ESTIMATION OF NITROGEN MINERALIZATION
FROM SOIL ORGANIC MATTER

by

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LITERATURE REVIEW

Accurate nitrogen (N) fertilizer recommendations depend upon knowing the amount of soil organic N that is mineralized. Therefore, a method that will estimate accurately the N mineralized under field conditions is urgently needed. Stanford and Smith (1972), developed an aerobic, long-term, incubation method to measure the net N mineralized by soils at 35 °C. With this procedure, soils were dried, sieved, and mixed with equal amounts of sand to give a homogeneous mixture before being placed into leaching tubes (containing a glass wool pad above and below the soil mixture) and incubated. Mineralized N was measured initially and following incubation intervals of 2,2,4,4,4,6, and 8 weeks, by leaching with 0.01 M $CaCl_2$ and a minus N nutrient solution. Optimum soil water contents were maintained during the incubation period by applying vacuum to the tubes until a particular gravimetric water content was obtained. The tubes were then stoppered before being placed in the incubator.

Since Stanford and Smith believed that the N mineralization rate was proportional to the quantity of mineralizable substrate in the soil, an equation was selected that allowed them to calculate a value for the potentially mineralizable N. They found that the data were

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best described by a first-order exponential equation:

$$N_t = N_o [1 - \exp(-kt)]$$

where N_t is the net N mineralized during time t, N_o is the potentially mineralizable N, and k is the mineralization rate constant. Their research also indicated that the mineralization rate constant (k) did not differ significantly among soils, and gave an average rate of 0.054 ± 0.009 week^{-1} at 35 °C. Consistent results with this method proved its reliability compared with other short- and long-term incubation methods.

Influence of Temperature on the Rate Constant of Mineralization

Soil temperature is one of the factors influencing decomposition and mineralization of soil organic matter. Although decomposing microorganisms have different optimum temperatures, the optimum temperature range tends to be between 0 and 35 °C (Stanford et al., 1973; Alexander, 1977; Haynes, 1986). Above 35 °C, ammonification will continue, but nitrification will cease at 45 °C (Harmsen and Kolenbrander, 1965). Myers (1975) reported the optimum temperature range to be between 30 and 40 °C, and determined that fluctuations in temperature within this range had little effect on the rate of decomposition.

Oien et al. (1974) studied the effects of deep-freezing (-26 °C) moist soil on the subsequent incubation

and release of N. They found that deep-freezing rapidly reduced biological activity, but significantly increased the subsequent amount of N mineralized. They theorized that deep-freezing influenced the composition of the microbial population and the rate at which mineralization occurred after thawing due to changes in the physical structure of the soil.

The influence of temperature on the rate of mineralization was investigated by Stanford et al. (1973) over the temperature range of 5 to 35 °C. They used a modification of the Arrhenius equation to fit data of mineralization rates at various temperatures:

$$\log k = \log A - B/T$$

where A is a constant, B is the slope of the regression of log k versus 1/T, and T is the absolute temperature (°K). A linear relationship was found between log k and the reciprocal of T. From measurements of N mineralized in 11 disturbed soil samples incubated at 5, 15, 25, and 35 °C, Stanford et al. (1973) found that the temperature coefficient describing the change in rate of mineralization for each 10-degree temperature change (Q_{10}) was approximately equal to 2, based on common (pooled) regressions for 11 soils. In addition, they found that the mineralization rate at 35 °C did not differ significantly among most soils. Many other investigations have confirmed

this Q_{10} value of 2 (Stanford and Epstein, 1974; Smith et al., 1977; Cassman and Munns, 1980; Campbell et al., 1981). Campbell et al. (1981) also found that Q_{10} decreased with increasing soil depth and noted that Q_{10} tended to decrease with increasing temperature or climate zones from a moderate (U.S.) to subtropical to tropical zones. This suggested that a difference in the biochemical nature of the potentially mineralizable organic N existed in each layer of soil. In further studies, Campbell et al. (1984) again concluded that Q_{10} decreased with increasing depth, suggesting a possible relation to the degree of degradation of the soil organic matter. Furthermore, they found that sandy soils had higher Q_{10} values than loamy and clayey soils.

In more recent work, Saito and Ishii (1987) found that the apparent activation energy (Ea), based on the Arrhenius equation: $k = A \exp(-Ea/RT)$ where A is a constant, R is the universal gas constant, and T is the absolute temperature (°K), more accurately described the temperature dependency of the N mineralization rate than did the Q_{10} coefficient. This was because Q_{10} did not remain constant in a wide range of temperatures and changed with the temperature level being tested. From mineralization curves of 12 Japanese soils, using a first-order model, they found that k ranged from 0.0040 to 0.0081 day^{-1} (25 °C), and the

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activation energy (Ea) ranged from 9900 to 23200 cal/mol.

Influence of Soil Moisture on N Mineralization

One of the most important factors affecting mineralization is the water content of the soil. Miller and Johnson (1964) showed that the maximum biological activity (mineralization rates) occurred at the highest water contents at which soil aeration remained non-limiting. They found the greatest microbial activity and the most N mineralized in a range from -15 to -50 kPa. Cassman and Munns (1980) showed the optimum N mineralization rates to be in the range of -33 to -200 kPa, whereas Stanford and Epstein (1974) showed maximum N mineralized at -10 to -33 kPa. These results demonstrate that the exact range of optimum moisture for greatest microbial activity varies with different soils and experimental conditions. However, in all cases, the optimum moisture content was close to field capacity.

H.F. Birch (1958) found that wetting and drying cycles of soils greatly affected the decomposition rate of soil organic matter. From respirometer readings, he concluded that a pattern of initial high rate of decomposition followed by a decline in rate occurred after the wetting of an air-dried soil. This pattern of decomposition seemed to follow first-order kinetics regardless of how many wetting

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and drying cycles occurred. Birch (1960) further proposed that the increase in surface area of a soil was responsible for each flush of N mineralized. In addition, N mineralization was affected by the length of time that the soil was dried before rewetting. He theorized that the main reason drying increased decomposition was due to the increased availability of the substrate. As the soil becomes dry, more of the surface of organic colloids is exposed due to the shrinking of clay interlayers and subsequent exposure of organic material held between clay layers. As the soil is rewetted, the existing microbial population expands, using the newly exposed organic surfaces and the bodies of expired microbes as substrate. Birch associated the initial rapid decomposition following rewetting of a dried soil to the physiological youth of the expanding microbial population, and the decline thereafter to their aging and resting stages. Later work by Herlihy (1979) also showed that the rate of N mineralization increased when soil water levels fluctuated in the available range possibly due to enhanced substrate availability from drying and wetting. Seneviratne and Wild (1985) also concluded that even mild drying gave greater mineralization rates than that of an untreated (constant moisture) sample. Mineralization was shown to be greater in soil dried for four days compared to shorter

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periods (hours) during incubations, and drying to -1500 kPa had more effect than drying to -100 kPa.

Stanford and Epstein (1974) developed a relationship between the N mineralized and soil water contents in the range from optimum (-33 to -10 kPa) to -1500 kPa at constant temperature. They developed the equation, $Y = X$, where Y is the relative N mineralized, and X is the percent of optimum soil water content. In contrast, Myers et al.(1982) believed that this equation was not suitable for generalized use, based on experiments conducted on five Australian soils and 18 Canadian soils. They developed the equation: $Y = bx + (1 - b) x^2$ where Y is the net N mineralized, b is a constant, and x is the normalized moisture content calculated as:

$$x = (M - M_o) / (M_{max} - M_o)$$

where M, M_{max}, and M_o refer to the actual moisture content, moisture content at -0.03, and -10 Mpa respectively. This equation fit their data better between the water potential range of -33 and -400 kPa.

Cassman and Munns (1980) further indicated that both the quantity and method of adding water to soil before incubation affected the amount of N mineralized. Soil samples were equilibrated at various water contents using a pressure-membrane method and a method in which various volumes of water were added to bulk soil. Based on the N

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mineralized, they determined that the latter method may not give uniform soil water contents and would give lower rates of N mineralization, particularly in the range near optimum (-33 kPa).

The results of several studies, involving a wide range of soil textures (covering clay to sands), indicated that the maximum aerobic microbial activity of a soil sample (for enhancing ammonification and nitrification) occurred at a water content equivalent to 60% of the water-holding capacity (Pal and Broadbent, 1975; Greaves and Carter, 1920). Additional work by Seifert (1960, 1961) showed that maximum bacterial numbers occurred between a water-holding capacity of 50 to 70%. More recent studies by Linn and Doran (1984) found that the percentage of soil pore space filled with water (percent water-filled pores, %WFP) that supported maximum aerobic activity was 60% WFP regardless of how the soil had been tilled in the field. They found that relative rates of respiration and nitrification, as determined by measuring CO_2 and N_2O production and O_2 uptake of surface samples of a soil with a silty clay loam texture, increased linearly with increasing soil water content to a maximum at 60% WFP and then decreased thereafter. Percent WFP was calculated from the equation:

$$\% \text{ WFP} = (\Theta_v \text{ / TP}) \times 100$$

where Θ_v is the percent volumetric water content ($m^3 H_2O/m^3$

soil), and TP is the percent total porosity = $(1 - P_B / P_P)$ x 100, where P_P = soil particle density (assumed to be 2.65 Mg/m^3), and P_B = soil bulk density (Mg/m^3). Since soil aeration appears to be the major limiting factor for microbial activity above 60% WFP, and the relationships between aerobic microbial processes and WFP appear to be linear between 30 and 60% and also between 60 and 70% WFP, an equation was developed by Linn and Doran to estimate the relative aerobic activity for a particular soil's water content:

Relative aerobic activity = % WFP / 60%, for WFP < 60%, and Relative aerobic activity = 60% / % WFP, for 60% <WFP< 70%. Since the above research was conducted on a limited range of textures (particularly coarser textured soils), this relation may need to be tested more thoroughly.

Cassman and Munns (1980) also found significant moisture by temperature interaction on the rate of N mineralized. They incubated samples from a Yolo soil profile at four temperatures in factorial combination with six soil moisture levels. Based on multiple regression analysis, they found a significant interaction between temperature and soil water content on the amount of N mineralized during a two week laboratory incubation.

Influence of Soil Texture and Mineralogy on N Mineralization

Soil texture is another physical property affecting the decomposition and mineralization rates of soil organic matter. Craswell and Waring (1972) found that the type and amount of clay was important to the amount of organic matter protected from microbial decomposition. They showed that montmorillonite, an expanding 2:1 layer silicate, gave proportionally greater increases in mineralization due to soil grinding than did kaolinite, a nonexpanding 1:1 layer silicate. They concluded that montmorillonite protected organic matter from decomposition better than kaolinite. According to Craswell and Waring (1972), the adsorption of decomposition products was the reason why fine-textured soils accumulate more organic matter than do coarse textured soils. For the same reason, montmorillonite-clay soils tend to maintain organic matter better than other clay-type soils with similar cultivation and environmental conditions.

Sand and silt can also influence decomposition by acting as mechanical barriers to microbial movement and by preventing contact between the cell or enzyme and substrate (Alexander, 1977). Herlihy (1979) found that nitrogen availability, based on determined values of N_o and k, increased with increases in surface area in the textural

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sequence from loamy sand to coarse sandy loam to loam. The N mineralized, determined with successive leachings of these soils, was directly related to their texture, but varied with differing crop histories and pretreatments such as drying.

Methods for Estimating N_O

Most methods used to determine the potentially available N in soil organic matter involve lengthy soil incubations with periodic leachings to measure the N mineralized during that incubation period. Stanford and Smith (1972) found that measurements of N mineralized following two weeks of preincubation were more precise for estimating N_O than without preincubation. This was believed to be due to factors such as non-uniform pretreatments such as the various degrees of drying that the soil samples received. These findings suggest that short incubation methods would be less accurate in estimating N_O. Additional work by Stanford et al. (1974) substantiated these findings and concluded that one to two weeks of preincubation were required to decompose plant residue and compensate for drying of disturbed soil samples.

Because of the long incubation time required when using their earlier incubation method (Stanford and Smith, 1972), they investigated the feasibility of estimating N_O

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from measurements of N produced by hydrolysis of soil organic N during 16 hours of autoclaving with 0.01 M $CaCl_2$ at 121 °C (Stanford and Smith, 1976). A total of 54 soil samples were used to study the relation between N_0 (potentially mineralizable N) from the incubation study and NH_4^+-N extracted from soil (N_i), measured after autoclaving for 16 hours in 0.01 M $CaCl_2$. Regression coefficients suggested that N_0 could be reasonably estimated from the chemical index N_i. Gianello and Bremner (1986) recently developed two other chemical methods of assessing potentially available nitrogen in soils. These methods included determining contents of NH_4^+ -N produced from soil organic N as determined (i) from steam distillation with pH 11.2 phosphate-borate buffer for eight minutes and (ii) by adding 2 M KCl to the soil sample and heating at 100 °C for four hours and then steam distilling the mixture. In each case, the initial ammonium concentration was determined using steam distillation, and this value was subtracted from the method under investigation. Thirty soil samples from Iowa were used to compare these two methods with ten other chemical methods and four biological methods. Biological incubation methods included short- and long-term incubations, and both aerobic and anaerobic procedures. Because these biological incubation methods have shown to provide the best reliability in estimating

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N_o, Gianello and Bremner (1986) compared their chemical methods with the results of the biological methods. The results demonstrated that the two newly developed chemical methods were the best chemical indices developed for laboratory assessment of potentially available organic N in soil. In other recent work, Hadas et al. (1986) compared several chemical indices and N fractions for their effectiveness in predicting first-order N mineralization rate parameters using incubated disturbed soil samples which were periodically leached for 32 weeks. Linear regression of N_o x k (0.054 week^{-1}) on various soil parameters showed that total N, weighted with respect to soil layer depth (total N / depth$^{1/2}$, where depth is the average depth of the layer in decimeters), was the best estimate of potentially mineralizable N in soil profiles. They also found that the first-order rate constant (k) varied without any consistent trend in the profile or between soils. This follows the conclusions of several other workers (Marion et al., 1981; Campbell et al., 1984; Saito and Ishii, 1987; Cabrera and Kissel, 1988a,b) and indicates that the rate constant (k) must also be determined in addition to N_o.

Models Used to Determine N_o and k

The first-order kinetic model proposed by Stanford and Smith (1972) was questioned by Addiscott (1983). He found that net N mineralized was linearly related to time (t) and not to the square root of time based on N mineralization data of several samples from Rothamsted, England. He used the zero-order model, $N_m = kt$, which best explained the data of cumulative N mineralized with respect to time. Moreover, Addiscott (1983) concluded that differences in sample preparation (drying) could have accounted for the differences in results obtained by Stanford and Smith (1972).

The first-order reaction model proposed by Stanford and Smith (1972) was also questioned as to its validity for the first 12 weeks of incubation (Molina et al., 1980). They concluded that two distinct pools of decomposable organic N were present in the disturbed soil samples of their study: one pool (15.8%) decomposing rapidly during one to two weeks, and another larger pool (84.2%) with a low specific decomposition rate. Their mineralization data exibited an excellent fit to a non-linear model that was the sum of two first-order models:

$$N_m = N_1[1 - exp(-k_1 t)] + N_2[1 - exp(-k_2 t)]$$

where N_m is the N mineralized in time t, N_1 and N_2 are fast

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and more slowly decomposable pools of mineralizable N respectively, and k_1 and k_2 are the respective rate constants for the two pools. From least square fitting of their model using data from Stanford and Smith (1972), Molina et al. (1980) concluded that (i) the two-pool model gave a better fit for the data of cumulative N mineralized with time over the entire 32 weeks of incubation and (ii) the first-order model would only apply for incubation periods following 12 weeks of incubation. In response to these findings, Stanford et al. (1980) agreed that the two-pool model could describe the data over the entire incubation time, but that the one-pool model was still adequate in predicting the amounts of N mineralized between 2 and 30 weeks in a given soil sample. These findings were later repeated by comparing the one- and two-pool models with determined quantities of N mineralized in a number of different studies (Hadas et al., 1986; Deans et al., 1986; and Inubushi and Wada, 1987). In studies with data of N mineralized from several paddy soils given various pretreatments (such as drying), Inubushi and Wada (1987) suggested that the soil pretreatments converted a part of the slowly mineralizable pool (N_2) to a more quickly mineralizable pool (N_1). Therefore, both N_1 and N_2 are derived from the same reservoir of soil organic matter, with a size equal to $N_1 + N_2$. More recent work on three

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disturbed soil samples by Cabrera and Kissel (1988b) also concluded that a two-pool model best predicted N mineralization rates. In their study, mineralized N (NH_4^+- and NO_3^--N) was measured after incubations at 35 °C by leaching with 0.01 M $CaCl_2$ and a N-free nutrient solution. This procedure was repeated every 28 days of incubation for 252 days. After fitting one- and two-pool models to their data, they found that a model consisting of a large slowly mineralizable pool and a smaller pool of rapid decomposition (two-pool model) yielded the best fit. Their work further indicated that drying may have produced the small pool of mineralizable N in these soils.

Because disturbance was believed to change the mineralization characteristics of a soil sample, Cabrera and Kissel (1988a) collected undisturbed soil cores from soils mapped in the Haynie, Kahola, Wymore, and Ladysmith series for comparison with disturbed samples. Net N mineralized was measured using the same leaching and incubation schedules similar to those used for disturbed soil samples (incubation intervals of 35 days and 35 °C temperatures were used and the samples were kept in a high humidity chamber). The one-pool model (Stanford and Smith, 1972) gave the best fit of data of cumulative N mineralized from undisturbed cores. Cabrera and Kissel (1988a) also found that the large pool of disturbed samples predicted a

larger amount of N mineralized than the single pool of undisturbed samples. This suggested that the differences in N mineralized found in incubations of disturbed samples was indeed a consequence of soil pretreatment.

As noted above, most past studies to assess the quantity of potentially mineralizable N in soils involved aerobic, long-term incubations of soils using dried and sieved samples. Data of cumulative N mineralized with time were usually described by one- or two-pool regression models. Recently, Bonde and Lindeberg (1988) evaluated data of cumulative N mineralized with time from other studies that were characterized by an initial lag-phase using fresh (field moist) soil samples. The mineralization data from the lag-phase curves could not be fit to Stanford and Smith's one-pool or to the above two-pool model. Therefore, mineralization data from these soils were fit to three other proposed models which described their plot of cumulative N mineralized with time by means of nonlinear regression analysis. The models included a one-component model developed by Brunner and Focht (1984):

$$N_m = N_o[1 - \exp(-k_1 t - k_2 t^2/2)]$$

a mixed/first-order, two-component model:

$$N_m = N_1[1 - \exp(-k_1 t - k_2 t^2/2)] + N_2[1 - \exp(-k_o t)]$$

and a mixed/linear, two-component model:

$$N_m = N_1[1 - \exp(-k_1 t - k_2 t^2/2)] + Ct$$

where these components have been previously defined, and Ct denotes the slope of the straight line that may follow the pattern of the mixed-order expression. Using these models to describe the mineralization data with a lag phase, Bonde and Lindberg determined that the mixed/first-order or mixed/linear model provided the best description of their data. Bonde and Lindberg (1988) suggested that the use of fresh soil samples may result in the initial N immobilization and subsequent N mineralization whereas pretreatment of these soil samples through grinding and drying would produce an initial flush of mineral N similar to that observed in previous studies. They suggested that the use of fresh field-moist soil samples would give rates of mineralization similar to rates in the field.

Use of N_o and k to Predict N Mineralized in the Field

Early studies to predict the net N mineralized under field conditions have generally consisted of laboratory incubations of soils in order to estimate their N mineralization potential (N_o) and the use of a constant value of k (Stanford and Smith, 1972) which may vary according to a Q_{10} of 2. Several investigators have used N_o from a first-order model fit to laboratory incubation data of cumulative N mineralized with time as a basis to predict N mineralized under field conditions (Stanford et al., 1973; Stanford et al., 1974; and Stanford and Epstein,

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1974). Smith et al. (1977) also tested the first-order model of Stanford and Smith for predicting the N mineralized from eight Oklahoma soil samples. They incubated the samples for 26 weeks in order to estimate values of N_o. The actual N mineralized in the field was determined monthly from increases in soil inorganic N using soil samples buried in plastic bags or in glass filter tubes. Soil temperature and soil water contents were measured in the field. The temperature coefficient, Q_{10}, was assumed to be 2, with the rate constant, k, equal to 0.0270 week^{-1} for 25 °C. Field capacity was assumed to be -33 kPa. Relative N mineralized was considered to be a linear function of soil water content calculated as: actual water content / optimum water content (Stanford and Epstein, 1974). Hence, the total predicted N mineralized for one week would be calculated as: $N_m = N_o$ x k x W where N_m is the total N mineralized for that week, N_o is the mineralization potential from laboratory studies, k is the mineralization rate constant calculated for that week's average temperature, and W is the relative water content factor (actual water content / optimum water content). This calculation and N measurement was carried out during two cropping seasons with eight soils. Since the soil samples used for field inorganic N measurement were in plastic bags, they remained more moist than the surrounding

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field soil. Nonetheless, calculated amounts of N mineralized were similar to the N mineralized measured in the field. Average errors (calculated as [(predicted − observed) /observed] x 100) ranged between −19 to 11.4%, lending support to the view that N mineralized under field conditions can be estimated from N_O when soil temperature and soil water variations are considered. Reasonable success was also found using this method and estimates for soil temperature and moisture fluctuations from climatological data in cropped plots (Stanford et al., 1977), and for fallow plots (Herlihy, 1979) where temperature was measured at the 5 cm depth, and moisture contents were kept near field capacity in shallow pots. More recently, Cabrera and Kissel (1988a) found that N mineralized in fallow plots could be more accurately predicted using N mineralization parameters obtained from undisturbed soil samples than from disturbed samples. Cabrera and Kissel (1988b) also measured N mineralized in the field in both cropped and fallow plots for 2 years using a N balance. Soil moisture was measured weekly and linearly interpolated to a daily basis taking precipitation into consideration. The daily N mineralized was then adjusted according to a 0 to 1 water adjustment factor. Daily soil temperatures were also measured at two depths (7.5 and 37.5 cm), and the value of k was adjusted assuming

a Q_{10} of 2. Overpredictions of the N mineralized in cropped plots were suggested to be due to (i) an inadequate soil water content factor, (ii) the enhancement of microbial biomass (which could increase N immobilization), (iii) possible N losses through leaves, and (iv) the use of disturbed samples to predict N_o. In other recent work, Campbell et al. (1988) also used a N balance procedure and lysimeters (15 cm in diameter and 120 cm long) to calculate the N mineralized in the field. Both N_o and k were estimated for each soil using Stanford and Smith's first-order model fit to the data of cumulative N mineralized with time. Since their previous work suggested that Q_{10} did not remain constant, Q_{10} values were determined for each soil. In addition, they suggested that the rate constant (k) was linearly related to the fraction of optimum available soil water as well as to temperature. Consequently, they combined the two functions by multiplication to modify the rate constant. Their model took the form of:

$$N_m = N_o[1 - \exp(-kty)]$$

where N_m, N_o, k, and t have been described earlier, and y is the moisture function described by Myers et al. (1982). The calculated net N mineralized for each treatment was lower than the measured values. The possible reasons for the underpredictions were the use of only the 0-15 cm depth

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layer to predict N mineralized, flushes in mineralized N from wetting and drying cycles not accounted for in the model, and the removal of macroscopic crop residues from the soil prior to incubating in the laboratory.

It has been documented that total soil N is closely correlated to potentially mineralizable N (Marion et al., 1981; Saito and Ishii, 1987; and Cabrera and Kissel, 1988b). Cabrera and Kissel (1988a) also found that the mineralization parameters N_o and k could be estimated from the soil characteristics total N and clay contents. They found that the product of N_o and k, and then each component separately could be estimated from the equations:

$$N_o \times k = -0.53 + 1.91 \times \text{Total N} - 0.0043 \times \text{Total N} \times \text{Clay}$$
$$(R^2 = 0.808)$$

$$k = 0.0017 + 0.00489 \times (N_o \times k) \qquad (R^2 = 0.798)$$

where total N is the total nitrogen in the soil (g/kg) and clay content expressed as (g/kg). Furthermore, N_o could then be calculated from the equation: $N_o = (N_o \times k) / k$. They further proposed that the ratio of clay/total N could be used to index the degree of protection from microbial attack that clays provide to organic matter. Since only limited work was done to test this theory and model, further research would be needed on undisturbed soils covering a wide range of organic matter and clay contents.

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CHAPTER 1.

A METHOD TO SECURE, LEACH, AND INCUBATE
UNDISTURBED SOIL CORES

ABSTRACT

Accurate nitrogen (N) fertilizer recommendations
depend upon knowing the amount of soil organic N that is
mineralized. A promising method developed by Stanford and
Smith (1972) to predict N mineralized with disturbed soil
samples allows for adjustment in the mineralization rate
due to field variations in soil temperature and water.
Recent work has indicated that undisturbed soil cores could
more closely represent the field soil and its
mineralization characteristics. Therefore, a method was
needed to secure undisturbed soil cores in a container that
would maintain their field integrity and allow them to be
incubated and leached periodically as per Stanford and
Smith's technique. The method utilizes a 6.3 cm i.d.
polyvinyl chloride (PVC) compression coupler to hold an
undisturbed soil core. The undisturbed soil sampling
device consists of a lever and anchor system, which can put
pressure on a soil cutter and adjustment bar to force soil
into the coupler. After a soil core is obtained from the
field, the coupler is adapted so that the soil within can
be leached, equilibrated to a constant water potential, and
incubated. In extensive sampling of 19 soils that varied

widely in clay and organic carbon contents, samples could be obtained rapidly if soil was near field capacity. This method of sampling and incubation was relatively inexpensive and simple and produced data of cumulative N mineralized with time that could be fit with a first-order kinetic model.

INTRODUCTION

Stanford and Smith (1972) developed an aerobic incubation method with disturbed soil samples to measure the N mineralized over a 30-week period at optimum temperature and moisture conditions. A first order kinetic model was used to fit the data of cumulative N mineralized over time. The curve-fitting parameters were the potentially mineralizable N at the beginning of mineralization, N_o, and the first-order rate constant, k. One purpose of the model was to predict the N mineralized under field conditions. Stanford et al. (1974) suggested that their model could be used to predict the actual N mineralized in the field taking into account soil temperature and water content fluctuations. They also suggested that the method of soil pretreatment (drying) could increase mineralization rates. Work by Cabrera and Kissel (1988a) indicated that N mineralized from undisturbed soil cores could also be fit to a first-order

model. They showed that adjacent soil samples that were disturbed gave much larger values of N_o and k than the undisturbed samples. It was also found that N_o and k values from undisturbed cores more closely predicted mineralization rates in the field as determined using an N balance (Cabrera and Kissel, 1988b).

Since soil mineralization rates could be characterized accurately with undisturbed soil cores, a procedure was needed that would allow undisturbed cores to be secured, leached, and incubated easily. Our objective was to develop a system that would allow rapid sampling of undisturbed soil cores and an appropriate apparatus to secure the undisturbed cores for leaching and incubation. The method needed to be inexpensive and simple so that undisturbed soil cores could be rapidly secured in a container that would maintain their field integrity and allow them to be leached periodically as per Stanford and Smith's technique. The system also needed to allow the soil to be reset to a constant water potential each time that it was returned to the incubator.

MATERIALS AND METHODS

The system utilizes a standard polyvinyl chloride
(PVC) compression coupler for 5 cm i.d. PVC pipe to hold
the soil core. This is a common plumbing supply used to
join sections of 5.0 cm PVC, iron, steel, and copper pipe.
The coupler has an internal length of 12.5 cm (total length
of 15.3 cm) and a threaded cap and rubber gasket at each
end. When a 5.0 cm pipe is placed into the coupler, the
cap can be tightened, compressing the rubber gasket onto
the pipe and providing a leak-proof seal. Sizes of
compression couplers range from 1.3 cm to 10 cm, but our
system was developed for soil using the 5.0 cm size, which
has an inside diameter of 6.3 cm.

Sampling Apparatus

The undisturbed soil sampling device (Fig. 1) consists
of a reinforced lever and anchor system which can put
pressure on a soil core cutter through a pusher with depth
adjustment to force soil into the coupler. The anchor was
a commercially available screw anchor 120 cm long by 1.6 cm
diameter, which had two flights (10.2 cm diameter and 21 cm
apart) near one end. A bracket drilled with 1.7 cm
diameter holes was welded to the other end of the anchor,
which was used first to screw the anchor into the soil
approximately 60 cm deep using a 70 cm long by 1.5 cm

diameter steel bar for leverage (not shown) and then to attach the lever with a nut and bolt. Attachment to the anchor allowed the lever to exert a downward force on the soil cutter. The lever also could be moved radially around the anchor to sample at more than one location from the same pivot point. A flat plate was welded to the underside of the lever to give a flat pushing surface for an even downward force. Although 14 gauge steel tubing (274 cm long by 2.2 cm square) was used in constructing the lever, reinforcement with additional steel tubing (1.3 cm square) on both sides and the top was necessary to eliminate any horizontal or vertical bending when force was exerted to the end of the lever.

The soil core cutter was machined from a stainless steel pipe 20 cm long by 8.8 cm diameter. The loading end had an internal diameter of 7.8 cm and the cutting end about 6.2 cm i.d., beveled at 1.5 cm from the end to produce a cutting edge. This cutting diameter was approximately 0.1 cm less than the inside diameter of the PVC coupler (6.3 cm). Swallow et al. (1987) has shown that this smaller cutting diameter will minimize disturbance to the soil core, yet allow the core to fit tightly in the cylinder. The internal diameter of the soil cutter was sufficient to receive the outside diameter of the coupler (7.8 cm), so that the coupler (without caps and rubber

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gaskets) could be loaded into the soil cutter and removed after sampling the soil. Because the coupler contained a beveled, recessed region (larger i.d.) at each end to hold the rubber gaskets, a stainless steel spacer ring (1.4 cm long by 6.9 cm o.d. and 6.4 cm i.d., beveled at 0.9 cm from one end) was machined to replace the rubber gasket during soil sampling. The spacer ring created a constant diameter cylinder from the cutting edge of the soil core cutter into the PVC coupler, which allowed easy passage of soil into the coupler.

The pusher with depth adjustment was designed with a recessed end to just fit into the top of the soil cutter. The length of the recessed end was sized to securely hold the coupler between the pusher and cutting end of the soil core cutter (recessed 3.2 cm from the end of the pusher with depth adjustment). This enabled the soil to be forced into the coupler without movement of the coupler inside the soil core cutter. The depth adjustment piece was constructed by welding a section of steel pipe (6.0 cm diameter by 26.5 cm long and 0.3 cm wall thickness) on top of the piece machined to give the recessed end. A smaller pipe (49 cm long by 4.8 cm diameter and 0.3 cm wall thickness) with 1.4 cm diameter holes drilled every 2.5 cm was placed inside the larger pipe and secured at 2.5 cm intervals with a steel pin (1.3 cm diameter by 10.5 cm

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long) that was chained to the larger pipe. This pusher enabled us to apply nearly straight downward force by incrementally adjusting the length of the pusher, while sampling to depths of 45 cm. We considered a vertical force important to secure a completely undisturbed sample.

The cost of these materials was less than $100.00; however, construction and machining costs would be extra. The combined weight of the sampling apparatus was approximately 26.4 kg which made it field portable.

Leaching Apparatus

After an undisturbed soil sample was removed from the field, the coupler (Fig. 2) was adapted so that the soil within could be leached with 0.01 M $CaCl_2$ to remove NO_3^-- and NH_4^+-N, equilibrated to a constant water potential, and incubated. To produce a 2.5 cm long core, an approximately 3.7 cm long soil core (measured above the rubber gasket space) was sampled in the field. This enabled us to remove about 0.6 cm of the soil from both ends of the core in the lab and replace it with acid-washed sand on top and diatomaceous earth on the bottom.

In order to prepare the level 2.5 cm soil core following field sampling, a "rototiller" device was constructed (not shown). The "rototiller" was constructed from a perforated acrylic plate (6.2 cm o.d. by 0.5 cm

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thick having approximately 0.2 cm diameter holes spaced 0.5 cm apart). Small box nails (2.0 cm long by 0.1 cm diameter) were placed into the holes of the perforated acrylic plate, the heads cemented to one side of the plate, and the heads then sandwiched between it and a solid acrylic plate. A section of 5.0 cm PVC pipe (10 cm long) was then cemented to the solid acrylic plate and then cemented into a standard 5.0 cm PVC slip coupling. The slip coupling was then beveled 0.7 cm from the bottom edge with a lathe to produce a stop when placed on the beveled region of the compression coupler. By gently turning the "rototiller" and removing the excess soil until it reached the stop, a level 2.5 cm core could be obtained for leaching. The "rototiller" was also used on the bottom of the soil core to remove about 0.6 cm of soil for the diatomaceous earth, however, a stop was not used.

Although not shown in Fig. 2, a piece of cheesecloth cut to the inside diameter of the coupler, was placed between the top of the soil core and the acid-washed sand layer. This enabled us to easily separate the soil core from the sand layer following incubation in order to obtain the dry weight of the soil core. A perforated acrylic plate (approximately 0.2 cm diameter holes spaced 0.5 cm apart) was placed on top of the cheesecloth and sand layer. This combination allowed uniform resistance on the surface

of the soil to prevent swelling, while allowing free movement of leaching solution onto the surface of the soil core. The acrylic plate was held in place by a length of 5.0 cm PVC pipe secured by the cap and rubber gasket. The acrylic plate secured with the PVC pipe prevented clay soils from swelling and maintained a representative field bulk density value, especially important for lower soil depths that have some overburden pressure from upper soil layers in the field. Since removal of this overburden pressure has been shown to greatly increase saturated hydraulic conductivity (Kissel and Ritchie, 1974), we felt it could increase pore space, perhaps exposing some protected organic matter to microbial attack, and hence increase mineralization rates. This enhanced mineralization due to swelling would likely be greater at lower depths because of increasing overburden removal with increasing depth.

The diatomaceous earth placed at the bottom of the core provided a good porous connection between the soil core and the porous ceramic plate. We found no problems with separating the diatomaceous earth from the soil core following incubation.

A "filter stick" was designed to leach and equilibrate the soil core to a constant water potential following leaching. To make the filter stick, a 5.0 cm schedule 80

PVC pipe (6.5 cm length) was cut and countersunk 1.0 cm with a lathe to hold a 5.3 cm diameter porous ceramic plate level with the top of the pipe. The plate was cemented into the PVC pipe with an epoxy cement and checked for leaks under a water pressure system. The 0.5 bar high flow porous ceramic plate (part no. 606D11-B.5M2) was purchased from Soil Moisture Equipment Corp. (Santa Barbara, CA) and had dimensions of 28 cm diameter by 1.0 cm thick. Seventeen smaller plates (5.3 cm diameter) were cut from the single large plate using a saber saw.

To facilitate leaching, the filter stick was fitted with two rubber stoppers (no. 11 in the filter stick end and no. 8 for the side-arm flask) connected on an 11 cm long by 0.5 cm i.d. glass tube. This apparatus could then be placed on a 1000 mL Nalgene side-arm flask to leach mineralized N from the soil core, as shown in Figure 2. The leachate (from 2.5 cm cores) was made up to a volume of 1 L with 0.01 M $CaCl_2$ and inorganic N concentrations (NH_4^+-N and NO_3^--N) were determined with colorimetric procedures (Technicon Industrial Systems, 1977a,b). The side-arm flask was connected to a vacuum system which, following leaching, could be adjusted to -33 kPa overnight in order to equilibrate soil water to a constant potential.

The filter stick was constructed so that it could be removed and replaced with an acrylic plug during

incubation. This plug was constructed from a 5.8 cm diameter by 0.5 cm thick acrylic plate with a 3.2 cm long by 1.2 cm square acrylic block glued to one side to facilitate removing the plug. Spots of epoxy were placed at 2 cm increments along the edge of the plug to give a tight fit in the coupler and allow air entry to the bottom of the core. The use of acrylic plugs (not shown) during incubation allowed us to reuse the same filter stick on other samples, keep construction costs low, and conserve space in the incubator.

Approximate costs for each leaching apparatus (without filter stick) was $4.50. Each filter stick cost about $7.00 to construct (assuming porous plates were cut from a single large plate, and 1987 prices).

To illustrate the utility of the device, we sampled 19 soils across the state of Kansas in the spring of 1987. At each of the 19 sites, we took duplicate undisturbed cores sampled from the center of the 0-15, 15-30, and 30-45 cm depths. Several disturbed cores (1.9 cm diameter) were taken right around the periphery of each undisturbed sample in order to describe the physical and chemical properties of the soil. Considering all 19 soils and the three sampling depths, these samples ranged in texture from sand to clay. These samples were used to characterize mineralization in a wide range of soils, but these results

will be presented elsewhere. For the purpose of this paper, we present N mineralization data from two of these soils, one mapped as Keith silt loam, 0 to 1 percent slopes (fine-silty, mixed, mesic Aridic Argiustolls) taken at the Colby Branch Experiment Station, and Pratt loamy fine sand, undulating (sandy, mixed, thermic Psammentic Haplustalfs) taken at the Sandyland Experiment Field of Kansas State University. In order to maintain field moisture, the soil cores were covered with a piece of plastic wrap, which was held in place with a rubber band, and were placed in an ice chest for delivery to the lab. The undisturbed samples remained in cold storage (approximately 10 °C) until use. Disturbed samples were dried at 35 to 40 °C for 48 h, crushed to pass through a 0.002-m screen, and stored in air-tight, plastic containers.

RESULTS AND DISCUSSION

The 19 soils varied widely in texture (ranging from
sand to clay) and in organic carbon (OC) content (2.0 to
28.0 g kg^{-1} OC). Since almost all samples were taken from
fallow or no-till locations, sufficient moisture was
present to allow easy sampling. We recommend that soils be
sampled at water contents near -33 kPa, which is the
approximate swelling limit for undisturbed soils (Yule and
Ritchie, 1980), so that they are at or near a bulk density
representative of field capacity at the respective soil
depth. By confining the soil from lower layers, additional
swelling upon addition of leaching solution will be limited
even though the overburden soil has been removed. Moisture
contents near field capacity also allow the core cutter to
be pushed more easily into the soil. We were unable to
sample one high-clay soil (ranging from 31 to 59% clay),
which was in wheat during a very dry period. Another
consideration with soils high in percent clay is
compaction. The internal diameter of the PVC coupler
varied slightly between couplers, resulting in soil core
compaction (determined visually by comparison to the
elevation of surrounding soil) on approximately three
samples from the nearly 120 samples taken. We took two
cores at each soil depth to ensure that one sample from

each depth would leach easily. Sampling of six cores (two duplicate cores from each depth) from each site could be done in an hour or less.

Although the coupler can receive any length of soil core up to 12.5 cm, we initially decided upon sampling a 5.0 cm core. Because many of the soil cores high in clay could not be leached and equilibrated within a 24 hour period, we determined that a better core length was 2.5 cm. This allowed using half of the leachate (0.01 $\underline{M}$ $CaCl_2$) to obtain the same pore volume exchange and, hence, a shorter leaching time. In previous studies, it was determined that the number of pore volumes of leachate needed to remove all of the soil NO_3^--N was approximately 20 for a core from the Wymore series, which ranged from 30 to 35% clay and 40 to 50% sand (Cabrera and Kissel, 1988a). Therefore, we recommend at least 20 pore volumes of leaching solution to adequately remove NO_3^--N from the soil cores. Soils with more clay may require more than 20 pore volumes of leaching solution.

The undisturbed soil cores were incubated at 35 °C in a Plexiglas high humidity chamber. The use of such a chamber is needed to maintain the soil samples at optimum water content. Incoming humid air was regulated by a flow meter to reduce CO_2 build-up (assuming average respiration rates) and maintain the level of oxygen. Soil core weights

were taken before and after each incubation period to measure the moisture loss. Table 1 gives some results of the moisture loss over a 35-day period of incubation for two sampling depths. We felt that the incubator and humidity chamber kept soil moisture levels adequate for near optimum mineralization rates. Water loss from the Pratt soil (sandy textured) represented extremes in water loss, whereas the Keith soil was about average for the 19 soils tested (Table 1). Another more recent adaptation was to place two damp sponges (3.5 cm diameter by 5 cm long) into the upper portion of the reservoir section of the leaching apparatus prior to incubation. The sponges were saturated with distilled water and then squeezed out by hand to remove all excess water. The use of damp sponges eliminated any measurable moisture loss from the soil cores during the incubation period. Previous work in our lab with residue amended disturbed soils showed that the use of damp sponges did not reduce soil respiration rates compared to containers without sponges.

The cumulative N mineralized at the center of the 0-15 cm depth for undisturbed samples (not incubated with damp sponges) of these two soils with contrasting textures are shown in Figure 3. The mineralization data were fit to a first-order kinetic model using a non-linear procedure (PROC NLIN METHOD = MARQUARDT) found in SAS (1982). Root

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mean square errors (RMSE) were calculated from the predicted versus observed fit and gave values of 0.40 and 1.22 mg kg^{-1} for the Pratt and Keith soils respectively. This example illustrates that the method worked well for two soils with contrasting properties.

PERSPECTIVE

Because mineralization rates from disturbed soil samples overestimated mineralization rates in the field, and because adjacent undisturbed samples would better characterize mineralization rates, we felt that undisturbed soil samples might be used to accurately predict N mineralization potentials for any particular field. Although it could be argued that many agricultural soils are plowed, disked, sweeped, roto-tilled, and otherwise disturbed, we believe that the undisturbed soil sampling method will describe soil mineralization characteristics most accurately. In typical mineralization studies, soil samples are often dried, crushed, and sieved resulting in far greater disturbance than would occur naturally in field tillage operations. Furthermore, mineralization does occur in subsurface soil layers that are not usually tilled. Therefore, undisturbed soil cores would also best describe mineralization rates for deeper soil layers.

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ACKNOWLEDGMENT

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Table 1.   Water loss from two soils incubated
           at 35 °C for 35 days.

| SOIL | DEPTH | TEXTURAL | WATER CONTENT | |
| SERIES | | CLASS | INITIAL$_1$ | FINAL$_2$ |
----
	cm		g/g	%
KEITH	0-15	SILTY CLAY	0.355	92
	30-45	SILT LOAM	0.273	93
PRATT	0-15	SAND	0.035	83
	30-45	SANDY LOAM	0.170	92
----

1 Equilibrated at -33 kPa.
2 Calculated as a % of initial.

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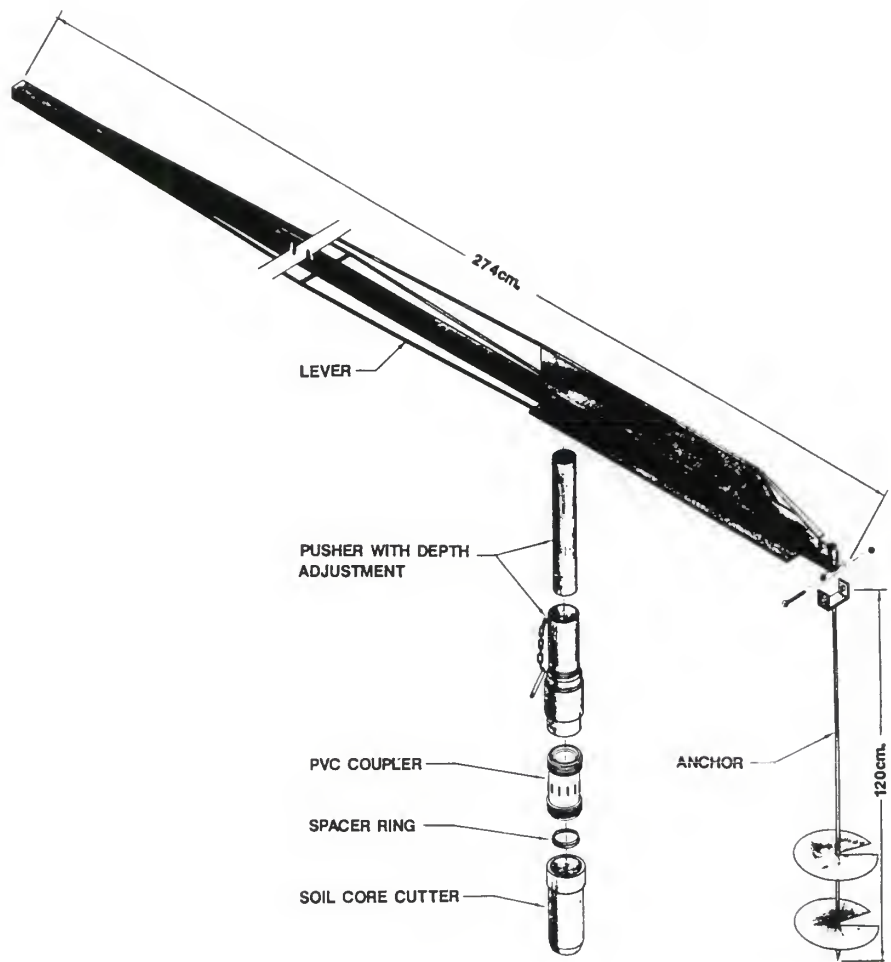
Figure 1. Undisturbed soil core sampling apparatus.
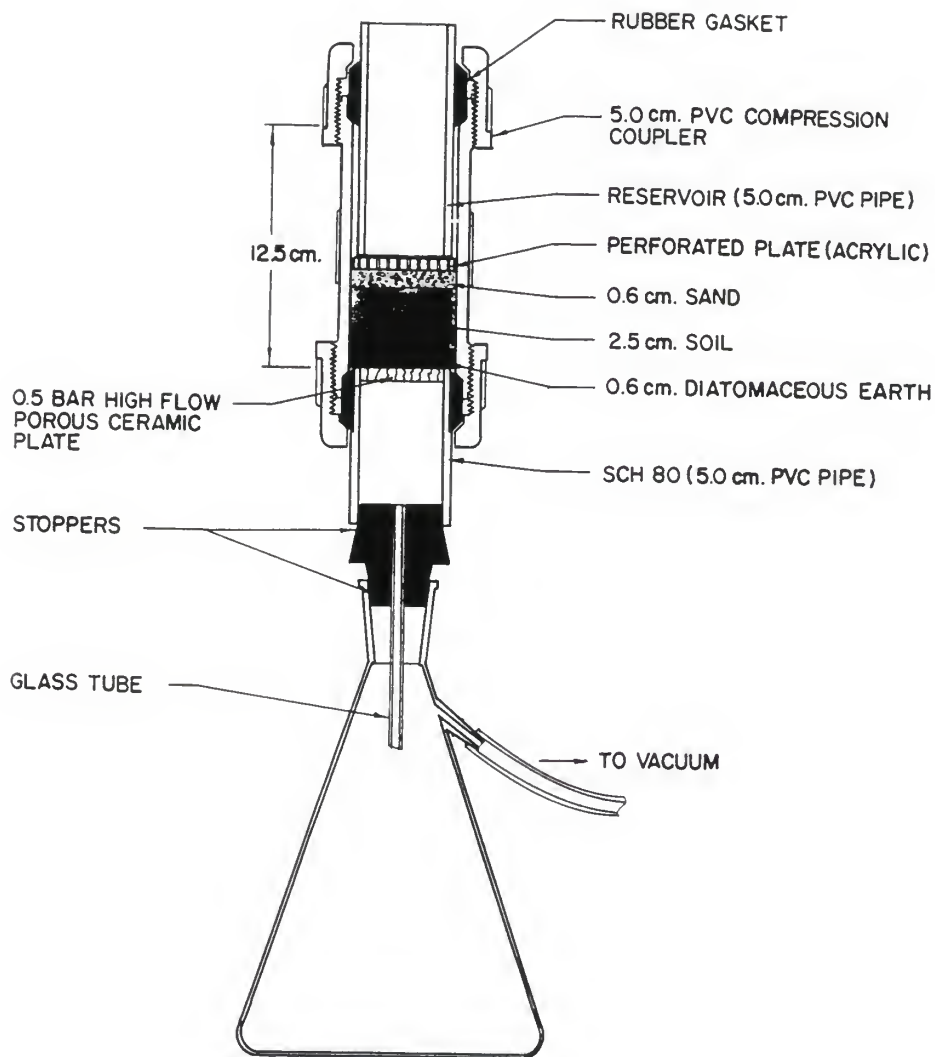
Figure 2. Undisturbed soil core leaching apparatus.

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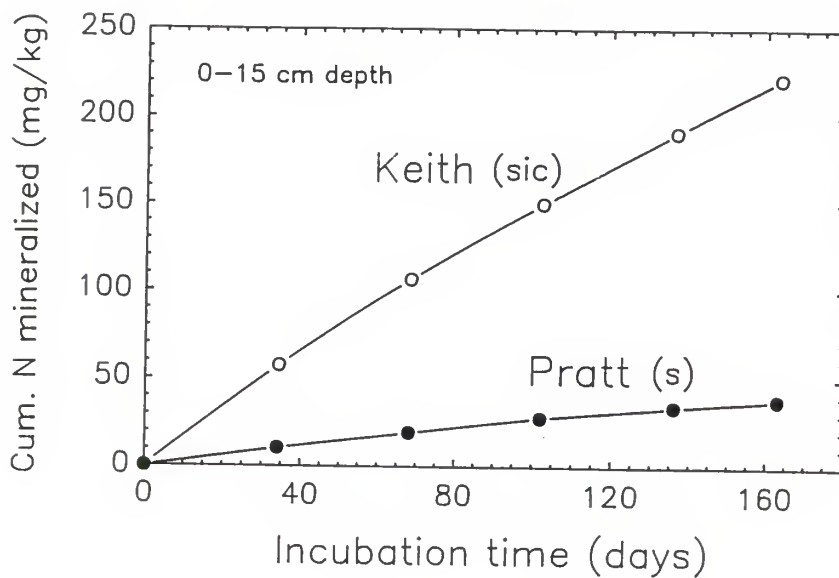
Figure 3. Cumulative N mineralized with time for undisturbed soil cores sampled from the center of the 0-15 cm depth for two soils in 1987.

CHAPTER 2.

NITROGEN MINERALIZATION
IN UNDISTURBED SOIL CORES

ABSTRACT

In order to calculate accurate N fertilizer recommendations, a method is needed to quantify N mineralization from soil organic matter. Because methods using disturbed soil samples for incubation studies tend to overpredict N mineralized in the field, a laboratory study was conducted, using incubated undisturbed soil cores, to describe cumulative N mineralized with time. In general, a mixed-order model fit the data better than Stanford and Smith's first-order model. It appeared that a lag in the build-up of microorganisms occurred in these soils. Model parameters could be used to reasonably predict N mineralized in the field when daily values of soil temperature and water content were considered for fallow plots of Kahola (fine-silty, mixed, mesic Cumulic Hapludolls) and Haynie (coarse-silty, mixed, calcareous, mesic Mollic Udifluvents) soils. Mineralization parameters from both first- and mixed-order models could be estimated from organic N, CEC, and clay contents of the soil samples.

INTRODUCTION

Supplying optimum nitrogen (N) fertilizer rates to crops is not only important economically, but, by avoiding overfertilization, contamination of ground water and the environment can be minimized. Typically, N fertilizer rates required for crops are determined by multiplying the expected total biomass of the crop and the average N concentration in that tissue, then subtracting the N supplied by the soil, manure, and other sources etc. However, the nitrogen supplied by the soil is difficult to quantify. Most of the N supplied to a crop comes from (i) inorganic N in the soil at the beginning of the season, (ii) net N mineralized from the organic fraction of the soil and from residue during the season, and (iii) fertilizer N. Inorganic soil N can be measured with present analytical methods; however, N mineralization is more difficult to determine. For this reason, more accurate N fertilizer recommendations are dependent upon finding a reliable method to predict the N mineralized from soil organic matter.

Cabrera and Kissel (1988a) found that the cumulative N mineralized over time by undisturbed soil cores incubated at optimum temperature and moisture could be fit to a

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first-order kinetic model $N_m = N_o(1 - e^{-kt})$, where N_m is the N mineralized in time (t), and N_o and k are the potentially mineralizable N and rate constant, respectively. Their work also suggested that the model parameters N_o and k might be used to predict the amount of N mineralized by soils in the field. However, determining values of N_o and k involve considerable time and effort, and spatial variability can cause a single core to not represent a field. Consequently, Cabrera and Kissel (1988a) attempted to predict N_o and k from selected physical and chemical properties of the soil. Their results demonstrated that the parameters N_o and k could be estimated from total soil N and clay contents of the four soils used in their study.

The objectives of this chapter were to (i) measure N mineralized in undisturbed soil samples, (ii) find models that would describe the data obtained, (iii) determine if the soil N mineralization parameters of undisturbed soil cores could be used to predict N mineralized in the field, and (iv) determine if mineralization parameters from incubation of undisturbed soil samples could be estimated from selected physical and chemical properties.

MATERIALS AND METHODS

Soil Sampling

Sites for sampling undisturbed soil cores were chosen according to the criteria that they represent (i) a large acreage of arable farmland in Kansas, (ii) a wide diversity of Kansas soils, and (iii) a wide range in texture and organic matter. Some characteristics of sampling sites from studies conducted in 1988 and 1987 are given in Table 1 and A1, respectively. In most cases, the 1988 samples were taken in the same location as those taken in 1987. Undisturbed soil samples were collected from 19 different soils in 1987 and 1988 using the method described in Chapter 1. Samples in 1987 were taken between 11 May and 3 June, and those in 1988 were taken between 13 April and 23 April.

The undisturbed soil cores were sampled using a 2.5 cm core taken at the center of the 0-15, 15-30, and 30-45 cm layers in 1987 and at the 0-15 and 30-45 cm depth in 1988. All undisturbed cores were sampled in duplicate except for the Riley County sites that were used in the N balance studies. These were sampled in triplicate in 1987 and quadruplicate in 1988.

After the undisturbed soil core cutter had been pressed into place and before retrieving it, approximately 10 cores, 1.9 cm in diameter and 2.5 cm long, were taken

around the periphery of the sampler. These samples were
centered at the middle of the undisturbed core and were
used to describe the physical and chemical characteristics
of the undisturbed cores. These samples were dried at 35 to
40 °C for 48 h, crushed to pass a 2 mm screen, and stored
in air-tight plastic containers.

Laboratory Procedures

Selected physical and chemical properties from soils
sampled in 1987 and 1988 are given in Tables A2 and A3,
respectively. Particle size distribution was determined
using the pipet method (Method 3A1 of the Soil Survey
Staff, 1972). Samples containing more than 17.2 g
organic carbon (OC) kg^{-1} soil were treated with 30% H_2O_2 to
remove organic matter before determining particle size
(Jackson, 1975). Particle size fractions determined
included sand, silt, total clay (<2 μm), and fine clay
(<0.2 μm).

Cation exchange capacity (CEC) was determined using a
modification of a method by Jaynes and Bigham (1986). A
2.0 g soil sample was extracted with 1 M NH_4OAc on a
mechanical vacuum extractor. The sample was then washed
twice with 35 mL additions of 95% ethanol. Finally, the
soil was extracted with approximately 50 mL of 2 M KCl,
brought to 100 mL volume, and the concentration of ammonium

in the extract was determined with an automated colorimetric procedure (Technicon Industrial Systems, 1977a).

To determine OC and total N concentrations, the soil was further ground using a mortar and pestle. Total C was measured with a WR-12 Leco Carbon Analyzer (Leco Corp., St. Joseph, Michigan). Soil pH was determined using a 1:1 soil:water ratio. Any sample having a pH greater than 7.0 was analyzed for inorganic carbon content (Bundy and Bremner, 1972) and OC was calculated by subtracting the inorganic C from the total C contents. Total soil N was measured with the same colorimetric procedure used for ammonium determination in CEC-KCl extracts following a salicylic-sulfuric acid digestion (Bremner and Mulvaney, 1982).

Initial inorganic N in disturbed samples and final inorganic N in the incubated undisturbed soil samples was determined. The soil sample was dried at 40 °C for 24 h, a 2.0 g subsample was weighed into 50 mL Erlenmeyer flasks, twenty mL of 2 M KCl was added to the soil, and the mixture was allowed to shake for 30 minutes. After filtering through Whatman #41 filter paper in a glass funnel, the leachate was analyzed for inorganic N contents (ammonium and nitrate plus nitrite) with colorimetric procedures (Technicon Industrial Systems, 1977 a,b). Organic N

content of the soil was calculated by subtracting the initial inorganic N from the total N contents.

Laboratory Incubation

Undisturbed soil cores were sampled and prepared for leaching as described in Chapter 1. When a 2.5 cm long soil core was used, the upper reservoir section could hold about 300 mL of leaching solution. The undisturbed cores were leached before incubation by placing each PVC coupler containing the undisturbed soil core and filterstick on top of a 1 L side-arm flask connected to a vacuum line, and then allowing 900 mL of 0.01 M $CaCl_2$ to percolate through the soil. Previous work showed that a soil core with a silty clay loam texture required approximately 20 pore volumes of leaching solution to remove all of the nitrate-N (Cabrera and Kissel, 1988a). We found that 900 mL of leaching solution usually provided at least 20 pore volumes when a 2.5 cm sample was used. The leachate was then made up to a volume of 1 L with 0.01 M $CaCl_2$ and inorganic N concentrations (ammonium and nitrate plus nitrite) were determined with the same colorimetric procedure used for inorganic N contents in KCl extracts. After leaching, the cores were equilibrated under vacuum adjusted to -33 kPa for approximately 8 hours (overnight).

Undisturbed soil cores were incubated in Plexiglas high humidity chambers placed inside an incubator at 35 °C.

Humidified air was circulated through each chamber at a sufficient rate to keep O_2 concentrations in the box similar to those in the laboratory and to avoid CO_2 build-up in the chamber. Previous work in our lab with a Kahola soil sample gave a respiration rate of 1 μL CO_2 g^{-1} soil h^{-1}. We assumed an average respiration rate for all soils of 2 μL CO_2 g^{-1} soil h^{-1}. Calculations with this rate gave air flow rates of approximately 3.33 mL s^{-1} for a chamber containing 48 soil cores. In addition, we placed an open container of 2 M KOH in each chamber to trap CO_2. Since these containers were changed during every leaching period, we felt that CO_2 levels in the chamber would be equal to or less than average soil atmosphere concentrations. In addition, damp sponges (wet with distilled water and then squeezed by hand) were placed into the reservoir sections of each soil core before incubation in 1988. Soil core weights were taken before and after each incubation period. The combination of high humidity chambers and damp sponges eliminated any water loss during the incubation period. Previous work in our lab indicated that the use of damp sponges did not affect respiration rates in the soil. The undisturbed cores were retrieved from the incubator and leached as previously described at 34, 68, 102, 136, and 163 days in 1987, and at 13, 27, 54, 58, 122, and 156 days of incubation in 1988. The first leaching time (13 days)

was omitted for subsurface and several slowly mineralizable soils in 1988 which had slow mineralization rates based on the data of cumulative N mineralized with time for similar soil samples taken in 1987.

Field Procedures

In 1987 N mineralized in the field was measured in fallow plots established in areas mapped as Smolan silt loam, 1 to 4% slopes (fine, montmorillonitic, mesic Udic Argiustolls), and Kahola silt loam (fine-silty, mixed, mesic Cumulic Hapludolls) at the North Agronomy Farm near Manhattan, KS. Because of the high clay contents and the difficulty in leaching undisturbed samples in the laboratory, the Smolan site was abandoned for 1988. In 1988 N mineralized in the field was again measured in fallow plots at the Kahola site and in areas mapped as Haynie very fine sandy loam (coarse-silty, mixed, calcareous, mesic Typic Udifluvents) at the Ashland Agronomy Farm, and Reading silt loam, 0 to 1% slopes (fine, mixed, mesic Typic Argiudolls) at the Konza Natural Prairie Research Area, also near Manhattan, KS. At each site, all previous crop residue was removed, and three or four plots (3 by 5 m each) were established in 1987 and 1988, respectively. Within each plot, two subplots, 1 m square each, were established, one for initial and final soil

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sampling to depths of 1.2 m for inorganic N, and the other to monitor weekly soil water contents. Because of its sandy texture throughout the profile, the Haynie soil was sampled to depths of 1.5 m. After the initial sampling, a neutron probe access tube was installed in the center of each plot, and the soil was roto-tilled to a depth of approximately 10 cm. The initial and final sampling dates were 5 June and 21 October, respectively, in 1987, and 16 May and 3 September, respectively, in 1988. The soils were sampled with a Giddings hydraulic probe using a tube 4 cm in diameter. Six cores were composited from each plot at 15 cm depth increments starting at the soil surface down to 60 cm, and 30 cm thereafter. In addition, 15 smaller cores (1.9 cm diameter) were taken from the 0 to 15 and 15 to 30 cm depth in order to better quantify N mineralized in these layers, and they were composited along with the other cores. These composite samples were then ground to pass a sieve with an opening of 2 mm in diameter, extracted with 2 M KCl, and analyzed for ammonium and nitrate contents using the same procedure followed for initial soil inorganic N contents in the laboratory study. Mineralized N from the profile could be calculated by considering bulk density values and summing the mineralized N contributions from each composite layer. The net N mineralized during the measurement period was calculated as the difference between

the $NO_3^- -N$ (kg ha^{-1}) at the end of the season and that measured initially in the profile.

Gravimetric water content of the upper 15 cm of soil was monitored by taking 2 cores in each plot. Volumetric water content of lower layers was monitored each week with a neutron probe. These weekly measurements were used to estimate daily water content using linear interpolation.

During the measurement period, soil temperature was measured at each site. Mean daily soil temperatures were recorded at the 7.5 and 37.5 cm depths with a Datapod DP 212 digital recorder using thermocouples (Omnidata Inc., Logan, UT). These measurements were then used to calculate average daily temperatures at the 22.5 cm soil depth by averaging daily temperatures from the other two depths.

In order to calculate final mineralization rates and to convert gravimetric water contents to a volumetric basis, bulk density measurements were made in each plot. Cores were sampled with a Giddings hydraulic probe to include the entire depth of inorganic N sampling. A 5 cm length core was taken at the center of each 15 cm increment, weighed, and dipped in hot wax to seal all pores. A water displacement method (Blake, 1965) was used to measure total core volume,and soil water content was determined in order to calculate bulk density.

Weeds were controlled by hand removal in 1987 and with

a mixture of an ester of 2,4-Dichlorophenoxyacetic acid (0.75 kg a.i. ha^{-1}) and Glyphosate (0.55 kg a.i. ha^{-1}) in 1988. The Haynie and Reading plots received two applications whereas the Kahola plot received only one.

N Mineralization Models

The Marquardt option of the SAS nonlinear curve-fitting procedure, NLIN (SAS Institute Inc., 1982), was used to fit first-order models in 1987 and both first-order and mixed-order models to the data of cumulative N mineralized with time in each of the field study samples in 1988. Only the mixed-order model was fit to all of the soil samples in 1988 because most of the data showed a lag-phase in mineralization. Those samples which would not meet convergence criteria of a mixed-order model or gave a negative k_2 value, were also fit to a first-order model. The first-order model is of the form (Stanford and Smith, 1972)

$$N_m = N_o \left[1 - \exp(-k_o t) \right]$$

whereas the mixed-order model is of the form (Brunner and Focht, 1984)

$$N_m = N_o \left[1 - \exp(-k_1 t - k_2 t^2 / 2) \right]$$

where N_m is N mineralized in time t, N_o is the pool of mineralizable N, and k_o, k_1, and k_2 are rate constants of mineralization.

Prediction of N Mineralized in the Field

The rate constants of mineralization k_o, k_1, and k_2 were adjusted for soil temperature using an average Q_{10} of 2 between 15 and 35 °C (Stanford et al., 1973). The predicted amount of N mineralized was then corrected for soil water content (Linn and Doran, 1984). They found that maximum aerobic activity (optimum water content) in the soil occurred at 60% water-filled porosity (WFP). Consequently, the N mineralized was corrected by a 0 to 1 soil water content adjustment factor of the form:

$$W = \%WFP / 60\%, \text{ for WFP} < 60\% \text{ and}$$

$$W = 60\% / \%WFP, \text{ for } 60\% < WFP < 70\%.$$

The predicted amount of N mineralized during the first day was calculated as follows:

$$N_{m1} = N_1 \times k_{01} \times W_1 \quad \text{(for first-order model) and}$$

$$N_{m1} = N_1 \times (k_{11} \times k_{21}t) \times W_1 \quad \text{(for mixed-order model)}$$

where k_{01}, k_{11}, and k_{21} are the rate constants k_0, k_1, and k_2, respectively, adjusted by the mean soil temperature of day 1, W_1 is the soil water content factor for day 1, and t is time in days (taken to be 1 for the first day, 2 for the second day, and so on). The predicted cumulative amount of N mineralized by the end of the second day was calculated as follows:

$$N_{m2} = N_{m1} + (N_1 - N_{m1}) \times k_{02} \times W_2 \text{ (first-order model) and}$$

$$N_{m2} = N_{m1} + (N_1 - N_{m1}) \times (k_{12} \times k_{22}t) \times W_2 \text{ (mixed-order)}$$

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and so on for the following days. These calculations were done for each of the three 15 cm layers in the upper 45 cm of each plot. The parameters for plots in 1987 were determined for all three layers whereas the parameters for only the 0 to 15 and 30 to 45 cm layers were determined in 1988. Values for the 15 to 30 cm layers were averaged from the other two layers for all plots sampled in 1988.

RESULTS AND DISCUSSION

Models Used to Describe Cumulative N Mineralized With Time

The mixed-order model fit the 1988 N mineralization data better than the first-order model of Stanford and Smith (1972) as indicated by a lower residual sum of squares (Table 2). This was because in most cases, the curves of cumulative N mineralized with time resulted in an initial lag-phase. Plots of cumulative N mineralized with time for all undisturbed soil samples taken in 1988 are shown in Figures A1-A19. This mixed-order model was applied by Bonde and Lindberg (1988) who compared several models to describe this lag-phase phenomenon found in field-moist and manure-amended soils. They found that a mixed-order model described the lag-phase better than a first-order model for cumulative N mineralized with time.

The mixed-order model allows for a linear growth function where growth is a function of time in addition to a function for first-order degradation of a single pool of organic substrate. This model suggests that a period of time is necessary to build-up optimum populations of nitrifiers and/or ammonifiers in the soil before the substrate is the only limiting factor. Brunner and Focht (1984), who developed this model to describe sigmoidal degradation patterns, felt that this linear growth model

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could best reflect decomposition patterns in soils. A lag in mineralization is evident by positive parameter values for k_2 in the mixed-order model. Larger lags are evident based on increasing k_2 values. When no lag is present, k_2 values from the mixed-order model approach zero and the model becomes identical to the first-order expression. A negative k_2 parameter in the mixed-order model indicates an initial flush in mineralization.

The data from the 1987 mineralization study did not exhibit a lag-phase as clearly as those data from the 1988 study. Several reasons may account for this difference. First, the undisturbed soil cores sampled in 1988 were obtained approximately one month earlier than those obtained in 1987. Average daily temperatures were lower when the 1988 cores were taken, which may have resulted in lower initial nitrifier and/or ammonifier populations. The undisturbed samples taken in 1988 also were obtained following rainfall events which enabled sampling much closer to field capacity moisture conditions. The samples taken in 1987 were drier on the average; thus, wetting them initially to -33 kPa during the laboratory procedure may have resulted in a mineralization flush, masking the effect of any lag-phase. A few initial flushes were noted in the 1988 data, which may have been due to such wetting differences caused by variation in soil moisture. Finally,

the leaching schedule was changed in 1988 from leaching intervals at 34, 68, 102, 136, and 163 days of incubation to intervals at 13, 27, 54, 88, 122, and 156 days of incubation. This change in the leaching schedule provided a better description of the mineralization process during the first few weeks of incubation. In addition, improvements were made in the leaching and incubation method for the 1988 samples, and all samples from 1988 were confined. For these reasons, the results from the 1988 undisturbed soil cores are considered to be more accurate than those from 1987, and the following discussion will be based on the 1988 mineralization data unless stated otherwise.

Description of N Mineralization Parameters

The mineralization data from all 1988 samples were fit to the mixed-order model. Those curves, which could not be fit to this model, did not show any lag, or gave a k_2 value which was negative, were also fit to the first-order model. All data from the field-plot samples were fit to both models. A listing of the N mineralization parameters from soils sampled in 1987 and 1988 can be found in Tables A4 and A5. Values for N_o in 1988 ranged from 9 to 570 mg N/kg soil and generally decreased with depth. N_o was also slightly lower using the mixed-order model compared to the first-order model when a lag-phase was evident. This

difference may have been reduced if samples showing a lag had been incubated for longer periods of time. The opposite effect was true when no lag was present. The first-order mineralization rate constant, k_0, ranged from 0.00103 to 0.01229 d^{-1} and decreased with depth. The mixed-order mineralization rate constant, k_1, ranged from -0.00064 to 0.01086 d^{-1} ($\bar{x}$=0.00388, SD=0.00206, n=69) and also decreased with depth. The mineralization rate constant k_2 ranged from -0.000025 to 0.00024 d^{-1} ($\bar{x}$ =0.000063, SD=0.000058, n=69) and increased with depth. These rate constants were different among soils and within a soil profile. This follows the conclusions of several other workers (Cabrera and Kissel, 1988a,b; Campbell et al., 1984; Hadas et al., 1986) and indicates that the rate constant (k) must also be determined in addition to N_o.

Possible Reasons for Mixed-order Lag

A number of reasons have been suggested for the presence of a lag-phase with cumulative N mineralized with time. One theory is that relatively undecomposed residue in the soil may lead to initial immobilization of N. Bonde and Lindberg (1988) found that a lag-phase occurred in mineralization, especially in manure-amended soil. The data from these soils of Bonde and Lindberg would not fit a first-order model but would fit a mixed-order expression.

Because most of the undisturbed soil cores in the present study were sampled between the rows of no-till farmed crops, residue was not considered to influence the lag-phase. Furthermore, little or no residue was found in any of the cores after dismantling at the completion of the laboratory procedure. Particularly noteworthy was the Kahola soil which had been sampled the previous year, cleared of any residue on the plots, roto-tilled, kept free of weeds, and fallowed one year before sampling in 1988. The mineralization data from soil cores without residue from this plot showed considerable lag (Figure A6). Moreover, the mineralization rate constant, k_2, generally increased with increasing depth, indicating that the lag-phase curve was more dominant at this depth where undecomposed organic matter would be expected to be at a minimum.

Another possible reason for the lag-phase may have been a lag in nitrification. Soil temperatures would have been low during early spring of 1988 when the samples were taken, resulting in lower numbers of nitrifiers. Because mineralized NH_4^+-N may not be completely extracted with 0.01 M $CaCl_2$, it seemed reasonable that the lag-phase encountered was simply a consequence of this phenomena. To test this, a subsample of the undisturbed soil core following the final leaching was extracted with 2 M KCl to

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determine if any mineralized N remained. In addition, 6 undisturbed soil cores from a 0.5 m square area were sampled from the 30-45 cm depth of two Crete soils. Cores from these soils showed some lag effect in 1987. Two of the cores from each soil were used for the entire incubation study whereas four of the undisturbed cores were taken apart following 4 weeks of incubation. Following leaching with 0.01 M $CaCl_2$, the cores were removed, subsampled, and extracted with 2 M KCl. A 10 g soil sample of each core was dried at 40 °C, and extracted by shaking for 30 minutes with 60 mL of 2 M KCl. The soil extract was then filtered under suction through Whatman #41 filter paper, washed with three 10 mL additions of KCl, brought up to a volume of 100 mL, and ammonium- and nitrate-N determined. The percentage of ammonium extracted by 0.01 M $CaCl_2$ was calculated assuming that the 2 M KCl extracted all of the exchangeable NH_4^+.

The results indicated that 0.01 M $CaCl_2$ was a poor extractant of total (2 M KCL extracted) ammonium (Table 3 and A6). If 0.01 M $CaCl_2$ did not remove greater than about 85% of the nitrate, the undisturbed core was assumed to have had some channeling effect through or around the core or there was an inadequate exchange volume during leaching. The percent ammonium extracted with 0.01 M $CaCl_2$ following 156 days of incubation ranged from 5 to 41% and varied

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with soil texture (Tables A3 and A6). The coarser the texture, the greater the percentage of NH_4^+ extracted with 0.01 M $CaCl_2$. In addition, ammonium left in the soil after leaching with 0.01 M $CaCl_2$ (i.e., that extracted with 2 M KCl) was equal to or slightly less following the first 27 days of incubation compared to following the last 34 days (156 days total incubation) of incubation for both soils (Table 3). If the nitrifier population was limiting during the early incubation period (the first 27 days), more ammonium would have been extracted with 2 M KCl at the end of this period. The total mineral N at both leaching times was about the same (averaging within 1 mg N/kg). Since the nitrifier population should have been greater the last 34 days of incubation, perhaps some of the KCl extractable ammonium was not available to microorganisms (i.e. there may have been some unmineralized ammonium that was fixed in the interlayer of expanding 2:1 layer silicates and then released during the drying and extraction procedure). Certainly, more work is needed to evaluate current leaching techniques in their effectiveness to quanititatively measure mineralized N at each leaching interval and what effect, if any, this has on producing a lag in mineralization.

Predicting N Mineralized in the Field

In predicting N mineralized in the field, N release below the 45 cm depth was ignored because previous studies indicated this did not exceed 10% of the total (Cabrera and Kissel, 1988b). Ammonium was also ignored when calculating actual N mineralized in the field. In previous work, Kissel and Cabrera (1988b) found that drying of soil samples prior to analysis increased extractable ammonium and that plant uptake correlated poorly with initial ammonium and with the ammonium balance.

Predicted N mineralization was relatively close to measured values using the first-order parameters for fallow plots for the Kahola soil in 1987 and the Haynie soil in 1988 (Table 4). Measured values of N mineralized for Kahola plots in 1988 were negative or near zero and, therefore, not included due to leaching or denitrification loss of nitrate from the profile. The Kahola site had a high water table in 1988 which was not as evident in 1987. Weekly soil water measurements with a neutron probe revealed a saturated zone near the 120 cm depth of the Kahola site following heavy rainfalls in 1988. Rainfall events were less during the 1988 measurement period (16), compared to the 1987 measurement period (23), however, total rainfall amounts were about the same (247 and 258 mm of rain for year 1987 and 1988 respectively). In 1988,

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highest rainfall amounts were 69, 44, 40, and 34 mm of rain for days of the year 181-182, 191, 197, and 226 respectively; whereas in 1987, all rainfall amounts were less than 31 mm and averaged about 11 mm of rain.

Observed and predicted N mineralized were in close agreement in plots of Kahola in 1987 and of Haynie in 1988 (Table 4). Average errors were reduced when parameters from the mixed-order model were used to predict N mineralized in 1988 Haynie plots. Predicted amounts of N mineralized from plots on Haynie and Reading in 1988 tended to be greater than N mineralized in the field. The average error from the Reading soil was significantly different from zero at the 0.05 probability level. Calculated errors of predicted versus observed N mineralized from each plot on the Reading soil increased in order from plot 1 to plot 4 (Table 4). The Reading plots decreased rapidly for the 30-45 cm depth in organic N and C from plot 1 to plot 4 (Table A3) and gave observed values of N mineralized, which also decreased in the same order. One possible reason for the overpredictions in this plot may be the use of soil cores sampled at the center of the 0-15 and 30-45 cm layers, which were used to describe N mineralization of the surface 45 cm of soil. Overpredictions may have also resulted from overestimating the 15-30 cm layer contribution to the N mineralized. Another reason may have

been that the 2.5 cm cores were not representative of each 15 cm layer. This factor was especially crucial in this soil which exibited a wide range in organic carbon contents (Table A3).

On the other hand, overpredictions in 1988 may have resulted from an inadequate water content factor, particularly for the Haynie site because of its coarse texture. Linn and Doran (1984) suggested that the optimum water content for mineralization in sandy soils may not be at 60% WFP. To test this, a water content factor similar to that of Myers et al. (1982) was used on each of the field plots of the form

$$W = (WC - AD)/(OWC - AD)$$

where WC is the actual water content, AD is the air-dry water content, and OWC is the optimum water content assumed to be at -33 kPa for the Kahola and Reading soils and calculated at -20 kPa for the Haynie soil from previous work with that soil (McInnes et al., 1986). Use of this water content adjustment factor greatly increased the predicted amounts of N mineralized in Haynie plots. Average percent errors using this water content factor increased from 21 to 60% (which was significantly different from zero at the 0.05 probability level), and from 13 to 50% using the first- and mixed-order parameters of Haynie, respectively. This water content factor was also used to

predict mineralization for Kahola and Reading soils. Predicted values using this factor for these soils increased slightly; however, the predicted values were similar to those in Table 4, which were obtained using the water content factor proposed by Linn and Doran (1984). It appears from these data that the water content factor using % WFP may give reasonable predictions even when using sandy soils. However, this validation for sandy soils has not been established. Furthermore, % WFP remained less than 60% throughout the measurement period for the Haynie soil, which may suggest that some other factor is responsible for the overpredictions in this soil.

Questions were also raised concerning use of an average temperature coefficient (Q_{10}) of 2 for the rate constants, k_1 and k_2 between the temperature range of 15 and 35 °C. Campbell et al. (1984) suggested that Q_{10} increased in sandy soils compared to loamy and clayey soils and that it was also related to the degree of organic matter degradation. This may explain some of the overpredictions particularly in the Haynie plots and may merit Q_{10} determination. Indeed, further study is needed to determine the accuracy of this water content factor and to quantify the temperature dependency of differing soils in predicting N mineralized in the field. Work is also needed to determine the length and number of cores needed

to describe the mineralization characteristics of a particular soil layer, especially when chemical and physical properties vary greatly with depth as exhibited by the Reading soil.

Estimation of N Mineralization Parameters

Because of the large number of undisturbed soil cores needed to describe N mineralization in a field, and the time and effort required to obtain these values, it would be advantageous to estimate the mineralization parameters from selected physical and chemical properties of a composite (disturbed) sample. Cabrera and Kissel (1988b) found that the value of (N_o x k_o) from undisturbed soil cores could be predicted from total N and clay content. It was determined that this product could also be predicted from the present study with parameters from undisturbed soil samples taken in 1987 if only the 0-15 cm depth was considered. When data from all depths or when only lower depths were considered, R-square values were very low.

Because CEC (corrected for organic matter contribution) is highly correlated to total surface area of soils (Farrar and Coleman, 1967), we decided to try to account for surface area in predicting (N_o x k_o) for the soil samples of the present study. We used CEC (corrected for OC contribution) to estimate surface area of the soil

samples and found that a better prediction could be obtained with this factor than with using clay contents in its place. R-square values were lower in all cases when CEC was replaced with clay contents. In order to calculate CEC without organic C, we used a contribution factor of organic C to total CEC of 101 cmol/kg for the 0-15 cm depth (Martel et al., 1978). This value was multiplied by the OC contents for each sample, and then subtracted from the total CEC value to obtain a CEC value corrected for OC contributions.

The value of N_O from the 1987 mineralization data could be estimated from the value of $(N_O \times k_O)$ as follows:

$$(N_O \times k_O) = 0.77 - 0.038 \text{ CEC} + 0.002 \text{ ON} \times \text{clay}$$

$$R^2 = 0.776$$

$$N_O = 482.52 (N_O \times k_O) \quad R^2 = 0.618; \quad n = 30$$

(In these equations, all variables are significant at the 0.001 level of probability). Similarly, the model parameters from the 1988 mineralization data could be predicted in the same manner at the 0-15 cm depth if soil samples containing clay contents greater than 35 and less than 15% were removed from the data set. The data from first-order mineralization parameters were estimated as follows:

$$(N_O \times k_O) = -1.00 + 0.0011 \text{ ON} + 0.034 \text{ CEC}$$

$$R^2 = 0.882$$

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$$N_O = 202.07 \ (N_O \times k_O) \qquad R^2 = 0.806; \quad n = 11,$$

(In these equations, all variables are significant at the 0.05 probability level) whereas the data from the mixed-order mineralization parameters were estimated by

$$(N_O \times k_1) = -1.10 + 0.0018 \ ON + 0.051 \ CEC - 0.004 \ ON \times clay$$

$$R^2 = 0.75$$

$$N_O = 224.89 \ (N_O \times k_1) \qquad R^2 = 0.855; \quad n = 19$$

(In these equations, the variables ON and $(N_O \times k_1)$ are significant at the 0.01 level of probability and all others are significant at the 0.1 probability level). Also, when considering the variables in these equations and in the ones above, organic N (ON) and N_O are expressed in mg N/kg soil, k_O and k_1 in d^{-1}, clay contents as %, and CEC (without organic C contribution) as cmol (+)/kg.

Prediction of the rate constant, k, were attempted from the product of $(N_O \times k)$, but in all cases the parameter, N_O, could be more easily predicted from this product.

SUMMARY

In summary, cumulative N mineralized with time could be generally described with a mixed-order model. This model accounts for a lag in mineralization which may be a result of a lag in the build-up of nitrifiers and/or ammonifiers. The extent of this lag differs among soils, with soil depth, and perhaps with initial sampling conditions (i.e. temperature). If no lag was evident, mineralization curves could be fit to a first-order mineralization model (Stanford and Smith, 1972). In general, the use of parameters from undisturbed soil cores could be used to give reasonable predictions of N mineralized in the field when adjustments were made for changes in temperature and soil water content. It was possible to estimate the model parameters, (N_o x k) from undisturbed samples taken at the 0-15 cm depth from the organic N, CEC, and clay contents of the soil.

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Table 1. Description of 1988 undisturbed soil sampling sites.

SOIL MAPPING UNIT	FAMILY CLASSIFICATION	KANSAS COUNTY	MAJOR SOILS REGION [1]	PREVIOUS CROP	TILLAGE
CRETE sicl, 3-7% (high-OM)	Fine, montmorillonitic, mesic Pachic Argiustolls	Dickinson	Central Loess Plains	wheat-diverted	reduced
CRETE sicl, 3-7% (low-OM)	Fine, montmorillonitic, mesic Pachic Argiustolls	Dickinson	Central Loess Plains	wheat-diverted	reduced
EUDORA 2 sil	Coarse-silty, mixed, mesic Fluventic Hapludolls	Shawnee	Flood Plain	corn	no-till
HARNEY sil, 0-1%	Fine, montmorillonitic, mesic Typic Argiustolls	Ellis	Chalk or Limestone Hills	sorghum	no-till
HAYNIE vfsl	Coarse-silty, mixed, calcareous, mesic Typic Udifluvents	Riley	Flood Plain	pearl millet	convt.5
KAHOLA sil	Fine-silty, mixed, mesic Cumulic Hapludolls	Riley	Terrace and Flood Plain	sorghum-fallow	chemical
KEITH sil, 0-1%	Fine-silty, mixed, mesic Aridic Argiustolls	Thomas	High Plains	wheat	no-till
KEITH 1, 0-1% (SATANTA) [3]	Fine-loamy, mixed, mesic Aridic Argiustolls	Finney	Sandy High Plains	sorghum	reduced
KENNEBEC sil [3]	Fine-silty, mixed, mesic Cumulic Hapludolls	Jackson	Flood Plain	corn	no-till
LADYSMITH sicl, 0-1%	Fine, mont., mesic Pachic Argiustolls	Harvey	Central Outwash Plains	sorghum	no-till
NARON fsl	Fine-loamy, mixed, thermic Udic Argiustolls	Pawnee	Great Bend Sandy Plains	corn	reduced
PARSONS 4 sil, 0-2% (high-OM)	Fine, mixed, thermic Mollic Albaqualfs	Labette	Cherokee Prairies	sorghum	no-till
PARSONS sil, 0-2% (low-OM)	Fine, mixed, thermic Mollic Albaqualfs	Labette	Cherokee Prairies	sorghum	no-till
PAWNEE cl, 1-3%	Fine, montmorillonitic, mesic Aquic Argiudolls	Jackson	Loess and Till Hills	sorghum	no-till
PRATT lfs, undulating	Sandy, mixed, thermic Psammentic Haplustalfs	Stafford	Great Bend Sandy Plains	sorghum	reduced
READING sil, 0-1%	Fine, mixed, mesic Typic Argiudolls	Riley	Flint Hills	wheat	reduced
RICHFIELD sil, 0-1%	Fine, montmorillonitic, mesic Aridic Argiustolls	Finney	High Plains	sorghum	reduced
WOODSON sil, 0-1%	Fine, mont., thermic Abruptic Argiaquolls	Franklin	Shale and Limestone Hills	sorghum	no-till
WOODWARD 1, 1-3%	Coarse-silty, mixed, thermic Typic Ustochrepts	Clark	Rolling Red Plains	sorghum	none

1 From General Soils Map, Kansas, rev. 1986.
2 An inclusion of Sarpy series.
3 Described by area Soil Scientist as Satanta series and classified accordingly.
4 Described by area Soil Scientist (Soil Survey not yet published).
5 Conventional tillage (plowed).

Table 2. Nitrogen mineralization parameters and residual sum of squares (RSS) from first- and mixed-order models fitted to data obtained with undisturbed samples from field plots in 1988.

SOIL SERIES	DEPTH	PLOT	FIRST-ORDER MODEL			MIXED-ORDER MODEL			
	cm		N_0 mg/kg	k_0 d^{-1}	RSS	N_0 mg/kg	k_1 d^{-1}	k_2 d^{-1}	RSS
KAHOLA	0-15	I	80	0.0061	2.37	64	0.0073	0.000027	2.13
		II	92	0.0048	1.56	71	0.0061	0.000018	1.45
		III	79	0.0061	1.91	85	0.0057	-0.000004	1.90
		IV	91	0.0066	10.88	105	0.0057	-0.000007	10.85
	30-45	I	42	0.0042	1.05	24	0.0062	0.000065	0.77
		II	63	0.0022	1.26	21	0.0047	0.000084	0.77
		III	58	0.0027	0.77	26	0.0052	0.000053	0.56
		IV	51	0.0033	0.93	24	0.0054	0.000080	0.41
HAYNIE	0-15	I	79	0.0070	10.6	94	0.0059	-0.000009	9.97
		II	85	0.0072	2.18	71	0.0082	0.000027	1.89
		III	113	0.0123	4.24	129	0.0110	-0.000027	2.87
		IV	110	0.0081	1.82	130	0.0069	-0.000012	1.43
	30-45	I	17	0.0036	0.12	21	0.0029	-0.000003	0.12
		II	16	0.0038	0.13	20	0.0030	-0.000003	0.13
		III	52	0.0010	0.02	13	0.0037	0.000025	0.018
		IV	39	0.0013	0.06	ND			
READING	0-15	I	262	0.0055	13.6	317	0.0046	-0.000006	13.2
		II	571	0.0019	4.11	ND			
		III	425	0.0032	0.60	ND			
		IV	464	0.0028	12.9	ND			
	30-45	I	ND			39	0.0018	0.000032	1.02
		II	92	0.0020	0.77	32	0.0047	0.000056	0.30
		III	ND			23	0.0033	0.000096	0.18
		IV	ND			26	0.0024	0.000115	0.08

ND Not determined. Data would not converge to fit model.

Table 3. Ammonium and nitrate extracted following 27 and 156 days of incubation of two undisturbed soils taken at the center of the 30-45 cm depth. The soil was leached with 0.01 M CaCl$_2$, removed from the cores, and then further extracted with 2 M KCl.

SOIL SERIES	SAM-PLE	DAYS INCUBATED	0.01 M CaCl$_2$ NH$_4^+$	0.01 M CaCl$_2$ NO$_3^-$	2 M KCl NH$_4^+$	2 M KCl NO$_3^-$	0.01 M CaCl$_2$ NH$_4^+$	0.01 M CaCl$_2$ NO$_3^-$
				------mg N/kg------			------ % ------	
CRETE (high-OM)	1	156	0.6	4.8	3.1	0.6	16	89
	2	156	0.6	5.7	4.0	0.7	13	89
	3	27	0.2	6.3	2.8	0.5	7	93
	4	27	0.2	6.7	2.5	0.5	9	93
	5	27	0.2	5.9	2.1	0.3	10	95
	6	27	0.2	4.8	2.8	0.6	7	89
CRETE (low-OM)	1	156	0.5	4.2	2.9	1.2	14	78
	2	156	0.5	3.9	2.9	0.6	14	88
	3	27	0.2	5.1	2.9	0.6	6	89
	4	27	0.2	5.2	2.7	0.6	7	90
	5	27	0.2	5.1	2.8	0.7	7	88
	6	27	0.2	4.5	3.0	0.7	6	87

% extracted calculated as [ammonium-N] or [nitrate-N], (mg/kg), in CaCl$_2$ leachates divided by the sum of the ammonium or nitrate concentrations in both extraction methods x 100.

Table 4. Observed and predicted N mineralized in fallow plots in 1987 and 1988. Predicted values were obtained from parameters of undisturbed cores that were adjusted according to daily field temperature and water content data.

SOIL SERIES	YEAR	PLOT	OBS.	FIRST-ORDER PRED.	FIRST-ORDER ERROR1	FIRST-ORDER AVG. ERROR	MIXED-ORDER PRED.	MIXED-ORDER ERROR	MIXED-ORDER AVG. ERROR
			---kg N/ha---		-- % --		kg N/ha	-- % --	
KAHOLA	1987	I	55	70	27				
		II	113	104	-8	-0.7			
		III	133	105	-21				
KAHOLA	1988	I	ND	86	—		96	—	
		II	ND	81	—		91	—	
		III	ND	84	—		90	—	
		IV	ND	92	—		98	—	
HAYNIE	1988	I	67	81	21		74	10	
		II	98	88	-10	21	87	-11	13
		III	93	141	52		130	40	
		IV	91	111	22		NF	—	
READING	1988	I	158	227	44		215	36	
		II	125	204	63		NF	—	
		III	112	234	109	88*	NF	—	
		IV	95	222	134		NF	—	

For 1987, N mineralized was calculated from Day of the Year 162 through day 294. For 1988, N mineralized was calculated from Day of the Year 140 through day 247.

*   Indicates significantly different from zero at the 0.05 level of probability.
ND   Not determined. Nitrate lost through the profile.
NF   Not able to fit a mixed-order model, would not converge.
1   Percent error calculated as [(Pred. − Obs.)/Obs.] x 100.

APPENDIX

Table Al. Description of 1987 undisturbed soil sampling sites.

SOIL MAPPING UNIT	FAMILY CLASSIFICATION	KANSAS COUNTY	MAJOR SOILS REGION 1	PREVIOUS CROP	TILLAGE
CRETE sicl, 3-7% (high-OM)	Fine, montmorillonitic, mesic Pachic Argiustolls	Dickinson	Central Loess Plains	wheat	reduced
CRETE sicl, 3-7% (low-OM)	Fine, montmorillonitic, mesic Pachic Argiustolls	Dickinson	Central Loess Plains	wheat	reduced
EUDORA 2 sil	Coarse-silty, mixed, mesic Fluventic Hapludolls	Shawnee	Flood Plain	corn	no-till
HARNEY sil, 1-3%	Fine, montmorillonitic, mesic Typic Argiustolls	Ellis	Chalk or Limestone Hills	sorghum	reduced
KAHOLA sil	Fine-silty, mixed, mesic Cumulic Hapludolls	Riley	Terrace and Flood Plain	sorghum	no-till
KEITH sil, 0-1% (high-OM)	Fine-silty, mixed, mesic Aridic Argiustolls	Thomas	High Plains	sorghum	convt.5
KEITH sil, 0-1% (low-OM)	Fine-silty, mixed, mesic Aridic Argiustolls	Thomas	High Plains	wheat	no-till
KEITH 1, 0-1% (SATANTA) 3	Fine-loamy, mixed, mesic Aridic Argiustolls	Finney	Sandy High Plains	sorghum-fallow	chemical
KENNEBEC sil	Fine-silty, mixed, mesic Cumulic Hapludolls	Jackson	Flood Plain	corn	no-till
LADYSMITH sicl, 0-1%	Fine, mont., mesic Pachic Argiustolls	Harvey	Central Outwash Plains	sorghum	no-till
NARON fsl	Fine-loamy, mixed, thermic Udic Argiustolls	Pawnee	Great Bend Sandy Plains	corn	reduced
PARSONS sil, 0-2% (high-OM)	Fine, mixed, thermic Mollic Albaqualfs	Labette	Cherokee Prairies	bare	convt.5
PARSONS sil, 0-2% (low-OM)	Fine, mixed, thermic Mollic Albaqualfs	Labette	Cherokee Prairies	sorghum	no-till
PAWNEE cl, 1-3%	Fine, montmorillonitic, mesic Aquic Argiudolls	Jackson	Loess and Till Hills	soybean-sorghum	no-till
PRATT lfs, undulating	Sandy, mixed, thermic Psammentic Haplustalfs	Stafford	Great Bend Sandy Plains	sorghum	reduced
RICHFIELD sil, 0-1%	Fine, montmorillonitic, mesic Aridic Argiustolls	Kearney	High Plains	sorghum	convt.5
SMOLAN sil, 1-4%	Fine, montmorillonitic, mesic Udic Argiustolls	Riley	Terrace and Flood Plain	sorghum	no-till
WOODSON sil, 0-1%	Fine, montmorillonitic, thermic Abruptic Argiaquolls	Franklin	Shale and Limestone Hills	sorghum	no-till
WOODWARD 1, 1-3%	Coarse-silty, mixed, thermic Typic Ustochrepts	Clark	Rolling Red Plains	oats-fallow	reduced

1 From General Soils Map, Kansas, rev. 1986
2 An inclusion of Sarpy series.
3 Described by area Soil Scientist as Satanta series and classified accordingly.
4 Described by area Soil Scientist (Soil Survey not yet published).
5 Conventional tillage (plowed).

Table A2. Selected physical and chemical properties for undisturbed soil cores sampled in the spring of 1987.

SOIL SERIES	DEPTH (cm)	SAMPLE	TEXTURAL CLASS	SAND	SILT	CLAY	FINE CLAY	ORGANIC C (g/kg)	N (mg/kg)	C:N	pH	CEC (cmol/kg)
						--- % ---						
CRETE (high-OM)	0-15	1	sic	4.7	47.0	48.2	37.0	27.0	2263	11.9	5.5	21.2
		2	sic	7.0	44.7	48.3	37.9	28.0	2344	11.9	5.5	20.6
	15-30	1	c	4.5	36.6	58.9	49.9	17.9	1500	11.9	6.3	ND
		2	sic	5.7	42.2	52.1	43.0	18.2	1461	12.5	6.2	23.7
	30-45	1	sic	1.7	51.0	47.3	29.5	12.7	1087	11.7	7.0	36.5
		2	sic	3.3	53.5	43.2	26.7	14.3	1199	11.9	6.7	33.7
CRETE (low-OM)	0-15	1	sic	6.7	62.4	30.9	17.0	14.7	1307	11.2	5.5	21.6
		2	sic	5.8	62.4	31.8	17.7	14.4	1344	10.7	5.5	21.7
	15-30	1	sicl	6.6	63.7	29.7	15.8	11.8	975	12.1	5.8	ND
		2	sicl	7.5	63.8	28.6	15.8	11.7	961	12.2	5.6	19.4
	30-45	1	sicl	9.3	63.1	27.7	13.9	13.6	1046	13.6	6.0	19.3
		2	sicl	6.2	60.3	34.6	20.1	14.2	1085	13.1	6.4	25.0
EUDORA 2	0-15	1	sl	65.4	28.7	5.9	2.2	7.7	643	12.0	6.4	7.1
		2	sl	67.3	26.7	6.0	1.3	9.6	779	12.3	6.7	7.7
	15-30	1	sl	68.3	25.8	5.8	2.5	2.9	267	10.9	6.3	6.1
		2	sl	69.1	24.9	6.0	2.1	2.9	261	10.3	6.4	6.2
	30-45	1	sl	58.4	38.0	6.6	3.2	2.3	224	10.3	6.5	6.5
		2	sl	67.9	27.0	5.3	2.6	2.3	209	10.0	6.7	5.7
HARNEY	0-15	1	sicl	10.3	58.6	31.1	16.6	11.1	1088	10.2	6.6	21.9
		2	sicl	11.7	56.3	32.0	17.5	10.6	1050	10.1	6.6	ND
	15-30	1	sicl	7.6	57.5	34.9	19.4	8.3	824	10.1	7.0	24.9
		2	sicl	7.1	57.6	35.3	19.2	8.2	794	10.3	7.0	25.5
	30-45	1	sicl	6.4	60.7	32.8	15.9	5.6	675	8.3	7.8	ND
		2	sicl	6.1	59.0	34.8	16.6	5.6	675	8.3	7.8	27.2
KAHOLA	0-15	1	sil	11.5	68.5	20.0	9.7	13.4	1046	12.8	6.2	14.7
		2	sil	12.1	68.2	19.7	9.1	13.1	1044	12.5	6.5	14.4
	15-30	1	sil	12.2	68.7	19.2	8.3	14.0	1050	13.0	6.8	ND
		2	sil	10.1	70.6	19.3	9.3	13.6	1046	13.0	6.0	15.3
		3	sil	10.1	69.4	20.4	9.2	14.8	1138	13.0	7.1	16.7
	30-45	1	sil	9.2	70.4	20.4	9.3	13.6	1048	13.0	6.0	15.3
		2	sil	6.7	71.4	21.9	11.5	13.1	1011	13.4	6.4	16.3
		3	sil	6.4	71.7	21.7	11.7	12.6	974	13.2	6.1	16.6
KEITH (high-OM)	0-15	1	sicl	18.4	38.9	42.7	29.9	21.5	1926	11.2	7.0	21.2
		2	sicl	15.8	40.8	43.3	30.5	21.6	1899	11.4	7.0	20.1
	15-30	1	sil	22.0	55.3	22.7	10.2	12.0	1045	11.5	7.3	21.4
		2	sil	22.9	54.1	23.1	9.8	11.6	1010	11.5	7.4	21.9
	30-45	1	sil	23.6	51.9	24.5	10.4	8.0	762	10.4	7.7	21.9
		2	sil	25.7	55.4	23.8	9.7	8.6	823	10.4	7.7	21.0
KEITH (low-OM)	0-15	1	sil	22.3	55.9	22.3	6.4	8.9	762	10.6	8.0	21.0
		2	sil	21.8	55.4	22.4	6.4	8.3	785	10.4	8.0	21.2
	15-30	1	sicl	17.4	51.9	30.7	13.7	7.6	786	9.7	7.9	25.3
		2	sicl	19.3	53.3	27.4	12.9	7.4	749	9.9	7.9	25.5
	30-45	1	sicl	17.7	49.9	32.4	11.7	7.8	749	10.4	8.4	27.1
		2	sicl	19.7	48.8	31.6	11.1	7.7	749	10.3	8.3	26.8

Table A2 (continued). Selected physical and chemical properties of undisturbed soil cores sampled in the spring of 1987.

SOIL SERIES	DEPTH (cm)	SAMPLE	TEXTURAL CLASS	SAND	SILT	CLAY	FINE CLAY	ORGANIC C (g/kg)	N (mg/kg)	C:N	pH	CEC (cmol/kg)
				%	%	%	%					
KENNEBEC	0-15	1	sic	2.0	56.4	41.6	22.7	14.6	940	15.5	7.0	34.3
		2	sic	1.8	57.3	40.9	22.1	16.2	1125	14.4	6.8	ND
	15-30	1	sic	1.6	54.8	43.6	25.1	12.9	862	15.0	7.4	ND
		2	sic	1.7	53.6	44.6	26.2	8.3	525	15.8	7.9	33.8
	30-45	1	sic	1.3	51.7	47.0	28.3	11.5	750	15.3	7.5	ND
		2	sic	1.5	52.2	46.3	28.1	10.7	690	15.5	7.8	ND
LADYSMITH	0-15	1	sicl	8.1	57.7	34.2	22.3	13.0	1050	12.4	5.9	24.8
		2	sicl	7.7	58.9	33.4	21.6	13.2	937	14.1	5.9	ND
	15-30	1	sic	4.0	52.3	43.7	31.7	10.7	862	12.4	7.0	ND
		2	sic	4.2	52.4	43.1	30.8	9.9	825	12.0	7.0	ND
	30-45	1	sic	4.2	53.0	42.8	30.0	8.5	727	11.7	7.5	ND
		2	sic	5.2	54.1	40.8	28.1	8.7	763	11.6	7.6	ND
NARON	0-15	1	sl	76.8	14.1	9.1	4.6	8.5	750	11.1	5.5	7.4
		2	sl	75.8	16.3	7.9	4.9	8.6	744	11.6	5.6	7.4
	15-30	1	sl	76.8	9.8	13.4	9.3	4.5	444	10.1	6.6	9.6
		2	sl	74.3	12.5	13.2	9.1	4.5	473	9.5	6.3	9.1
	30-45	1	scl	55.0	20.0	25.0	17.6	5.3	524	10.1	6.6	17.1
		2	scl	53.0	21.2	25.8	18.0	5.6	552	10.1	6.8	17.1
PARSONS[3] (high-OM)	0-15	1	sicl	12.3	57.1	30.7	23.3	20.5	1526	13.3	6.9	15.9
		2	sicl	11.2	60.8	27.9	19.9	19.6	1522	12.9	5.3	16.5
	15-30	1	sil	13.7	67.3	19.0	7.5	10.5	897	11.7	5.6	14.2
		2	sil	14.0	68.0	18.1	7.2	11.1	896	12.3	6.0	14.0
	30-45	1	sic	9.9	45.1	45.0	30.0	10.8	1047	10.3	5.9	29.6
		2	sic	6.6	48.2	45.2	29.8	10.3	1050	9.8	5.9	ND
PARSONS[3] (low-OM)	0-15	1	sil	18.0	67.1	14.9	5.3	9.7	824	11.8	7.8	12.4
		2	sil	17.1	67.9	15.0	6.4	9.2	824	11.2	7.7	11.9
	15-30	1	sicl	15.1	52.5	32.3	21.1	7.3	750	9.7	6.4	20.1
		2	sicl	12.5	52.1	35.3	23.5	7.4	750	9.9	7.1	23.1
	30-45	1	sic	8.8	43.8	47.9	36.7	7.5	788	9.5	5.4	ND
		2	sic	8.3	43.8	47.9	35.6	7.0	750	9.3	5.5	ND
PAWNEE	0-15	1	sic	6.5	55.9	37.5	19.3	17.9	1608	11.1	7.7	2.6
		2	sicl	6.1	55.8	38.1	18.1	18.0	1463	12.3	7.8	ND
	15-30	1	sicl	3.1	54.5	42.5	23.3	13.6	1200	11.3	7.7	ND
		2	sic	2.8	55.2	42.1	22.4	13.2	1163	11.3	8.0	ND
	30-45	1	sic	3.7	53.5	42.8	23.9	7.5	746	10.1	8.2	31.0
		2	sic	5.3	52.8	41.9	22.6	7.3	750	9.7	8.4	ND
PRATT	0-15	1	s	94.0	4.3	1.8	0.0	3.3	258	12.8	6.5	2.0
		2	s	94.1	4.3	1.5	1.3	2.3	184	12.5	6.8	1.7
	15-30	1	s	90.2	5.8	4.1	0.9	2.7	261	10.3	5.1	3.0
		2	s	91.0	4.5	4.5	1.5	2.2	208	10.6	5.2	2.9
	30-45	1	sl	80.6	4.7	14.7	9.1	3.6	445	8.1	6.1	10.1
		2	sl	81.3	6.1	12.6	8.6	3.7	446	8.3	6.1	9.0

Table A2 (continued). Some physical and chemical properties for undisturbed soil cores sampled in the spring of 1987.

SOIL SERIES	DEPTH	SAMPLE	TEXTURAL CLASS	SAND	SILT	CLAY	FINE CLAY	ORGANIC C	N	C:N	pH	CEC
	cm					%		g/kg	mg/kg			cmol/kg
RICHFIELD	0-15	1	sil	24.5	52.8	22.7	12.0	9.8	930	10.5	6.8	18.5
		2	sil	25.4	50.4	24.2	12.2	10.4	922	11.3	6.7	19.3
	15-30	1	sil	21.9	52.2	25.9	13.4	8.5	821	10.4	7.5	ND
		2	sil	22.8	52.6	24.7	11.8	7.9	820	9.6	7.4	ND
	30-45	1	sicl	18.1	51.4	30.5	14.1	6.2	708	8.8	7.8	ND
		2	sicl	18.9	50.6	30.5	13.7	6.2	707	8.8	7.7	ND
SATANTA [4]	0-15	1	sl	59.1	27.5	13.4	5.4	7.3	626	11.7	7.1	9.9
		2	sl	60.7	26.1	13.1	5.6	7.4	652	11.3	7.2	10.3
	15-30	1	l	50.1	30.7	19.1	10.7	5.5	522	10.5	7.1	14.5
		2	sl	53.2	28.7	18.1	10.4	5.1	484	10.5	7.2	14.3
	30-45	1	l	35.4	41.1	23.6	14.6	5.3	507	10.5	7.4	19.1
		2	l	34.8	41.3	23.9	15.3	5.3	518	10.2	7.3	18.3
SMOLAN	0-15	1	sicl	9.0	56.9	34.0	19.2	13.7	1085	12.6	6.1	ND
		2	sicl	9.4	58.8	34.0	19.2	14.3	1125	12.7	7.0	ND
		3	sicl	9.2	57.7	33.1	16.5	14.3	1125	12.7	7.0	ND
	15-30	1	sic	5.1	54.8	40.1	24.2	11.1	1013	11.0	6.5	ND
		2	sic	5.3	54.3	40.4	25.8	12.8	1124	11.4	6.5	ND
		3	sic	4.6	54.3	41.0	26.8	12.0	1065	11.3	6.5	ND
	30-45	1	sicl	5.3	57.4	37.3	23.9	8.2	788	10.4	6.8	25.4
		2	sicl	4.8	55.7	39.6	25.4	9.1	863	10.5	6.8	ND
		3	sicl	5.4	55.3	39.3	25.9	8.0	788	10.2	6.8	ND
WOODSON	0-15	1	sil	3.8	72.9	23.3	11.3	17.8	1311	13.6	6.1	ND
		2	sil	4.5	73.3	22.2	10.8	17.9	1305	13.7	6.2	ND
	15-30	1	sicl	3.5	68.4	28.1	15.4	15.9	1013	15.7	6.4	20.1
		2	sicl	3.1	67.5	29.4	16.1	15.4	975	15.8	6.5	23.2
	30-45	1	sic	2.9	60.0	37.0	25.1	14.4	938	15.4	6.6	23.9
		2	sic	2.4	56.4	41.2	28.5	14.3	975	14.7	6.6	ND
WOODWARD	0-15	1	l	45.3	39.4	15.3	5.7	7.6	761	10.0	8.4	32.8
		2	l	45.0	39.3	15.7	5.5	7.6	785	9.7	8.4	12.4
	15-30	1	l	40.0	38.6	21.4	8.7	8.3	852	9.7	8.4	12.2
		2	l	40.4	39.1	20.5	9.6	8.4	867	9.7	8.4	13.1
	30-45	1	l	41.7	36.3	22.0	10.6	6.2	673	9.2	8.4	13.4
		2	l	41.5	36.5	22.0	10.1	6.5	670	9.7	8.4	13.3

1 Not determined.
2 An inclusion of Sarpy series.
3 Described by area Soil Scientist (Soil Survey not yet published).
4 Described by area Soil Scientist (mapped as Keith sil).

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Table A3. Selected physical and chemical properties of undisturbed soil cores sampled in the spring of 1988.

SOIL SERIES	DEPTH	SAMPLE	TEXTURAL CLASS	SAND	SILT	CLAY	FINE CLAY	ORGANIC C	N	C:N	pH	CEC
	cm			---------------------------- % ----------------------------				g/kg	mg/kg			cmol/kg
CRETE (high-OM)	0-15	1	sicl	6.7	61.6	31.7	21.8	26.6	2512	10.6	5.1	21.8
	0-15	2	sicl	5.6	63.8	30.6	20.0	26.5	2463	10.8	4.9	21.1
	30-45	1	sic	3.6	49.6	46.8	27.6	9.6	921	10.4	6.7	32.4
	30-45	2	sic	3.6	48.0	48.4	29.2	11.6	1110	10.5	6.7	35.2
CRETE (low-OM)	0-15	1	sicl	6.0	60.5	33.5	19.4	11.8	1017	11.6	5.4	21.8
	0-15	2	sicl	7.0	60.6	32.4	18.9	11.7	1071	10.9	6.2	21.8
	30-45	1	sicl	7.5	63.6	28.9	14.1	12.8	967	13.2	6.3	19.3
	30-45	2	sicl	7.1	64.2	28.7	14.1	12.7	954	13.3	6.3	19.3
EUDORA 1	0-15	1	sl	71.5	22.6	5.9	2.8	4.4	408	10.8	6.1	5.8
	0-15	2	sl	72.3	21.6	6.1	3.1	3.6	349	10.3	5.1	5.8
	30-45	1	ls	79.7	16.6	3.7	2.0	0.8	110	7.3	6.5	3.9
	30-45	2	ls	85.5	11.7	2.8	1.9	0.7	73	9.6	6.4	3.3
HARNEY	0-15	1	sicl	10.6	56.8	32.6	15.6	10.5	864	12.2	7.2	21.8
	0-15	2	sicl	10.3	56.6	33.1	16.4	10.4	858	12.1	7.2	21.8
	30-45	1	sic	9.3	50.0	40.7	24.9	7.0	671	10.4	6.9	26.9
	30-45	2	sic	13.4	46.8	39.8	25.0	6.4	597	10.7	7.0	25.6
HAYNIE	0-15	1	sl	58.0	33.6	8.4	4.9	4.8	409	11.7	6.4	7.1
	0-15	2	sl	58.9	33.0	8.5	4.5	5.6	484	11.6	6.3	6.8
	0-15	3	sl	59.5	32.0	8.5	4.4	5.5	485	11.3	5.9	6.9
	0-15	4	sl	61.7	30.6	7.7	3.8	5.5	461	11.9	6.5	6.5
	30-45	1	s	88.3	8.2	3.5	1.8	0.9	112	8.0	6.9	3.5
	30-45	2	s	88.4	8.1	3.5	1.9	0.9	112	8.0	7.1	3.4
	30-45	3	s	89.1	7.3	3.6	2.0	0.8	96	8.3	7.1	3.3
	30-45	4	ls	85.1	11.2	3.7	1.9	0.9	102	8.8	7.2	3.5
KAHOLA	0-15	1	sil	12.6	67.5	19.9	8.5	12.6	970	13.0	6.7	14.2
	0-15	2	sil	13.9	67.2	18.9	7.9	13.2	1007	12.9	6.3	14.1
	0-15	3	sil	14.3	65.6	20.1	8.8	13.2	992	13.3	6.1	14.0
	0-15	4	sil	13.7	66.9	19.4	8.1	13.1	1007	13.0	6.7	14.2
	30-45	1	sil	7.8	68.6	23.6	11.6	13.0	988	13.2	5.8	16.5
	30-45	2	sil	8.0	68.7	23.3	11.5	12.5	938	13.3	6.2	16.1
	30-45	3	sil	8.5	68.7	22.8	11.1	12.9	943	13.7	6.4	16.1
	30-45	4	sil	9.0	68.0	23.0	11.3	12.7	998	12.7	6.3	16.0
KEITH	0-15	1	cl	20.2	52.1	27.7	9.1	7.1	654	10.9	7.8	21.0
	0-15	2	cl	21.7	51.6	26.7	8.8	6.7	627	10.7	7.8	20.5
	30-45	1	sicl	14.4	51.2	34.4	9.7	8.1	701	11.6	8.2	26.7
	30-45	2	sicl	16.6	49.2	34.2	9.4	8.2	705	11.6	8.2	26.8
KENNEBEC	0-15	1	sicl	3.2	60.5	36.3	13.9	15.0	1190	12.6	7.8	26.3
	0-15	2	sicl	4.0	61.1	34.9	13.9	14.6	1191	12.3	7.8	26.3
	30-45	1	sicl	4.0	60.5	36.3	16.8	10.9	852	12.8	7.9	24.2
	30-45	2	sicl	4.0	61.8	34.2	16.7	11.1	889	12.5	7.9	23.9
LADYSMITH	0-15	1	sicl	7.1	53.8	39.1	23.9	12.5	991	12.6	6.0	26.8
	0-15	2	sicl	6.4	55.1	38.5	24.0	12.5	952	13.6	5.9	27.0
	30-45	1	sic	3.0	49.2	47.8	30.8	9.1	671	13.6	7.6	27.3
	30-45	2	sic	3.1	48.6	48.3	30.9	9.4	709	13.3	7.6	34.4

Table A3 (continued). Selected physical and chemical properties of undisturbed soil cores sampled in the spring of 1988.

SOIL SERIES	DEPTH	SAMPLE	TEXTURAL CLASS	SAND	SILT	CLAY	FINE CLAY	ORGANIC C	N	C:N	pH	CEC
	cm			------	-----	%	------	g/kg	mg/kg			cmol/kg
NARON	0-15	1	sl	67.9	21.9	10.2	4.8	8.6	657	13.1	6.3	7.6
		2	sl	68.4	21.4	10.2	4.5	8.3	635	13.1	6.5	7.6
	30-45	1	sl	72.6	13.5	13.9	9.1	3.6	334	10.8	6.7	9.3
		2	sl	71.6	13.9	14.5	9.3	3.6	319	11.3	6.7	9.6
PARSONS [2] (high-OM)	0-15	1	sil	11.4	65.6	23.0	12.8	22.2	1810	12.3	7.2	16.6
		2	sil	11.7	64.9	23.4	13.5	22.6	1795	12.6	7.1	16.7
	30-45	1	sicl	11.2	48.8	40.0	23.4	9.5	935	10.7	6.0	24.0
		2	sicl	11.1	51.3	37.6	21.2	9.6	897	10.2	5.9	22.4
PARSONS [2] (low-OM)	0-15	1	sil	19.6	63.5	16.9	5.5	8.4	696	12.1	7.5	12.0
		2	sil	19.5	64.1	16.4	5.8	8.1	673	12.0	7.7	11.7
	30-45	1	c	7.7	36.8	55.5	39.5	7.2	755	9.5	5.4	32.2
		2	c	7.5	37.0	55.5	40.2	7.5	762	9.8	5.4	32.4
PAWNEE	0-15	1	sic	6.6	50.3	43.1	22.6	16.8	1526	10.9	6.4	32.2
	30-45	1	sic	5.3	44.7	50.0	29.6	10.7	986	10.9	7.5	34.3
		2	sic	5.2	45.2	49.6	29.5	8.7	859	10.1	7.9	32.6
PRATT	0-15	1	s	93.4	3.4	2.4	0.8	2.9	186	15.6	6.8	2.0
		2	s	94.2	3.4	2.4	1.2	3.1	186	16.7	6.9	2.0
	30-45	1	ls	86.3	4.4	9.3	5.1	2.5	186	13.4	6.2	5.7
		2	ls	86.1	4.2	9.7	5.4	2.2	186	11.8	6.1	5.9
READING	0-15	1	sicl	5.7	60.8	33.5	23.5	22.5	1530	14.7	6.4	25.8
		2	sicl	6.1	56.2	37.7	25.8	23.0	1608	14.3	6.5	25.9
		3	sicl	5.9	56.0	38.1	26.2	23.4	1603	14.6	6.4	26.0
		4	sicl	5.5	57.7	36.8	24.3	23.8	1677	14.2	6.6	26.3
	30-45	1	sic	4.5	52.8	42.7	29.9	20.5	1226	16.7	6.7	27.1
		2	sic	4.6	54.6	40.9	29.2	20.7	1301	15.9	6.5	27.7
		3	sic	4.4	51.5	44.1	31.7	18.0	1149	15.7	6.6	28.3
		4	sic	5.1	52.1	42.8	25.3	14.0	928	15.1	7.0	28.1
RICHFIELD	0-15	1	sil	24.3	50.3	25.4	9.9	11.2	970	11.5	7.7	19.6
		2	sil	20.2	53.1	26.7	10.8	10.4	933	11.1	7.6	20.1
	30-45	1	sicl	13.5	56.1	30.4	14.3	5.4	521	10.4	6.5	22.5
		2	sicl	14.1	57.6	28.3	13.5	5.1	520	9.8	5.7	20.3
SATANTA [3]	0-15	1	ls	77.6	15.6	7.0	3.1	3.6	299	12.0	7.3	5.1
		2	sl	60.2	22.5	17.3	2.9	3.5	261	13.4	7.3	5.1
	30-45	1	sl	60.2	23.3	16.5	9.7	4.8	405	11.9	6.5	12.5
		2	sl	58.9	25.1	16.0	9.1	4.7	441	10.7	6.6	12.3
WOODSON	0-15	1	sic	2.5	57.3	40.2	27.4	12.6	968	13.0	6.5	29.4
		2	sic	2.2	59.2	38.6	26.6	12.9	981	13.1	6.6	29.5
		3	sic	1.9	55.6	42.5	30.0	12.6	1001	12.6	6.5	32.5
WOODWARD	0-15	1	l	42.4	39.6	18.0	5.9	8.0	747	10.7	8.3	11.2
		2	l	41.0	41.0	18.0	6.0	7.7	730	10.5	8.3	10.9
	30-45	1	l	38.2	36.9	24.9	11.1	6.1	597	10.2	8.4	15.0
		2	l	37.8	36.3	25.9	10.9	6.1	597	10.2	8.4	15.0

1 An inclusion of Sarpy series.
2 Described by area Soil Scientist (Soil Survey not yet published).
3 Described by area Soil Scientist (mapped as Keith sil).

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Table A4. Nitrogen mineralization parameters and soil dry weights from undisturbed soil cores sampled in 1987.

SOIL SERIES	DEPTH	SAM-PLE	SOIL WIEGHT	N_o	k_o
	cm		kg	mg/kg	d^{-1}
CRETE	0-15	1	0.085	2081	0.0010
(high OM)		2	0.074	2309	0.0010
	15-30	2	0.090	68	0.0057
	30-45	1	0.086	95	0.0016
		2	0.093	65	0.0028
CRETE	0-15	1	0.102	385	0.0029
(low OM)		2	0.097	893	0.0013
	15-30	2	0.104	174	0.0017
	30-45	1	0.104	37	0.0056
		2	0.110	56	0.0030
EUDORA	0-15	1	0.210	78	0.0121
		2	0.225	96	0.0086
	15-30	1	0.213	25	0.0037
		2	0.228	26	0.0087
	30-45	1	0.224	16	0.0032
		2	0.213	53	0.0009
HARNEY	0-15	1	0.107	268	0.0016
	15-30	1	0.102	61	0.0023
		2	0.107	40	0.0034
	30-45	2	0.096	62	0.0011
KAHOLA	0-15	1	0.083	110	0.0026
		2	0.096	93	0.0073
	15-30	1	0.093	187	0.0011
		2	0.087	89	0.0022
		3	0.097	147	0.0015
	30-45	1	0.103	66	0.0021
		2	0.082	98	0.0014
		3	0.100	59	0.0020
KEITH	0-15	1	0.157	408	0.0065
(high OM)		2	0.163	566	0.0030
	15-30	1	0.176	45	0.0059
		2	0.187	43	0.0054
	30-45	1	0.183	41	0.0037
		2	0.190	32	0.0049
KEITH	0-15	1	0.195	75	0.0057
(low OM)		2	0.176	141	0.0026
	15-30	1	0.163	40	0.0031
		2	0.208	201	0.0004
	30-45	1	0.211	90	0.0007
		2	0.198	76	0.0009

Table A4 continued.

SOIL SERIES	DEPTH	SAM-PLE	SOIL WEIGHT	N_O	k_O
	cm		kg	mg/kg	d^{-1}
KENNEBEC	0-15	1	0.105	94	0.0028
	15-30	1	0.117	ND	ND
		2	0.100	21	0.0076
LADYSMITH	0-15	2	0.121	58	0.0067
	15-30	1	0.108	ND	ND
	30-45	1	0.106	ND	ND
NARON	0-15	1	0.254	178	0.0067
		2	0.186	134	0.0058
	15-30	1	0.251	31	0.0035
		2	0.258	32	0.0038
	30-45	1	0.253	57	0.0017
		2	0.240	54	0.0019
PARSONS (high OM)	0-15	1	0.063	177	0.0063
		2	0.073	136	0.0074
	15-30	1	0.098	84	0.0012
		2	0.098	46	0.0045
	30-45	1	0.109	203	0.0008
PARSONS (low OM)	0-15	1	0.118	92	0.0054
		2	0.108	140	0.0028
	15-30	1	0.083	59	0.0023
		2	0.092	104	0.0016
PAWNEE	0-15	1	0.106	780	0.0009
	30-45	1	0.098	81	0.0019
PRATT	0-15	1	0.228	62	0.0056
		2	0.256	72	0.0047
	15-30	1	0.233	23	0.0038
		2	0.222	27	0.0030
	30-45	1	0.258	55	0.0010
		2	0.263	153	0.0004
RICHFIELD	0-15	1	0.104	680	0.0010
		2	0.068	266	0.0032
	15-30	1	0.116	ND	ND
		2	0.094	ND	ND
	30-45	1	0.095	ND	ND
		2	0.098	ND	ND

Table A4 continued.

SOIL SERIES	DEPTH	SAM-PLE	SOIL WEIGHT	N_O	k_O
	cm		kg	mg/kg	d^{-1}
SATANTA	0-15	1	0.108	202	0.0040
		2	0.104	106	0.0263
	15-30	1	0.119	236	0.0004
		2	0.119	591	0.0002
	30-45	1	0.095	ND	ND
		2	0.099	93	0.0009
SMOLAN	0-15	1	0.117	ND	ND
	15-30	2	0.094	ND	ND
	30-45	1	0.106	85	0.0014
WOODSON	0-15	2	0.214	156	0.0025
	15-30	1	0.211	109	0.0010
		2	0.228	189	0.0005
	30-45	1	0.230	ND	ND
		2	0.216	29	0.0043
WOODWARD	0-15	1	0.090	170	0.0035
		2	0.101	79	0.0058
	15-30	1	0.100	83	0.0013
		2	0.093	48	0.0028
	30-45	1	0.089	57	0.0018
		2	0.088	61	0.0020

Missing cores in the table could not be leached and equilibrated within a predetermined time period (24 hours).

ND   Not determined.   Data would not converge to fit the model.

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Table A5. Nitrogen mineralization parameters from mixed- and first-order models and soil dry weights for undisturbed soil cores sampled in 1988.

SOIL SERIES	DEPTH	SAM-PLE	SOIL WEIGHT	MIXED-ORDER N_o	k_1	k_2	FIRST-ORDER N_o	k_o
	cm		kg	mg/kg	d^{-1}		mg/kg	d^{-1}
CRETE	0-15	1	0.075	ND			ND	
(high OM)		2	0.069	394	0.0028	0.000172		
	30-45	1	0.087	50	0.0058	0.000020		
		2	0.082	58	0.0057	0.000017		
CRETE	0-15	1	0.083	373	0.0018	-0.000001	292	0.0023
(low OM)		2	0.086	243	0.0035	-0.000004	193	0.0044
	30-45	1	0.107	37	0.0041	0.000040		
		2	0.106	33	0.0044	0.000055		
EUDORA	0-15	1	0.105	ND			66	0.0037
		2	0.076	ND			37	0.0060
	30-45	1	0.093	9	-0.0024	0.000170		
		2	0.086	11	0.0023	0.000092		
HARNEY	0-15	1	0.083	54	0.0040	0.000050		
		2	0.067	96	0.0032	0.000011		
	30-45	2	0.094	25	0.0016	0.000077		
HAYNIE	0-15	1	0.091	94	0.0059	-0.000009	79	0.0070
		2	0.101	71	0.0082	0.000027	85	0.0072
		3	0.096	129	0.0110	-0.000027	113	0.0123
		4	0.088	130	0.0069	-0.000012	110	0.0081
	30-45	1	0.099	21	0.0029	-0.000003	17	0.0036
		2	0.101	20	0.0030	-0.000003	16	0.0038
		3	0.094	13	0.0037	0.000025	52	0.0010
		4	0.111	ND			39	0.0013
KAHOLA	0-15	1	0.063	64	0.0073	0.000027	80	0.0061
		2	0.061	71	0.0061	0.000018	92	0.0048
		3	0.067	85	0.0057	-0.000004	79	0.0061
		4	0.073	105	0.0057	-0.000007	91	0.0066
	30-45	1	0.097	24	0.0062	0.000065	42	0.0042
		2	0.098	21	0.0047	0.000084	63	0.0022
		3	0.098	26	0.0052	0.000053	58	0.0027
		4	0.094	24	0.0054	0.000080	51	0.0033
KEITH	0-15	1	0.083	105	0.0031	-0.000003	84	0.0039
		2	0.091	64	0.0045	0.000017		
	30-45	1	0.097	30	0.0029	0.000045		
		2	0.084	28	0.0018	0.000089		
KENNEBEC	0-15	1	0.095	ND				
		2	0.083	127	0.0035	0.000128		
	30-45	1	0.094	104	0.0031	0.000002		
		2	0.099	ND				
LADYSMITH	0-15	2	0.093	63	0.0036	0.000109		
	30-45	1	0.103	28	-0.00014	0.000117		
		2	0.095	26	-0.00064	0.000169		

Table A5 continued.

SOIL SERIES	DEPTH	SAM-PLE	SOIL WEIGHT	MIXED-ORDER N_o	k_1	k_2	FIRST-ORDER N_o	k_o
	cm		kg	mg/kg	-----d^{-1}------		mg/kg	d^{-1}
NARON	0-15	1	0.116	169	0.0047	-0.000006	139	0.0057
		2	0.112		ND		132	0.0031
	30-45	1	0.113	28	0.0023	0.000181		
		2	0.109	27	0.0036	0.000082		
PARSONS	0-15	1	0.076	252	0.0066	-0.000011	212	0.0077
(high OM)		2	0.092	244	0.0057	-0.000009	201	0.0068
	30-45	1	0.097	27	0.0035	0.000095		
		2	0.097	24	0.0063	0.000078		
PARSONS	0-15	1	0.105	57	0.0065	0.000013		
(low OM)		2	0.119	72	0.0040	0.000002		
	30-45	1	0.081	19	0.0029	0.000083		
		2	0.080	14	0.0014	0.000241		
PAWNEE	30-45	2	0.094		ND			
PRATT	0-15	1	0.108	40	0.0049	0.000113		
		2	0.089	53	0.0050	0.000057		
	30-45	1	0.119	20	0.0027	0.000173		
		2	0.110	22	0.0016	0.000148		
READING	0-15	1	0.082	317	0.0046	-0.000006	262	0.0055
		2	0.077		ND		571	0.0019
		3	0.089		ND		425	0.0032
		4	0.088		ND		464	0.0028
	30-45	1	0.102	39	0.0018	0.000032	ND	
		2	0.100	32	0.0047	0.000056	92	0.0020
		3	0.106	23	0.0033	0.000096	ND	
		4	0.092	26	0.0024	0.000115	ND	
RICHFIELD	0-15	1	0.085	153	0.0046	0.000074		
		2	0.088		ND		445	0.0024
	30-45	1	0.096	30	0.0034	0.000066		
		2	0.078	30	0.0032	0.000093		
SATANTA	0-15	1	0.110	40	0.0049	0.000112		
		2	0.113	40	0.0042	0.000091		
	30-45	1	0.098	31	0.0025	0.000069		
		2	0.105	23	0.0014	0.000108		
WOODSON	0-15	1	0.084	41	0.0032	0.000103		
		2	0.101	54	0.0028	0.000060		
		3	0.076		ND			
WOODWARD	0-15	1	0.092	100	0.0043	0.000081		
		2	0.106	96	0.0047	0.000054		
	30-45	1	0.080	29	0.0014	0.000122		
		2	0.094	37	0.0031	0.000038		

Missing soil cores could not be leached and equilibrated within a predetermined time period (24 hours).

ND Not determined. Data would not converge to fit the model.

Table A6. Percentages of ammonium and nitrate extracted with 0.01 M CaCl$_2$ following removal of undisturbed soil cores after 156 days of incubation, and extraction with 2 M KCl in 1988.

SOIL SERIES	DEPTH	SAM-PLE	CaCl$_2$ extracted NH$_4^+$	CaCl$_2$ extracted NO$_3^-$	2 M KCl extracted NH$_4^+$	2 M KCl extracted NO$_3^-$	0.01 M CaCl$_2$ extracted NH$_4^+$	0.01 M CaCl$_2$ extracted NO$_3^-$
	cm				mg N/kg		%	%
CRETE	0-15	1	0.8	69.1	6.0	3.7	12	95
(high OM)		2	0.7	47.1	5.7	1.2	11	95
	30-45	1	0.6	4.8	3.1	0.6	16	89
		2	0.6	5.7	4.0	0.7	13	89
CRETE	0-15	1	0.6	17.0	5.8	1.2	9	93
(low OM)		2	0.6	14.9	6.8	1.7	8	93
	30-45	1	0.5	4.2	2.9	1.2	14	78
		2	0.5	3.9	2.9	0.6	14	87
EUDORA	0-15	1	0.4	5.3	1.8	0	21	100
		2	0.6	3.4	2.7	0	19	100
	30-45	1	0.5	2.7	1.7	0	24	100
		2	0.4	1.1	1.7	0	25	100
HARNEY	0-15	1	0.2	6.7	3.1	0.5	7	93
		2	0.8	7.6	3.8	0.5	17	93
	30-45	2	0.5	3.8	3.5	0.7	13	85
HAYNIE	0-15	1	0	9.6	2.3	0.2	NC	98
		2	0	7.9	2.0	0.2	NC	98
		3	0	10.7	2.2	0.2	NC	98
		4	0	11.4	2.6	0.2	NC	98
	30-45	1	0	1.5	0.7	0	NC	100
		2	0	1.3	1.2	0.2	NC	87
		3	0	1.4	1.4	0.5	NC	74
		4	0	1.5	0.6	0.2	NC	88
KAHOLA	0-15	1	0	7.6	3.7	0.2	NC	97
		2	0	8.2	4.0	0.2	NC	98
		3	0	7.8	3.5	0.2	NC	98
		4	0	9.6	3.5	0.2	NC	97
	30-45	1	0	3.3	3.7	0.2	NC	94
		2	0	3.3	3.2	0.2	NC	94
		3	0	3.7	3.5	0.2	NC	95
		4	0	3.2	3.1	0.2	NC	94
KEITH	0-15	1	0.2	6.7	4.8	0.5	5	93
		2	0.2	6.8	3.6	0.5	6	93
	30-45	1	0.2	3.7	3.8	0.5	5	88
		2	0.2	3.8	4.5	0.5	5	88
KENNEBEC	0-15	1	0.5	20.8	5.7	0.8	9	96
		2	0.6	14.6	6.0	1.1	9	93
	30-45	1	0.5	7.1	5.7	0.6	9	93
		2	0.5	7.3	5.0	0.8	9	91
LADYSMITH	0-15	2	1.3	18.8	8.0	2.4	16	89
	30-45	1	1.1	4.5	6.5	2.0	14	70
		2	1.1	3.8	6.5	3.3	14	54

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Table A6 continued.

| SOIL SERIES	DEPTH	SAM-PLE	CaCl$_2$ extracted NH$_4^+$	NO$_3^-$	.2 M KCl extracted NH$_4^+$	NO$_3^-$	0.01 M CaCl$_2$ extracted NH$_4^+$	NO$_3^-$
	cm		----------- mg N/kg -----------				%	%
NARON	0-15	1	1.0	13.2	3.8	0.5	22	97
		2	1.1	7.9	3.5	0.3	24	98
	30-45	1	0.9	2.4	3.5	0.2	20	92
		2	1.0	2.5	3.5	0.2	22	92
PARSONS	0-15	1	0.6	21.1	4.5	1.2	13	95
(high OM)		2	0.5	18.2	5.0	0.7	10	96
	30-45	1	0.5	3.2	5.7	0.7	8	84
		2	0.4	2.8	4.5	0.2	10	94
PARSONS	0-15	1	0.4	5.8	3.2	0.2	13	97
(low OM)		2	0.4	5.9	3.5	0.2	11	97
	30-45	1	0.5	2.6	6.2	0.4	9	89
		2	0.5	1.5	6.0	0.2	10	91
PAWNEE	30-45	2	0.5	3.6	5.2	1.0	9	80
PRATT	0-15	1	1.0	4.8	1.8	0.3	36	94
		2	1.2	5.7	1.8	0.2	41	95
	30-45	1	0.8	1.7	2.9	0.2	23	90
		2	0.9	2.0	2.9	0.2	24	90
READING	0-15	1	0	25.4	3.7	1.1	NC	96
		2	0	29.5	3.3	0.7	NC	98
		3	0	30.7	3.1	1.5	NC	95
		4	0	31.3	2.6	4.7	NC	87
	30-45	1	0	3.9	2.4	0.7	NC	85
		2	0	3.7	2.2	0.5	NC	88
		3	0	3.3	2.1	1.1	NC	75
		4	0	4.0	3.1	1.0	NC	80
RICHFIELD	0-15	1	1.4	19.1	4.0	0.5	26	98
		2	1.4	25.2	5.3	0.7	21	96
	30-45	1	1.3	2.6	3.4	0.3	27	90
		2	1.5	3.2	3.3	0.4	32	90
SATANTA	0-15	1	1.1	4.3	2.1	0.2	34	96
		2	1.1	3.8	1.8	0.2	37	96
	30-45	1	1.7	3.1	2.6	0.3	41	91
		2	1.1	2.4	2.3	0.2	33	92
WOODSON	0-15	1	0.5	5.5	6.2	2.5	9	70
		2	0.5	6.0	6.2	1.5	7	81
		3	0.6	4.7	5.7	1.3	10	80
WOODWARD	0-15	1	1.3	12.0	4.3	1.0	23	92
		2	1.1	10.9	3.1	0.5	27	95
	30-45	1	1.5	3.4	2.8	0.5	35	87
		2	1.3	2.9	3.4	0.5	27	87

NC Not calculated, no ammonium was detected in 0.01 M CaCl$_2$
    leachates.
%   extracted was calculated as [ammonium-N] or [nitrate-N],
    (mg/kg), in CaCl$_2$ leachates divided by the sum of the
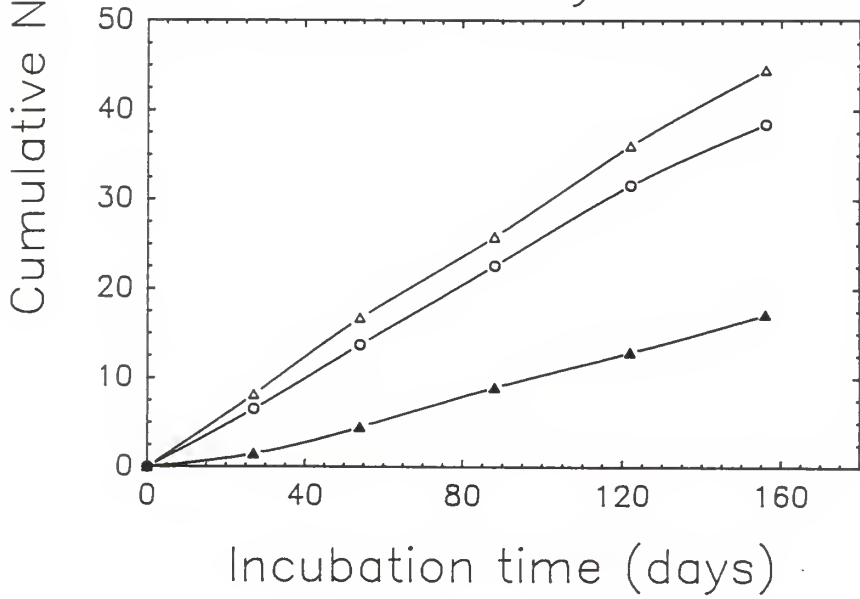   concentrations in both the 2 M KCL and 0.01 M CaCl$_2$ extracts x 100.
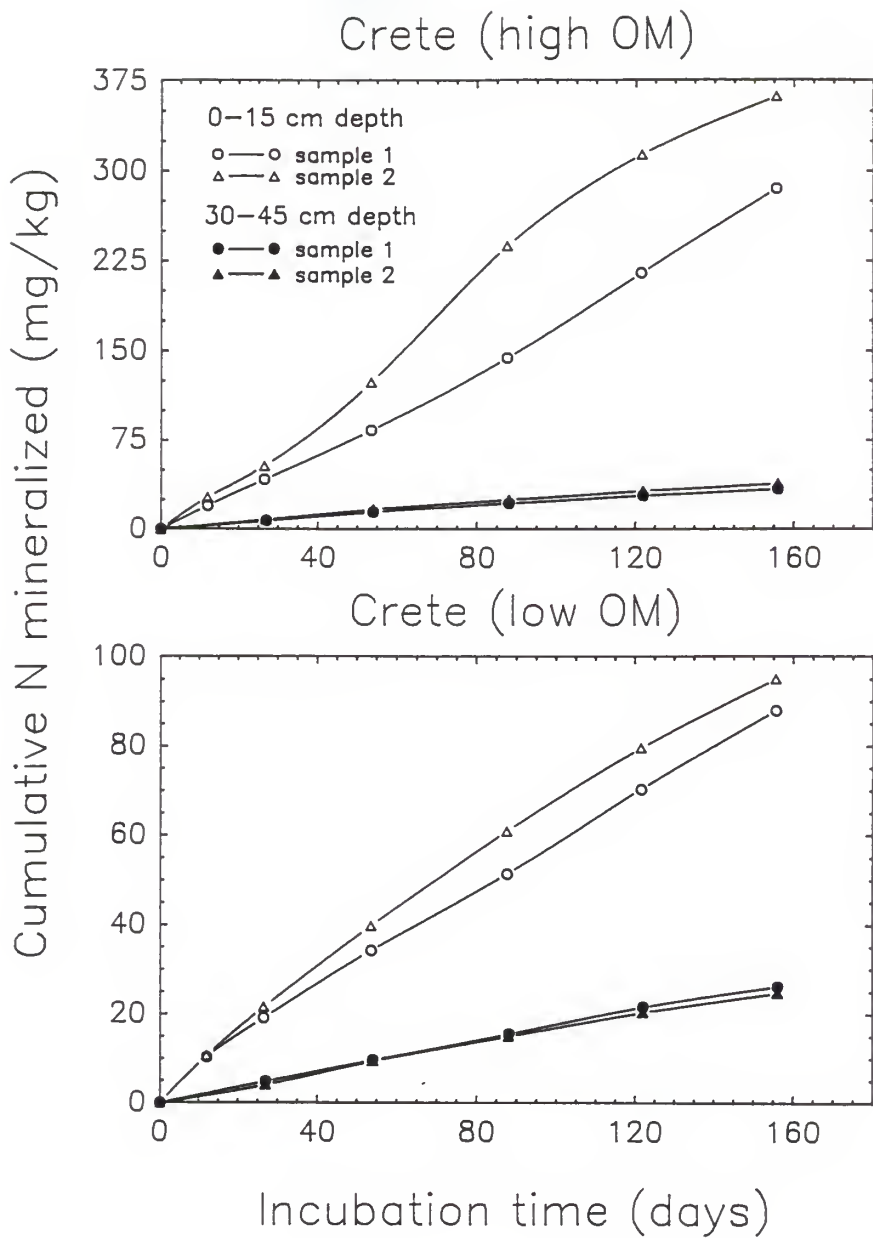
Figures A1 and A2. Cumulative N mineralized with time for
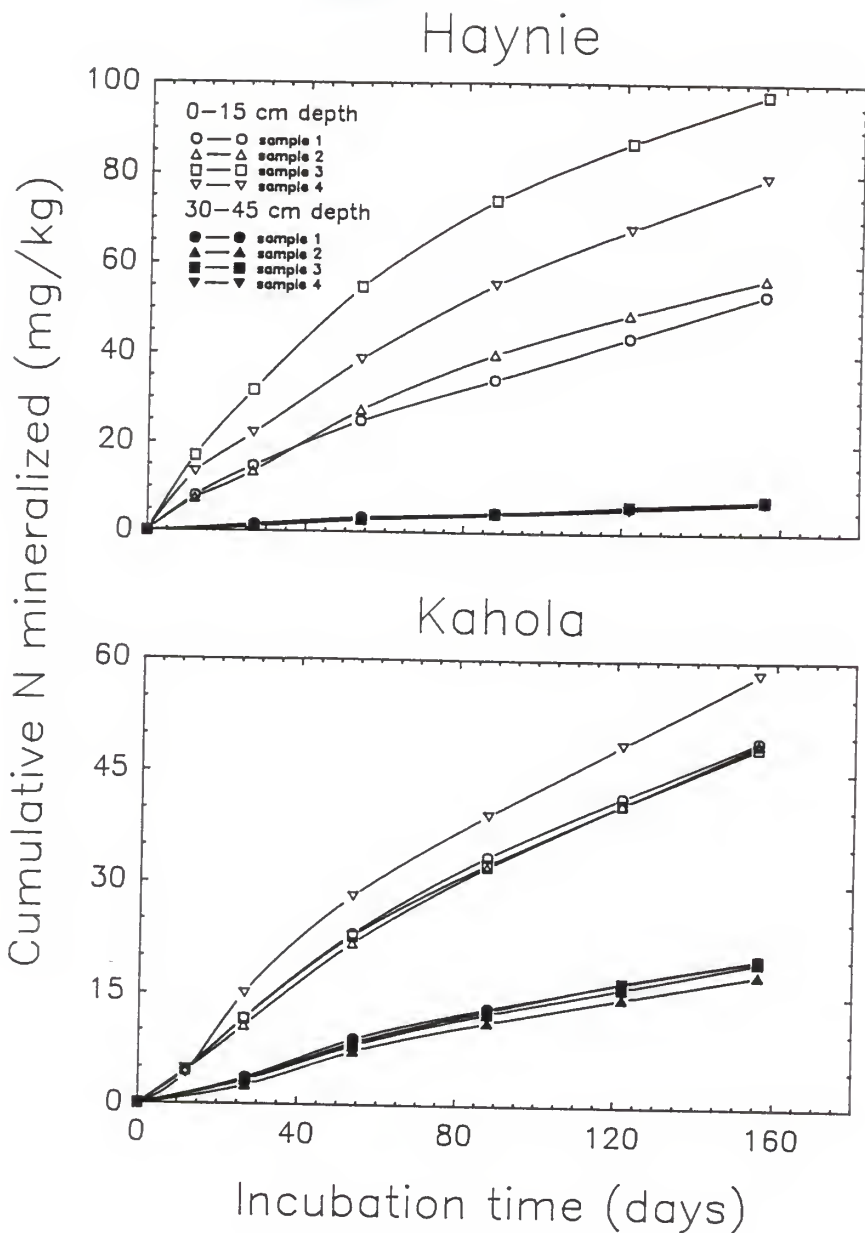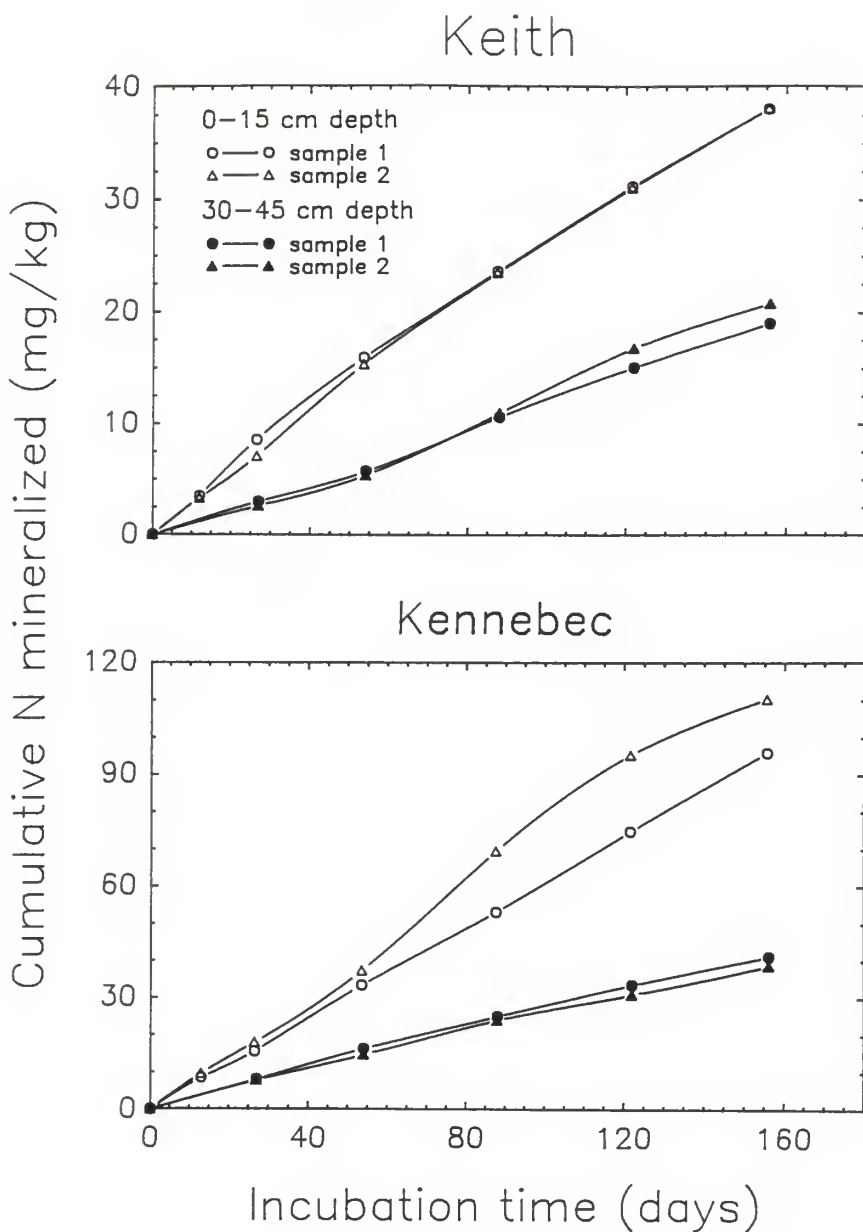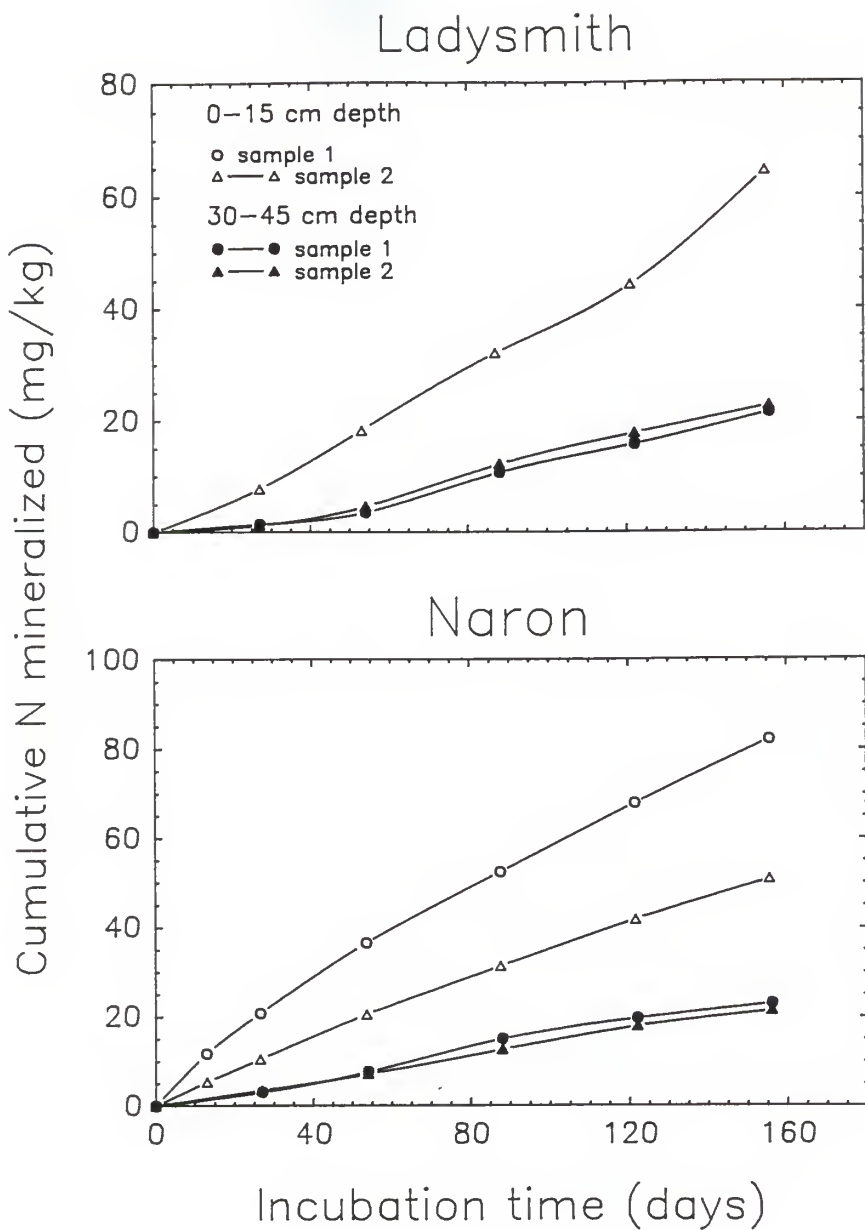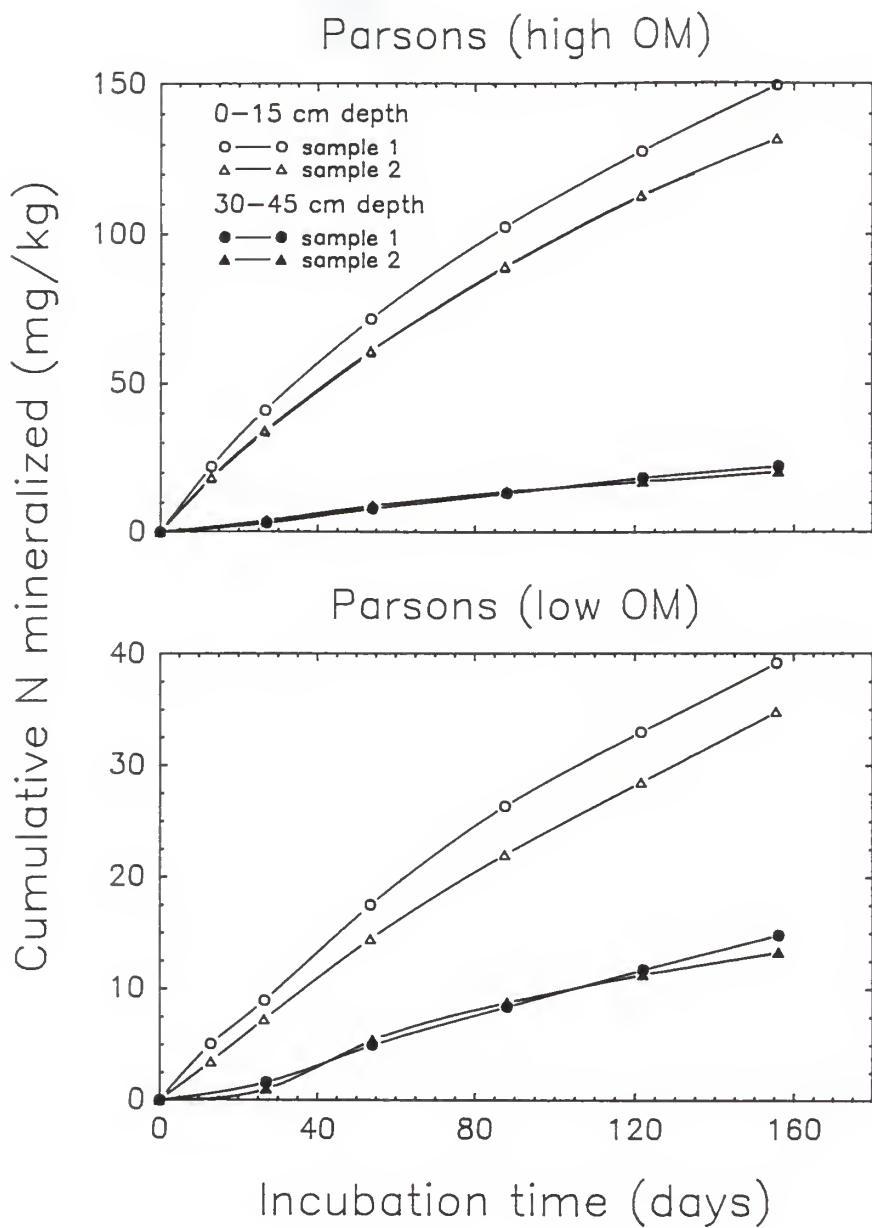undisturbed soil cores sampled at two depths in 1988.
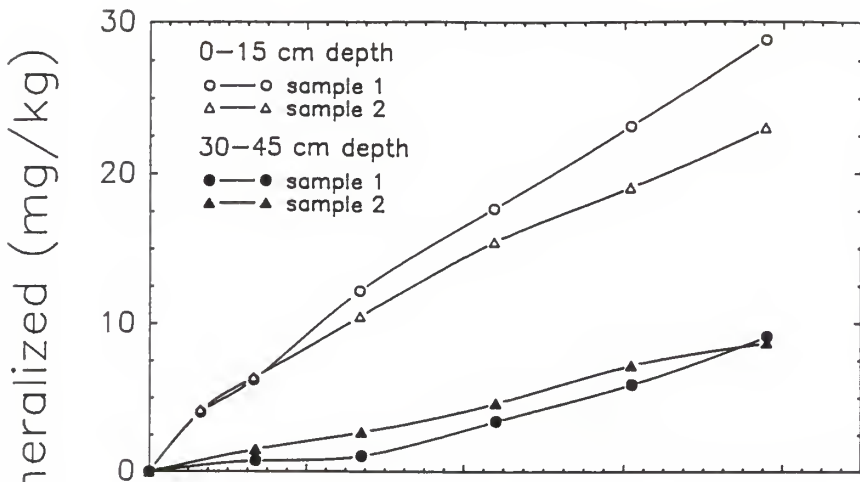
Figures A3 and A4. Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.
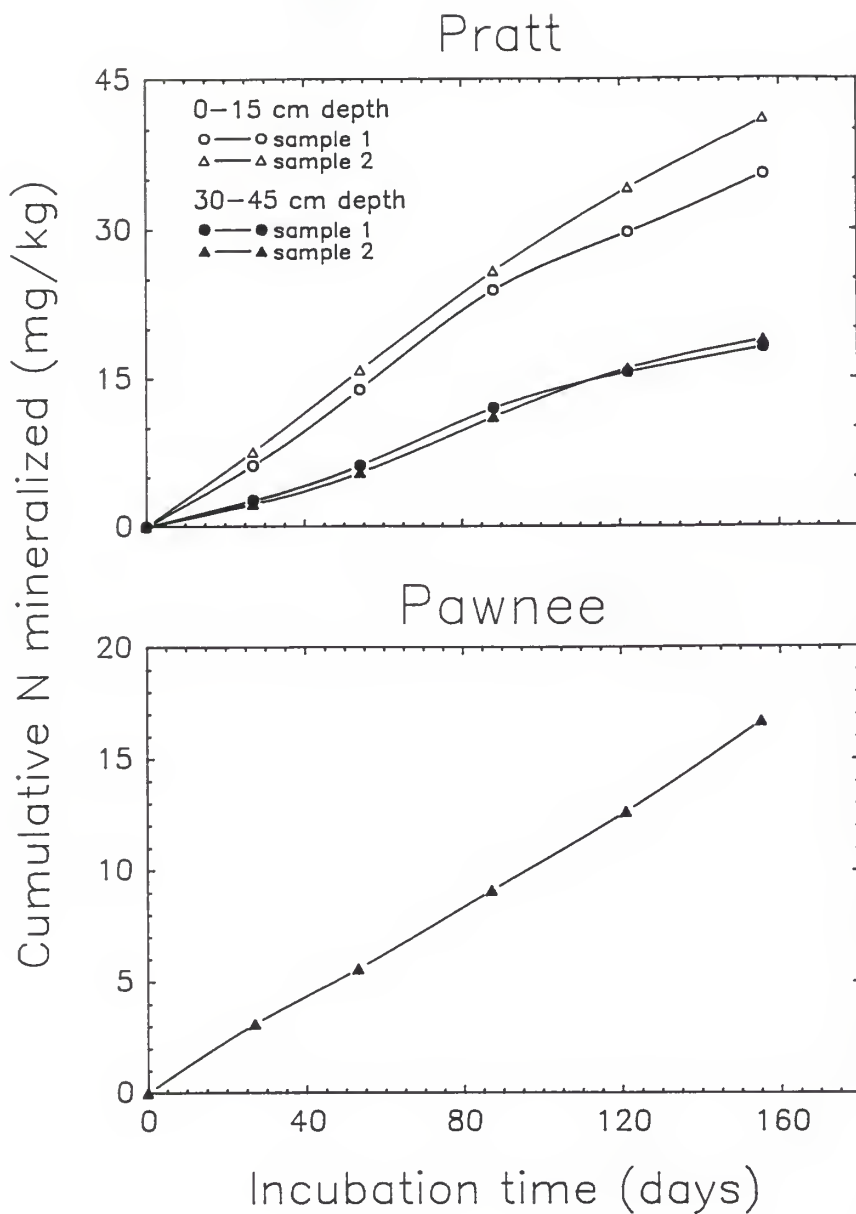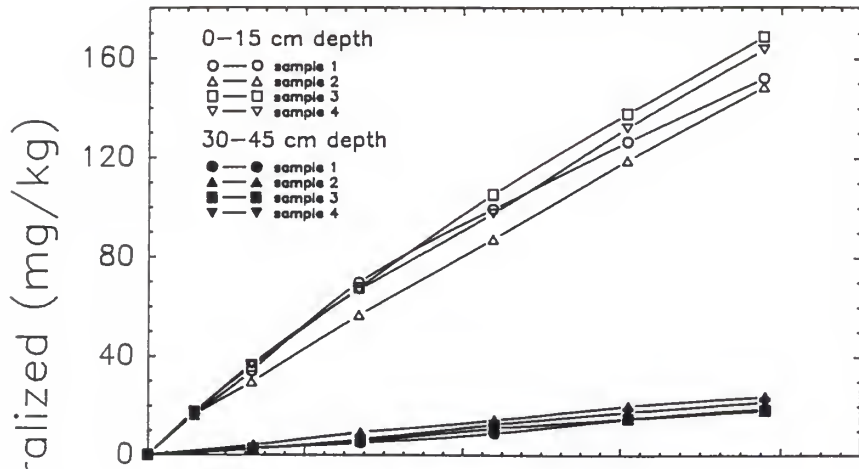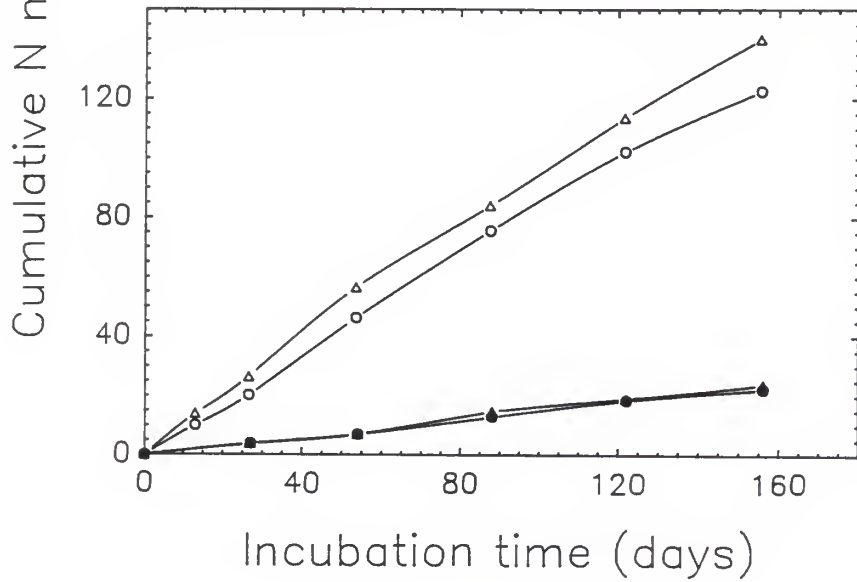
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Figures A5 and A6. Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.

Figures A7 and A8. Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.

Figures A9 and A10. Cumulative N mineralized with time for
undisturbed soil cores sampled at two depths in 1988.

Figures A11 and A12.   Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.
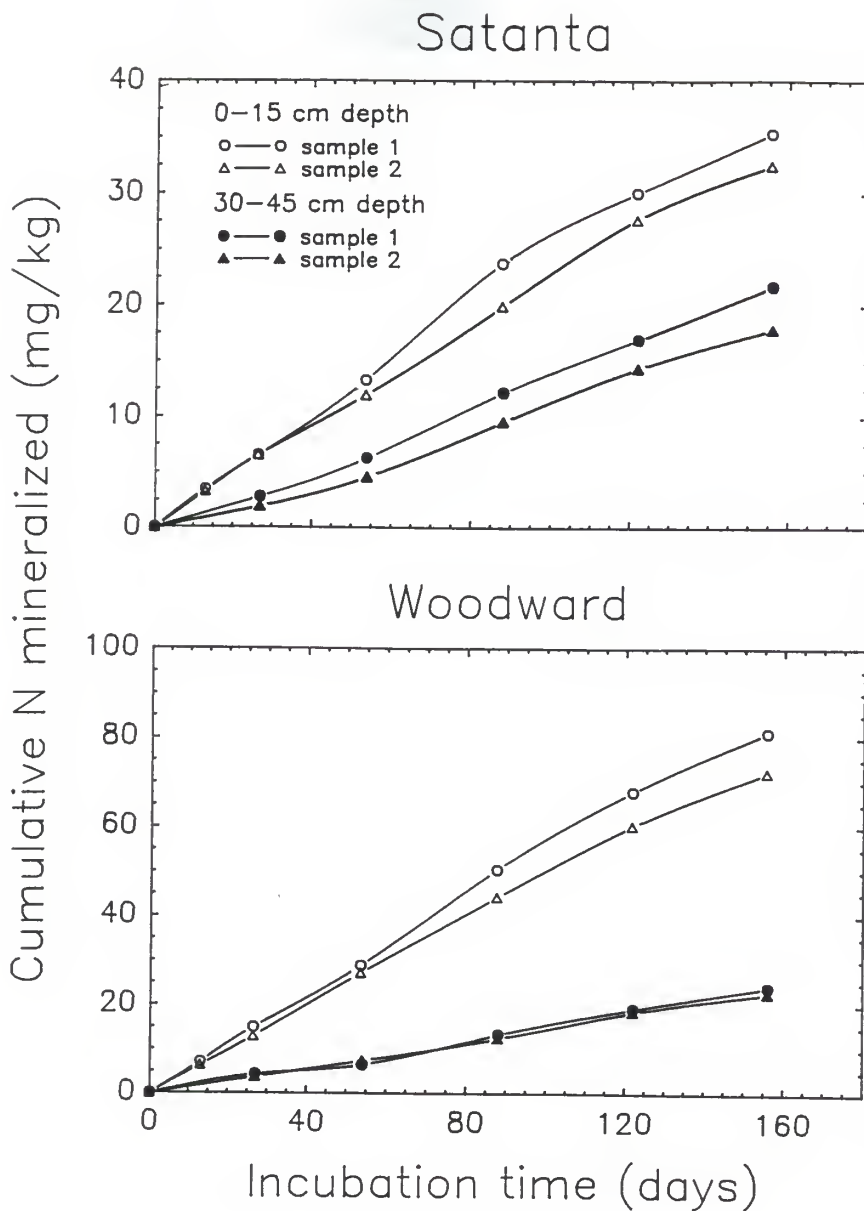
Figures A13 and A14.   Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.

Figures A15 and A16.   Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.

Figures A17 and A18. Cumulative N mineralized with time for undisturbed soil cores sampled at two depths in 1988.
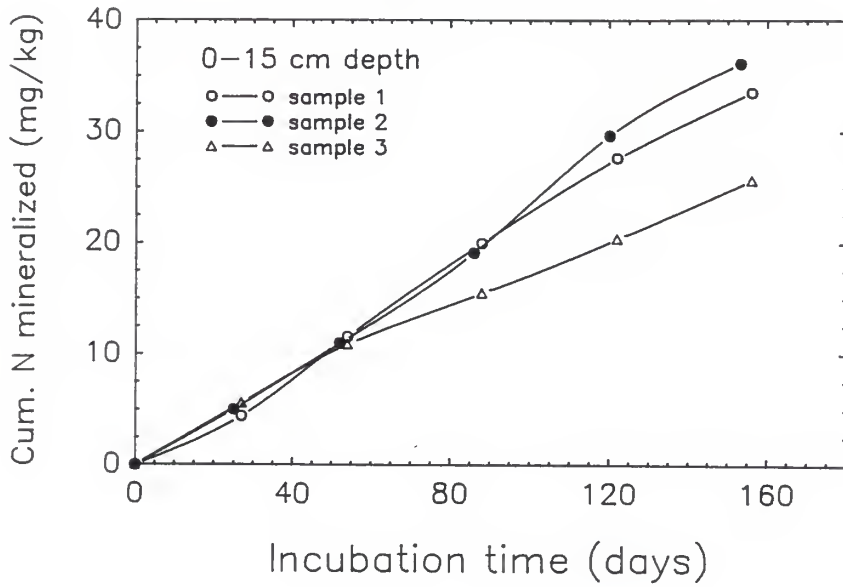
Figure A19.   Cumulative N mineralized with time for undisturbed soil cores sampled at two depths of a Woodson soil in 1988.

ESTIMATION OF NITROGEN MINERALIZATION
FROM SOIL ORGANIC MATTER

by

RODNEY GENE MYERS

B.A., Messiah College, Grantham, PA, 1985

AN ABSTRACT OF A THESIS

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Manhattan, Kansas

1989

ABSTRACT

A method to estimate the amount of nitrogen (N) miner-
alized from soil organic matter is needed in order to
calculate accurate N fertilizer recommendations. A method
developed by Stanford and Smith (1972) involves the use of
dried, crushed, and sieved soil samples which are incubated
and periodically leached to measure cumulative N mineral-
ized. Recent work has indicated that the use of un-
disturbed soil cores to estimate N mineralization
parameters could more closely represent the field soil.
Therefore,the objectives of this study were to (1) develop
a method to secure, leach, and incubate undisturbed soil
cores for the purpose of measuring cumulative N mineral-
ized, (2) model the cumulative N mineralized in the
undisturbed cores, (3) determine if the method accurately
predicted N mineralized in the field, and (4) determine if
the mineralization parameters could be estimated from a
knowledge of physical and chemical properties of the soil.
A method was developed which allowed undisturbed soil
samples to be periodically leached, equilibrated to a
constant water potential, and incubated. Data of
cumulative N mineralized with time showed an initial lag-
phase which could be best described with a mixed-order
kinetic model. Parameters from fallow samples of three

Kansas soils were used to predict N mineralized in the field and considerations were made for daily soil temperatures and soil water content. Overpredictions of N mineralized in the field ranged from -0.7 to 88% for the three samples. Mineralization parameters from both first- and mixed-order models could be reasonably estimated from organic N, cation exchange capacity, and clay contents of the soil.