biomass N and C (Fig. 2–1). These seasonal changes appeared to follow changes in soil water content. In contrast to the results obtained in soil from no-till plots, soil from conventional-till plots did not show defined seasonal changes in potentially mineralizable N and microbial biomass.

In summary, because N_0 may change during the year, it is important to collect soil samples at the beginning of the season for which N_0 is to be estimated. It is clear that more research is needed to understand the factors that affect these changes.

Effect of Soil Depth

Because organic N in soils decreases with depth, it is expected that mineralizable N would also decrease with depth. Stanford et al. (1974) found that potentially mineralizable N, expressed both in absolute amount and as a percentage of total N, decreased with depth in the upper three 15-cm layers of eight Idaho soils.

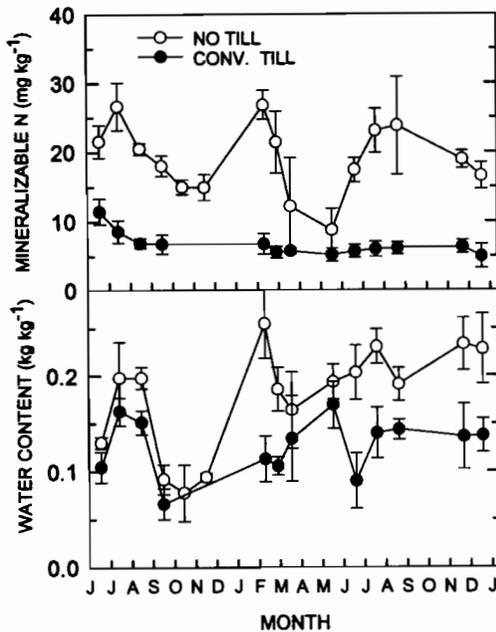


Fig. 2-1. Evolution of potentially mineralizable N and soil water content in the upper 2.5 cm of no-till and conventional-till plots on a Cecil sandy clay loam in Georgia.

Hadas et al. (1986) also found that potentially mineralizable N decreased with depth in several Israeli soils. They did not find any consistent effect of depth on the rate constant of mineralization. Cabrera (1986) fitted the double-exponential model to data from the four upper 15-cm layers (0-60-cm depth) of five Kansas soils, and observed that the slow pool of mineralizable N (expressed as % of total N) decreased with depth, whereas the fast pool remained constant or tended to increase with depth. If the fast pool of mineralizable N is assumed to be caused by drying the soil before the incubation, then the observed increase with depth in the percentage of the total soil N constituting the fast pool may be explained by fewer drying-rewetting cycles and less intense drying in the lower soil layers than in the surface ones. Soils with repeated drying-rewetting cycles show a decrease in the magnitude of the flushes due to a depletion of the organic reserves (Birch, 1958). Therefore, soils with fewer drying-rewetting cycles would be expected to show relatively larger flushes of N mineralization than soils with repeated cycles of drying and rewetting.

Hadas et al. (1986) estimated that the relative contribution of the top 20 cm of soil to the total N mineralization in the upper 60 cm varied from 45 to 75%. Similarly, in a 13-wk incubation, Cassman and Munns (1980) found that the total N mineralized from the upper 18-cm layer made up 42% of the total N mineralized in the upper 108 cm of soil. Cabrera (1986) estimated that the top 15 cm of soil contributed from 45 to 56% of the total N mineralized in 120-cm profiles of three Kansas soils, and that ~90% was mineralized in the top 45 cm.

The results summarized above indicate that subsurface layers may significantly contribute to the total N mineralized in a soil and may need to be considered when estimating N mineralized during a growing season. The relative importance of N mineralized from subsurface layers may increase when moisture is limiting in the surface soil, but not in subsurface layers.

Estimation of Potentially Mineralizable Nitrogen and Rate Constant from Chemical and Physical Tests

Stanford and Smith (1972) and Oyanedel and Rodríguez (1977) concluded that a common k value could be used for all the soils they studied. According to their results, only N_0 would need to be estimated to predict N mineralized in the field. This prompted a search for chemical methods of determining N_0 that would not be as time-consuming as long-term incubations. Stanford (1982) summarized studies that showed that N_0 could be predicted from the NH_4-N extracted by autoclaving the soil for 16 h in 0.01 M $CaCl_2$ (Stanford & Smith, 1976), or from the NH_4-N released by treating the soil with acid permanganate (Stanford & Smith, 1978). Recently, Gianello and Bremner (1986b) developed two chemical methods of soil N availability that showed high correlation with N_0 . One method consists of determining the NH_3-N produced by steam distilling the soil sample with phosphate-borate buffer solution of pH 11.2. The other method involves measuring the NH_4-N produced during treatment of the soil with 2 M KCl at 100°C for 4 h. Also, a high correlation between total N and N_0 was found by some workers (Marion et al., 1981; Gianello & Bremner, 1986b).

Recent results indicate that k may not remain constant within a soil profile or among soils (Griffin & Laine, 1983; Juma et al., 1984; Hadas et al., 1986; Cabrera & Kissel, 1988a). These results suggest the need for rapid methods to estimate both N_0 and k . Cabrera and Kissel (1988c) found that N_0 and k for 16 undisturbed soil samples could be estimated from total N and clay contents. Similarly, Myers (1989) reported that N_0 and k values for 30 undisturbed soil cores could be predicted from cation-exchange capacity and total N and clay contents. Clearly, more work is needed to elucidate the nature of organic pools contained in N_0 so that better predictive equations and better methods of measurement can be developed.

Use of Nitrogen Mineralization Potentials and Rate Constants to Predict Nitrogen Mineralized in the Field

Values for N_0 and k are developed from laboratory incubations at optimum temperature and soil water content. To use these parameters for estimating N mineralization in the field, it is necessary to apply correction factors for field temperature and soil water content.

Stanford et al. (1973a) found that the effect of temperature on k could be described with a modified Arrhenius equation. A pooled regression for 39 soils ($\log_{10} k = 6.16 - 2299/T$) indicated Q_{10} values (change in reaction rate for every 10°C increase in temperature), of 1.9, 1.8, and 1.8 for 5 to 15, 15 to 25, and 25 to 35°C, respectively. Campbell et al. (1981) also used a modified Arrhenius equation to describe the effect of temperature on k in five Australian soils. They found that for samples from the upper 15 cm of soil, the average Q_{10} values were 1.88, 1.81,

and 1.74 for 10 to 20, 20 to 30, and 30 to 40°C, respectively ($\log_{10} k = 6.14 - 2285/T$). For samples from the 15- to 30-cm layer, Q_{10} values were 1.68, 1.62, and 1.57 for the same temperature ranges described above ($\log_{10} k = 4.81 - 1861/T$).

Addiscott (1983) studied the effect of temperature on k in three British soils. He used a zero-order kinetics model and found that the Arrhenius equation properly described the dependence of k on temperature. The Q_{10} values measured between 5 and 15°C ranged from 2.31 to 3.18, whereas those observed between 15 and 25°C varied between 1.81 and 2.55.

In a subsequent study, Campbell et al. (1984) determined Arrhenius relationships between k and absolute temperature for 33 Canadian surface (0–15 cm) soils from five different zones. Because there were no significant differences in Arrhenius relationships among soils within each soil zone, average equations were developed for each zone (average Q_{10} values ranged from 2.0 to 2.75). Comparing their results with those of other workers, Campbell et al. (1984) noted that Q_{10} values tend to increase from warm climates to colder climates, possibly an indication of the resistance to degradation of the organic materials in soils of different climates. Thus, determination of Q_{10} values for a given area may be necessary to accurately represent the effect of temperature on N mineralization.

Prediction of N mineralized in the field also has to take into account the effect of soil water content. Stanford and Epstein (1974) used nine U.S. soils to study the relationship between soil water content and N mineralization. They found that if the values of cumulative N mineralized were expressed on a relative basis with respect to maximum N mineralized, then the effect of water content could be described as:

$$\text{Relative N mineralized} = \text{soil water content/optimum water content}$$

Similar results were obtained by Cavalli and Rodríguez (1975) with nine Chilean soils. In contrast, Myers et al. (1982) noted that the above expression was not suitable for five Australian and 32 Canadian soils. Instead, they proposed a model of the following form, constrained to pass through $X = 0, Y = 0; X = 1, Y = 1$:

$$Y = bX + (1 - b)X^2$$

where Y = relative N mineralized
 X = $[\text{SWC} - \text{SWC}(-4.0 \text{ MPa})]/[\text{OWC} - \text{SWC}(-4.0 \text{ MPa})]$
 b = regression coefficient
 SWC = soil water content
 SWC(-4.0 MPa) = SWC at -4.0 MPa
 OWC = optimum water content (about -0.03 MPa)

They found that in one Australian and nine Canadian soils, N mineralized showed a curvilinear response to X , a relationship that was described with b values ranging from 1.22 to 2.18. For the other soils b was equal to 1, giving a linear response with respect to X .

Therefore, it would appear that in certain cases the simple approach proposed by Stanford and Epstein (1974) may not be adequate to represent the effect of soil water content. In addition, Cassman and Munns (1980) showed

that N mineralization may be affected by a soil water content \times temperature interaction. This interaction is not considered in the model proposed by Stanford and Smith (1972).

There is some debate concerning the method used to correct for soil water content. In some studies (Campbell et al., 1988; Griffin & Laine, 1983), the water content factor, y , has been used to correct k as in: $N_{\min} = N_0 (1 - e^{-kyt})$, but Olness (1984) suggested using y to correct N mineralized as in: $N_{\min} = N_0 (1 - e^{-kt}) y$. Campbell et al. (1988) and Griffin and Laine (1983) observed that the first model produced slightly larger predictions than the second one.

The correction for temperature and soil water content has been performed using hourly (Campbell et al., 1984, 1988), daily (Cabrera & Kissel, 1988a), weekly (Smith et al., 1977; Marion et al., 1981), monthly (Oyanedel & Rodríguez, 1977; Stanford et al., 1977; Prado & Rodríguez, 1978), and yearly (Verstraete & Voets, 1976) time steps. Also, most workers have used Euler's integration method, whereas Campbell et al. (1984, 1988) used the integrated form of the model to estimate N mineralized within each time step.

Stanford (1982) summarized the first studies that attempted predictions of N mineralized from soil organic matter under greenhouse (Stanford et al., 1973b) and under field conditions (Prado & Rodríguez, 1978; Smith et al., 1977). We shall concentrate on subsequent studies.

Marion et al. (1981) used an approach similar to that proposed by Stanford and Smith (1972) to predict annual N mineralized in two chaparral soils. They incubated soil samples from the upper 30 cm of soil (in 10-cm increments) and determined N_0 and k by fitting the experimental data to a model of the form:

$$\log_{10}(N_0 - N_{\min}) = \log_{10}N_0 - kt^b,$$

where b is a regression coefficient and all other variables and parameters are as defined earlier. Predicted N mineralized agreed to within $\pm 10\%$ with independent estimates of N mineralized based on N balance equations.

Campbell et al. (1984) used N_0 and k values for the top 2.5 cm of a loam soil to predict N mineralized in the laboratory and in the field, taking into account soil water and temperature conditions. The model predicted well the N mineralized in the laboratory and tended to underpredict the N mineralized in the field at the two lowest water contents. These underpredictions were attributed to the accidental entry of water into some bags, which could have caused wetting and drying cycles and induced flushes of N mineralization (Campbell et al., 1988).

In another study, Campbell et al. (1988) conducted a more rigorous field evaluation of Stanford and Smith's (1972) approach. They used N_0 and k values for the upper two 7.5-cm layers of a loam soil, together with estimated temperature and soil water content, to predict N mineralized in lysimeters (15 cm diam., 120 cm long) subjected to summer fallow, dryland wheat (*Triticum aestivum*, L) and irrigated wheat treatments. Predicted N mineralized agreed with measured values during the first 45 to 60 d, and tended to underpredict observed values afterwards. Underpredictions for the entire growing season amounted to 16, 26, and 31% for irrigated wheat, summerfallow, and dryland wheat, respectively. The authors

explained the underpredictions as due to the model not accounting for the flushes in N mineralization that typically occur as a result of wetting-drying cycles.

In a Japanese study, Saito and Ishii (1987) measured N mineralized from the organic matter of four soils during the corn growing season. They estimated N_0 and k values and evaluated the dependence of k on temperature to predict N mineralized, adjusted for field temperature. In most soils, predicted amounts of N mineralized agreed closely with observed values in 1983, and tended to overpredict measured values in 1984 (Table 2-1). The authors attributed part of the overpredictions to the existence of dry conditions in 1984. Because the model used did not have adjustments for soil water content, it would be expected to overpredict N mineralized under dry field conditions.

Cabrera and Kissel (1988a) evaluated Stanford and Smith's (1972) approach in three Kansas soils during two sorghum seasons. Using the upper three 15-cm layers (0-45-cm total depth), they obtained overpredictions ranging from 114 to 343% of the actual amounts of N mineralized (32-51 kg N ha⁻¹). When only the upper 15-cm layer was considered, the overpredictions ranged from 7 to 181% (Table 2-2; Cabrera, 1986). Cabrera and Kissel (1988a) hypothesized that the overpredictions could have been due to an improper function for adjustment of the amounts of N mineralized based on soil water content, and to the crushing of the soil samples (to pass 2-mm sieve) before incubation. In a follow-up study, Cabrera and Kissel (1988c) showed that even after subtracting the initial N flush, samples that had been dried and crushed to pass through a 2-mm sieve showed higher N mineralization than undisturbed soil samples. These results suggest that with some soils it may be necessary to use undisturbed, field moist samples for determination of mineralization parameters.

In summary, the limited research results available indicate that it may be possible to predict N mineralized under field conditions following Stanford and Smith's (1972) approach. It would appear, however, that best results can be obtained if the soils samples are disturbed as little as possible to avoid an artificial enhancement of N mineralization. In addition, it may be necessary to include

Table 2-1. Measured and predicted N mineralized from four Japanese soils in two corn growing seasons (131-142 d) (adapted from Saito & Ishii, 1987).

Year	N Mineralized (kg ha ⁻¹)		% Error
	Measured	Predicted†	
	Ishidoriya		
1983	80	74	-8
1984	115	145	26
	Kuriyagawa		
1983	86	85	-1
1984	113	127	12
	Matsukawa		
1983	50	52	4
1984	93	131	41
	Toshima		
1983	83	103	24
1984	123	124	1

†Predicted considering only the upper 20 cm of each soil.

Table 2-2. Measured and predicted N mineralized from three Kansas soils in two sorghum growing seasons (105–162 d) (adapted from Cabrera, 1986).

Year	N Mineralized (kg ha ⁻¹)		% Error
	Measured	Predicted†	
Haynie			
1983	43	58	35
1984	46	49	7
Kahola			
1983	32	90	181
1984	51	107	110
Richfield			
1983	31	69	123
1984	36	50	39

†Predicted considering only the upper 15 cm of each soil.

the effects of drying and rewetting cycles to simulate N mineralization in soils where these cycles are common. Cabrera (1993) showed that in addition to causing an initial flush of N mineralization, drying and rewetting soils may also increase background mineralization when compared with soils that remain moist. More research in this area is needed to understand the mechanisms involved.

NITROGEN MINERALIZATION FROM CROP RESIDUES

Several complete reviews summarized how soil water content, temperature, and the physical and chemical nature of a crop residue affect the amount and rate of N mineralized or immobilized when that residue is mixed with soil (Bartholomew, 1965; Smith & Peterson, 1982; Sommers & Giordano, 1984). How we relate this information to fertilizer recommendations is still open to question. In the previous section, we described two methods for estimating N fertilizer rates, the N balance method, and the use of a simulation model. Both methods require estimates of N mineralization from crop residues. The next section will summarize some of the recent literature concerned with modeling and predicting the amounts and rates of crop residue N mineralization.

Magnitude

The amount of N mineralized or immobilized from crop residues will depend on soil type (Christensen, 1985, 1986), residue characteristics (Smith & Peckenpaugh, 1986; Vigil & Kissel, 1991), and environmental conditions (Boddy, 1983). Field experiments showed that residues with C/N ratios >50 initially immobilize N and eventually release a relatively low amount of N to subsequent crops (White et al., 1986; Seligman et al., 1986). In contrast, residues with C/N ratios <25 can supply considerable amounts of N to subsequent crops (Bowen et al., 1993; Wagger, 1989; Ranells & Wagger, 1992).

Estimating Nitrogen Mineralized from Crop Residues

Vigil and Kissel (1991) evaluated plant residue C, N, and lignin for the prediction of total seasonal net N mineralization. From that work, several linear

regression models were developed to estimate the maximum amount of N that may mineralize in a season from incorporated crop residues of different N contents. The best fitted model was of the form: $Y = 0.62 + 1.338 N - 0.875 L/N$, where Y is the amount of N mineralized expressed as a percentage of the residue N applied, and L and N are lignin and N concentrations (g kg^{-1}) in the residue, respectively. Whereas this equation predicts the seasonal net N mineralization, it is not valuable for assessing short-term mineralization or mineralization kinetics. Soil environmental factors such as soil water content, temperature, and crop residue management would all alter the rate of N mineralization. The use of a simulation model to predict N mineralization rates makes it possible to take into account soil environment and soil or crop residue management factors.

Vigil et al. (1991) evaluated a simulation model to predict field N mineralization of ^{15}N -labeled sorghum residues incorporated into a Smolan silt loam (fine, montmorillonitic, mesic Pachic Argiustoll) in Kansas. In that study, a N transformation subroutine derived from Version 2.0 of the CERES-Maize model (Jones & Kiniry, 1986) closely predicted the N mineralized after 110 d of decomposition (Fig. 2-2). Bowen et al. (1993) further evaluated the N submodel from CERES-Maize version 2.10 and found agreement between measured and simulated values of N mineralized from legume green manures incorporated into Brazilian soils.

In the two studies mentioned above, the model was tested for accuracy in simulating N mineralized from residues incorporated into the soil. In no-till and minimum-till systems, however, crop residues are either left intact on the soil surface, or are only partially buried. Additional modeling studies are needed to assess decomposition and N mineralization under those conditions. This requires the development of methods to measure or predict soil and crop residue water contents and temperature at the soil surface because these variables are major factors controlling microbial activity.

Bristow et al. (1986) developed a model for simulating heat and water transfer through a surface residue-soil system. Stroo et al. (1989) used Bristow's

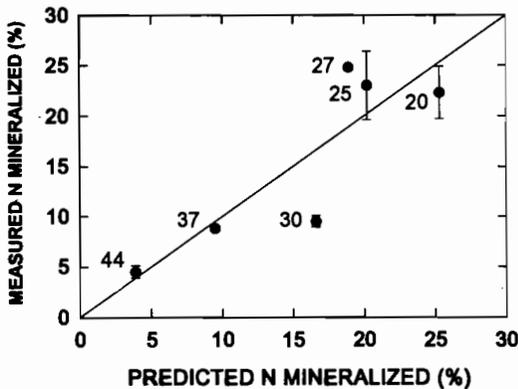


Fig. 2-2. Measured and predicted (by CERES N submodel) N mineralized from sorghum residues after 110 d of field decomposition in a Smolan silt loam in Kansas (numbers next to symbols indicate the C/N ratio of the sorghum residue; adapted from Vigil et al., 1991).

model and the model of Knapp et al. (1983) to develop a model for predicting residue decomposition at the soil surface. Stroo's model accurately predicted the mass loss of surface-placed wheat residues at both Bushland, TX, and Lafayette, IN. While the model calculates N mineralized or immobilized, it has not been independently validated for its ability to accurately assess N mineralization and immobilization of surface-placed residues.

The results reviewed above indicate that simulation models are promising tools for predicting N mineralized from crop residues. Further research and development of models is needed to improve their predicting capability.

CONCLUSIONS

Nitrogen mineralization is a complex process that depends on soil properties, crop residue quantity, and quality, as well as climatic conditions. Because of this complexity, computer simulation models will be very useful tools in the future for gaining a better understanding of the rate of N mineralization in the field. We also believe that these models can be used in soil testing programs for direct estimation of the amount of N that will be mineralized in individual farmers' fields.

The best methodology to model N mineralization from soil organic matter at this time is with long-term, multi-week incubations that allow one to determine the potentially mineralizable N for a soil, N_0 , as well as its rate constant of mineralization, k . Such a procedure, however, is not a practical method for our traditional soil testing programs that require rapid determinations and completed reports on soil nutrient availability within 2 or 3 d. It appears more likely that the model parameters needed for computer simulation of soil N mineralization could be determined from a quick soil test. Research is needed to evaluate the feasibility of this approach.

In order to make progress on N mineralization from crop residues, we must continue to refine the appropriate models. We cannot directly test a crop residue for N mineralization, so we must continue to study how crop residue characteristics such as its composition of lignin or hemicellulose affect the rate of decomposition and the N mineralization rate. Because of the recent emphasis on reduced tillage and no-till, we need to understand better how crop residues placed on the soil surface will behave with regard to rates of decomposition and N mineralization. The contact between residue and soil is clearly less under no-till management and the array of decomposing organisms will be different than for the case of crop residue buried in the soil. We must also understand and predict the temperature and water content more accurately at the soil surface so that we can provide the correct values of temperature and water potential for driving these models.

Finally, since N fertilizer recommendations are typically made prior to planting the crop, and since there is considerable uncertainty in future weather conditions (and therefore uncertainty in predicting future soil temperature and soil water content), it will not be possible to predict with high accuracy the amount of N that will be mineralized. It will be possible, however, to quickly simulate the estimated N mineralized for several years, having a range of climatic conditions. This would allow one to determine an average estimate of the

N likely to be mineralized. The other possibility is to use real time climatic data for early in the growing season to predict the N mineralized up to the time when N fertilizer is applied in a sidedress treatment. A similar modeling approach might also have considerable value in cropping systems that have fallow periods (such as in the Great Plains) during which N can mineralize and accumulate in the soil. The climatic conditions during these fallow periods and the soil and crop residue conditions can vary considerably, depending on the location and the year, and therefore result in quite different amounts of N mineralized. By using records of the climate in real time and by having measurements or estimates of crop residue properties, reasonably accurate simulations of N mineralizations should be possible under fallow conditions.

In summary, we believe that efforts should continue to gain a better understanding of the complex process of N mineralization, which supplies a substantial, and in some cases most of the N needed by crops. Our ability to predict the quantity of N mineralized in soils has been much improved by recent research. Further efforts to improve our ability to predict N mineralized under field conditions will help to increase the efficiency of use of N fertilizers to achieve economically and environmentally sound crop production.

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