NITROGEN MINERALIZATION POTENTIAL FOR DIFFERENT SOIL TYPES OF THE ARID AND SEMI-ARID REGIONS OF MOROCCO

By

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1980

Submitted to the Faculty of the Graduate College
of Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1987

I would like to dedicate this thesis to my beautiful daughter Nisrine El Gharous.

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PREFACE

Nitrogen mineralization potential for different soil groups of the arid and semi-arid regions of Morocco based on an incubation study were estimated and the rate constants for the six soil groups were generated.

Based on this data, a model for predicting N mineralization potential from chemical and physical soil characteristics was developed.

I would like to express my sincere appreciation to my major adviser, Dr. Robert L. Westerman, for his intelligent guidance and concern.

Special appreciation is extended to Dr. Parviz N. Soltanpour for his valuable criticisms and assistance. I am also thankful to the other committee members, Dr. Lavoy Croy and Dr. Gordon Johnson for their constructive criticisms.

The author wishes to express his appreciation and gratitude to the Agronomy Department of Oklahoma State University, Stillwater, Oklahoma and to the INRA/MIAC Project in Settat, Morocco for the facilities and financial support which made this study possible.

My gratitude is extended to all soil laboratory technicians of the Aridoculture Center in Settat, Morocco, and to Mrs. C. Kouriri and Miss N. Benmellah for their assistance in the final preparation and typing of this manuscript.

Special thanks go to my wife Aicha R. Hamdi and to my parents for their encouragement and patience during my stay in the United States.

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CHAPTER I

INTRODUCTION

Awareness of the importance of N in crop production, the deficiency of this element in many arable soils, and the rapid expansion in use of nitrogenous fertilizers have brought about the need for better methods of evaluating the capacity of soils and cropping systems to supply N.

Soils contain various forms of organic N that differ in rates of mineralization. In general, soil organic N can be placed in two categories. The first is a relatively stable material, humus, which is resistant to rapid decomposition. The second includes materials that range from fresh crop residues to those that are approaching a degree of stability.

Many procedures to determine soil capacity to supply mineral N have been proposed. Some are based on the quantity of N present in the soil and the crop's ability to use it. Others involve chemical extraction of a fraction of soil N. Relationship of the magnitude of this fraction to the response of field crops to N fertilizer is employed as a basis for fertilizer recommendation. A third type, one which has received widespread attention, involves biological mineralization of N during controlled incubation of soil samples.

The intensification of agriculture in countries situated in arid and semi-arid climates such as Morocco demands the use of N fertilizers, or at least that N supplied by the soil be used as efficiently as possible.

The objective of this study was to assess the N mineralization potential of different soil types of the Chaouia region in Morocco.

CHAPTER II

LITERATURE REVIEW

Nitrogen Cycle in Arid Soils

Cycling of N in soils of the arid and semi-arid regions is a complex matter due to the dynamic behavior of this element in these regions. To establish the N cycle, it is necessary to take into account the quantities of N mineralized, those coming from biological fixation and directly from the atmosphere, as well as the gaseous losses to the atmosphere. Symbiotic fixation of N varies greatly according to environmental conditions. Wetselaar (1967) showed that the effect of symbiotic fixation in raising soil N content is often overestimated. However, the contribution of the non-symbiotic N fixation in the arid and semi-arid areas is probably negligible (Pieri, 1983).

Losses by volatilization can be considerable when N fertilizer is applied to the surface. However, incorporation of the fertilizer at a depth of a few cm reduces the losses to a very low level.

The North African climate is characterized by winter rainfall, accompanied by lower temperatures and soils having higher moisture content. This of course is a general condition but the frequency and occurrence of rainfall in the wintertime is variable from year to year. Light rainfall occurring after the summer drought may lead to enhanced mineralization of organic N, resulting in an increased NH_4-N content followed shortly by an increase of NO_3-N (Chiang et al. 1983).

This phenomenon was observed earlier by Birch (1960), who explained that carbon oxidation can exceed N mineralization during the dry period, which, in turn, decreases the carbon : nitrogen ratio (C:N ratio). The net N mineralization is favored during the subsequent wet period.

Mineralization

The mineralization of organic compounds takes place in essentially three reactions: aminization, ammonification, and nitrification. The first two steps are carried out by heterotrophic microorganisms which require organic carbon for their source of energy. However, the third reaction is carried out by autotrophic soil bacteria which obtain their energy from the oxidation of inorganic salt and their carbon from the carbon dioxide of the surrounding atmosphere (Tisdale and Nelson, 1975).

Nitrogen release during microbial decomposition of the organic matter is the key process in making N available for plant growth (Lee and Stewart, 1978). Not surprisingly, point-in-time N measurement of either total or available soil pools are under certain conditions poorly correlated with plant N uptake (Harmsen and Van Schereven, 1955; Keeny, 1980). Also, the correlation between total soil N content and N mineralization is not good when comparing different soil types (Harmsen and Van Schereven, 1955).

However, in a laboratory study Standford and Smith (1972) studied N mineralization rates in 39 widely different soils over a 30-week period and reported (i) a consistent correlation between the N mineralization rate and the quantity of mineralized N estimated from a first-order rate equation:

$$(N_t = 1/N_0 + b/t);$$

where N_t is $\mu g \cdot g^{-1}$ of N mineralized (cumulative) during a specified period of time, t = weeks; b = slope; and N_0 is the N mineralization potential in $\mu g \cdot g^{-1}$. Assuming that the rate of mineralization is proportional to the quantity of mineralizable substrate in the soil, the kinetics of N mineralization can be described by the first-order equation:

$$\mathrm{Log}\ (N_0 - N_t) = \mathrm{Log}\ N_0 - (kt/2.303);$$

where k = mineralization rate constant; (ii) a linear relationship between cumulative N and the square root of the incubation time, and (iii) a similar mineralization rate constant (k = 0.054 per week at 35°C).

In a subsequent study N mineralization rates at depths to 45 cm in eight Idaho soils were also found to be linearly correlated to the square root of the incubation time (Standford et al., 1974).

The N mineralization as a percent of total N varied from 5 to 11% (Smith et al., 1980), 8 to 12% (Herlihy, 1979), and 11.5 to 15.5% (Standford and Smith, 1972).

Soil incubation directly measures the time course of N release, and the N released in incubation is highly correlated with plant N uptake (Harmsen and Van Schereven, 1955; Stanford et al., 1973b).

Factors Affecting N Mineralization

The rate of native soil mineralization is affected by many complex factors, such as the nature and quantity of organic matter, the nature and quantity of the previous crop residue, the nature of soil microflora, moisture, aeration, temperature, soil reaction, mineral content status, C:N ratio, and other biotic properties.

Moisture

Many studies have been carried out to determine the effect of moisture on N mineralization rates in soils. The optimum moisture for N mineralization was reported to vary from 0.15 to 0.5 bar (Miller and Johnson 1964). Cassman and Munns (1980) found that a moisture tension of 0.3 bar gave the maximal mineralization rate. Stanford and Epstein (1974) found the optimum moisture tension to be from 0.1 to 0.33 bar. Similar results were also reported by others (Reichman et al., 1966; Chiang et al., 1983; and Myers et al., 1982).

Moisture content and aeration are directly related. A minimum aeration is necessary for the oxidation of ammonium (Miller and Johnson, 1964). Robinson (1957) reported the optimum range of moisture content for nitrification to be between the wilting point and the field capacity. The effect of moisture on mineralization is related to its effect on aeration. The aerobic microorganisms involved in mineralization are dependent on having adequate oxygen supply. Amer and Bartholomew (1951) found the optimal oxygen concentration for nitrification to be about that in the ordinary air.

Also, it was found that additional moisture to the soil increased the uptake and utilization of N fertilizer by grass (Power, 1967).

Temperature

Soil N mineralization rate is affected profoundly by temperature within the range that is normally encountered under field conditions. Since mineralization essentially ceases near the freezing point, temperatures of greatest interest in soil biology generally occur in the range of 0 to 35°C. Over a large range of temperatures above 35°C, ammonification continues, but nitrification essentially ceases at 45°C (Harmsen and Kolenbrander, 1965). From 0 to 35°C complete conversion of ammonium to nitrate normally occurs in aerated soils when soil temperature effects were considered at optimum soil moisture levels. Cassman and Munns (1980) reported that the optimum temperature for N mineralization in soil is from 30 to 35°C.

Standford et al. (1973) found similar N mineralization rate constants in different soils for each temperature studied in the 5 to 35°C range using a temperature coefficient "Q_{10}" of approximately 2. Again, using "Q_{10}" of approximately 2, Burger and Pritchett (1984) developed an equation to adjust the rate constant k to a desired temperature. This equation is:

$$Q_{10} = (k_2/k_1)^{10/(T_2 - T_1)};$$

where T_1 is the temperature at which the mineralization constant k_1 was determined, and T_2 is the temperature for which an adjusted rate constant, k_2, is desired.

Soil temperature and moisture interaction effect on net N mineralization was shown by Kowalenko and Cameron (1976).

Fluctuation of low temperatures injures the soil microflora and thus impedes soil N transformations (Campbell et al., 1971).

Soil Reaction

The beneficial effect of liming on N mineralization has been shown by many laboratory studies (Alexander, 1961; Harmsen and Van Schereven, 1955). Awad and Edwards (1977) have suggested this as a reason for lime response in the field.

Ammonification is less sensitive to soil reaction than nitrification. The range of reaction over which nitrification takes place has generally been given as pH 5.5 to 10.0, with the optimum around 8.5 (Tisdale and Nelson, 1975). The influence of soil pH on the activity of nitrifying bacteria suggests the importance of liming. Awad and Edwards (1977) found that lime responses in Kikuyu grass were due to the stimulation on mineralization of organic N. Also, Edmeades et al. (1981) studied the effect of lime on N mineralization and reported that there was an increase in dry matter production due to an increase in the rate of net mineralization of soil organic N.

Mineral Nutrient Status

Nitrogen in some form is needed for the decomposition of organic matter by hetertrophic soil microorganisms. Haas et al. (1957) have shown that the uptake of soil N is greater under high-fertilizer N than under low treatments. Broadbent and Clark (1965) have attributed this to the osmotic effect of the added fertilizer salts on cell breakdown causing an increase in the mineralization of soil N. Standford and Smith (1972) noticed that the Mollisols of South Dakota and Minnesota, although containing appreciable levels of total N (0.19 to 0.29%) showed relatively low fractions of potentially mineralized N (11.5 to 13.5%). They attributed that to intensive cropping of these soils with little or no N fertilizer applied.

Besides the ammonium ion which is the substrate for the nitrifying bacteria, these bacteria need an adequate supply of Ca and P. They also need a proper balance of Fe, Cu, Mn, and probably other nutrients (Tisdale and Nelson, 1975).

Other authors reported the influence of various trace metals added to soil as salts on N mineralization (Chang and Broadbent, 1982; Liang and Tabatabai, 1977). However, usually, their accumulated presence in the soil has a depressing effect on N mineralization (Smith and Young, 1984; Reeder and Berg, 1977).

The Nature of Organic Matter

Standford (1968) reported the existence of two general pools of organic N in soils. The first pool undergoes relatively rapid transformation through microbiological action. The second pool is relatively stable material, which is somewhat resistant to further rapid decomposition. This fraction is not well-defined and contributes a relatively small proportion of N mineralization in a short-term incubation study or even during a cropping season. Also, it was found that N mineralized resulted from several pools (Juma and Paul, 1984).

Incubation Methods

The laboratory incubation technique is used to determine the relative ability of soils to mineralize N from organic matter. This technique is useful not only for estimating immediate fertilizer requirements but also for characterizing the productivity of soils and for research purposes in evaluating rotations and other soil management practices. Also, understanding the N cycle in soil needs data on rates of soil organic N mineralization under specific conditions (Mackay and Carefoot, 1981).

Incubation methods have been extensively used to evaluate the capacity of soils to supply N to growing crops. In general, these methods consist of incubating a sample of soil under optimal conditions and evaluating the net quantity of mineral N produced during incubation.

In incubation studies the rate of mineralization has been found to be rapid at first, and then to decline with the length of incubation period. Keeney and Bremner (1966) found that prolonged incubation markedly decreased all forms of N determined except fixed ammonium, which is practically not available to soil microorganisms.

In earlier studies of long-term N mineralization capabilities of soils, samples were incubated continuously; however, the N mineralization time curves obtained rarely provided a rational basis for estimating long-term N supplying abilities of soils. Sometimes, there was accumulation of inhibitiors of mineralization during the incubation period. For instance, Allison and Sterling (1949) observed appreciable drops in pH during 23 weeks of continuous incubation. However, Standford and Smith (1972) reported that long-term as well as short-term mineralization could be measured reliably using the modified version of the method proposed by Standford and Hanaway (1955). Johnson et al. (1980) reported that the period of aerobic incubation is critical and a short-term incubation using 1 to 4 weeks may be questionable.

Incubation has been used in evaluating soils for their N mineralization potential, which, in turn, is used to estimate the amount of N a soil can be expected to mineralize during a specified period of time. Work on this has been done by Standford and Smith (1972), Standford et al. (1974), and Smith et al. (1977).

The examination of the data of various research workers reveals that the incubation methods are feasible for assessing N mineralization potential of soils.

Predicting of N Mineralization Potential N_0

N_0 may be considered as the quantity of soil organic N that is susceptible to mineralization according to first-order kenitics (Smith et al., 1977).

Smith et al. (1977), working with some Oklahoma soils, were able to determine that N_0 has practical application for being used to predict amounts of N to be mineralized under field conditions. A comparison was made between amounts of N mineralized in the field and estimated values of mineralized N, based on values of N_0 obtained in the laboratory. Predicted values were based on average weekly soil water and temperature.

Field capacity was considered 100% soil water content and water content was expressed as a percent of field capacity. The value k, which changes twofold every 10°C change in temperature, was equal to 0.027 per week at 25°C, as determined by Standford and Smith (1972). Nitrogen to be mineralized was calculated by the equation:

$$N = N_0 \cdot k \cdot \%FC;$$

where N_0 is the N mineralization potential, k is the rate constant and FC is field capacity.

The measured values and the predicted ones in this study were highly correlated. In a study on sugar beets in Idaho, Standford et al. (1977) showed reasonable success in estimating N mineralization during the growing season. These findings support the idea that N mineralization under field conditions can be predicted from N_0 values when moisture and temperature are taken into account. A good correlation was also obtained when seasonal averages were used in the comparison (Smith et al. 1977).

The quantities of N mineralized under circumstances that closely simulated field conditions were in a similar sequence to that obtained from the use of N_0 and k (Herlihy, 1979). Also, N_0 was evaluated as an index of forest soil fertility and site productivity, and correlated well with foliar N content and productive potential of trees (Power, 1980).

Calculation

A number of mathematical relationships can be used to describe the data obtained when mineral N accumulation is analyzed as a function of time.

Generally, curvilinear relationships between the amount of nitrogen mineralized and the time of incubation have been found to occur (Standford and Smith, 1972; Molina et al., 1980).

These relationships are commonly described by the hyperbolic equation:

$$N = N_0 \cdot t/(b \cdot N_0 + t);$$

where N = cummulative N mineralized; N_0 = the potentially mineralizable N; t = time (weeks); and b = a constant (weeks$\cdot$(μg N g^{-1} soil)$^{-1}$).

The constant b in the hyperbolic equation can be written as:

$$b = T_c/N_0;$$

where T_c is the time required for half of N_0 to mineralize. Thus, replacing b with its value, the equation becomes:

$$N = N_0 \cdot t/(T_c + t)$$

(Juma et al. 1984). The first-order equation is:

$$N = N_0\ (1 - \exp(-kt));$$

where k is the first order kinetic rate (week^{-1}). It has been found that linear least square fitting of this equation leads to inaccuracy in N_0 and k estimates due primarily to the required log transformation of the data which results in concomittant log transformation of the experimental errors (Smith et al., 1980; Talpaz et al., 1981).

Molina et al. (1980) suggested that N mineralization could be viewed as the decomposition of two or more compounds with varying decay rates. However, they suggested mineralization should be modeled as the sum of two or more exponentials for some soils. Thus, they proposed the following equation:

$$N = N_0 \cdot S\ (1 - \exp(-ht)) + N_0\ (1 - S)(1 - \exp(-kt)) + \varepsilon$$

where S and (1 - S) represent rapid and slow decomposable organic N fractions, respectively, with rate constants of h and k, respectively plus an error term (ε).

CHAPTER III

MATERIALS AND METHODS

Soil Selection

This study was conducted on soils from the Chaouia region of Morocco. The area was selected for the following reasons:

1) A soil map is available for this area. Detailed studies on soil classification and characterization have been conducted on this area for the past five years (122,000 ha). The use of this area that is mapped would make the results of our study more meaningful.

2) The Chaouia region is one of the most important dryland regions of Morocco in grain crop production. In 1979-80, the production in this area was 26.8% of the national production (MARA, 1980). In the Settat area alone, which represents just a small portion of the Chaouia region, grain crop production from 1969-70 to 1973-74 was between 10.25% and 14.1% of the national production.

3) This region is a part of the area of interest for the INRA-MIAC Project.

Fourteen soil types were selected for this study, which represent six of the eight great groups mapped in the Chaouia region of Morocco. The classification and certain chemical and physical characteristics of the 14 soils are given in Tables I and II.

Climate

The climate is very important and especially rainfall and temperature since they are the two components that most affect the nitrogen mineralization rate.

Rainfall

The yearly means of rainfall show two gradients. The first decreases from the northern part of the region (Settat, 408 mm) to the southern part (Machraa Ben Abou, 232 mm). The second increases from the western part (Imfout, 258 mm) to the eastern part (Khouribga, 395 mm). About 70% of the annual rainfall occurs during the fall and winter seasons. Approximately 26 to 28% of the annual rainfall occurs during the spring, and 2 to 6% during the summer.

Temperatures

The yearly mean of the temperature in the region is about 17°C. The mean temperature of the coldest month (January) is 11°C, and that of the hottest month (August) is 27°C.

Daily and monthly variations are very important. Also, it is of interest to mention that rainfall is very erratic in the region, but the temperature, on the other hand, is very stable during the year.

Incubation Method

Surface soil was sampled (0 to 20 or 30 cm) and air-dried without delay. Methods of analysis used were Kjeldahl for total N (Bremner, 1965), and Walkey and Black for organic carbon (Allison, 1965). The pH values were obtained with the glass electrode using a soil-water suspension of 1:1 (w/v) ratio.

The N mineralization procedure followed the method used by Standford and Smith (1972). Triplicate samples of 30 g of soil and 5 g vermiculite were mixed thoroughly. Soil samples were then transferred to 50 ml leaching tubes and moistened using a fine spray of distilled water. Soil was retained in 50 ml leaching tubes by means of a glass wool pad. This pad was placed over the soil to avoid dispersing the soil when solutions were poured into the tubes.

Mineral N initially present was removed by leaching with 100 ml of 0.01 M $CaCl_2$ in 5 to 10 ml increments, followed by 25 ml of a nutrient solution devoid of N (0.002 M $CaSO_4$; 0.002 M $MgSO_4$; 0.005 M Ca $(H_2PO_4)_2$ H_2O; and 0.0025 M K_2SO_4). Excess water was removed under vacuum (0.2 bar). The tubes were then incubated at 32^{o}C plus or minus 1^{o}C. After two weeks, mineral N was recovered by leaching with 100 ml 0.01 M $CaCl_2$ and 25 ml of "minus-N" solution, followed by applying suction as described above. Tubes were returned to the incubator for periods of 2, 4, 6, 8, 10, 12, 14, and 16 weeks cumulative, with intermittent leachings of mineral N and restoration of optimal soil water contents which was maintained at about 0.2 bar.

Mineral N Determination

Twenty ml of the leachate was used to determine ammonium (NH_4-N) and nitrate (NO_3 - N) using MgO and Devarda alloy. Ammonium and nitrate were determined by acid titration (0.05 N H_2SO_4) after distillation into boric acid.

TABLE I

CLASSIFICATION, AREA OCCUPIED BY EACH SOIL IN THE REGION, AND CLAY CONTENT OF SOILS USED IN N MINERALIZATION STUDY

Soil no.	French classification	Soil great group	Area	Clay content
			------ %	-----
1	Sols peu évolvés	Orthents	2.40	18
2	Sols peu évolvés	Orthents	0.30	42
3	Vertisol modaux	Chromoxererts	1.60	51
4	Vertisol vertique	Chromexererts	3.20	64
5	Sols calcimagnésique rendzine	Typic Rendoll	12.77	33
6	" " "	Typic Rendoll	5.11	39
7	Sols calcimagnési-bruns calcair	Typic Eutrochrepts	4.54	35
8	Sols isohumique chatain modaux	Haploxerolls, Argixerolls, and Palexerolls	1.34	42
9	Sols isohumiques chatain encroûté	" " "	1.63	45
10	Sols isohumiques brun vertique	Xerollic Aridisol	1.40	37
11	Sols brunifiés bruns	Ustollic Aridisol	0.17	34
12	Sols a sesquioxydes de fer Fersialitique	Xerochrepts and Ustochrepts	2.90	33
13	" " " "	" "	0.83	16
14	" " " "	" "	0.06	44

TABLE II

CHEMICAL PROPERTIES OF SOILS USED IN THE N MINERALIZATION STUDY

Soil no.	Surface soil properties				
	pH	Lime	Organic C	Total N	CEC
		%	%	%	Cmol(+)Kg^{-1}
1	8.2	1.5	1.50	0.11	10.17
2	8.0	2.0	0.64	0.09	18.47
3	8.0	3.0	1.30	0.10	42.00
4	8.1	3.0	1.27	0.11	69.07
5	8.0	17.0	2.27	0.20	42.00
6	8.3	7.0	2.40	0.19	43.70
7	8.0	10.7	1.84	0.14	35.13
8	8.2	11.0	1.67	0.14	56.33
9	8.2	1.5	1.87	0.17	49.03
10	8.4	9.4	1.25	0.14	52.07
11	7.1	0.0	1.11	0.12	28.47
12	7.6	-	1.38	0.14	23.47
13	7.1	3.0	1.66	0.11	18.03
14	7.7	-	1.72	0.14	28.87

Calculation

Two models were used to describe the data of this study. The first one was:

$$N = N_0 \cdot (1 - \exp(-kt))$$

(Standford and Smith, 1972). This equation was applied to the data using the non-linear least square fitting. The second model was the one proposed by Juma et al. (1984):

$$N = N_0 \cdot t/(T_c + t)$$

The equation proposed by Molina et al. (1980), as follows,

$$N = N_0 \cdot S\ (1 - \exp(-ht)) + N_0\ (1 - S)\ (1 - \exp(-kt)) + \varepsilon$$

was also evaluated.

CHAPTER IV

RESULTS AND DISCUSSION

Trends in Net N Mineralization

The time course of N mineralization obtained by the incubation experiment with intermittent leaching according to the method of Standford and Smith (1972) is shown in Figs. 1, 2, 3, 4, 5 and 6.

All soils exhibited the same general trend of cumulative net N mineralization. Mineral N production was high during the first 6 to 8 weeks of incubation then the production of mineral N decreased with time. Mineralization in most soils started to stabilize after 12 weeks of incubation except soil no. 4, which is a Chromoxerert (Fig. 2), soils no. 6 and 7 which are Rendolls (Fig. 3) and soils no. 8 and 9 which are Palexerolls (Fig.4). These soils stopped producing mineral N after approximately 14 weeks of incubation.

The lowest quantity of mineral N produced during the incubation period was given by the Aridisols (Fig. 5). However, the highest quantity of mineral N was produced by soil no. 14 (Fig. 6) which belongs to Xerochrepts.

Mineral N produced by other soils ranged from 110 to 165 $\mu g \cdot g^{-1}$ of soil.

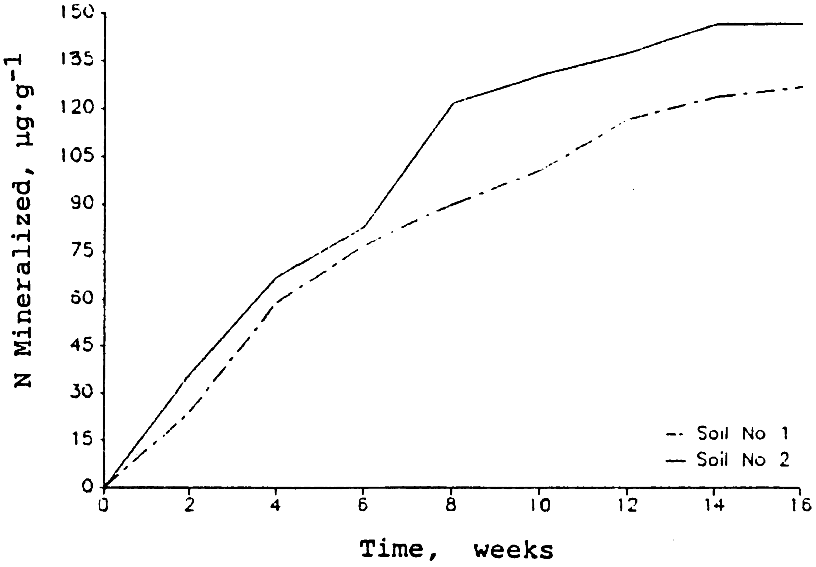

Fig 1. Cumulative N mineralization in Orthent soils.

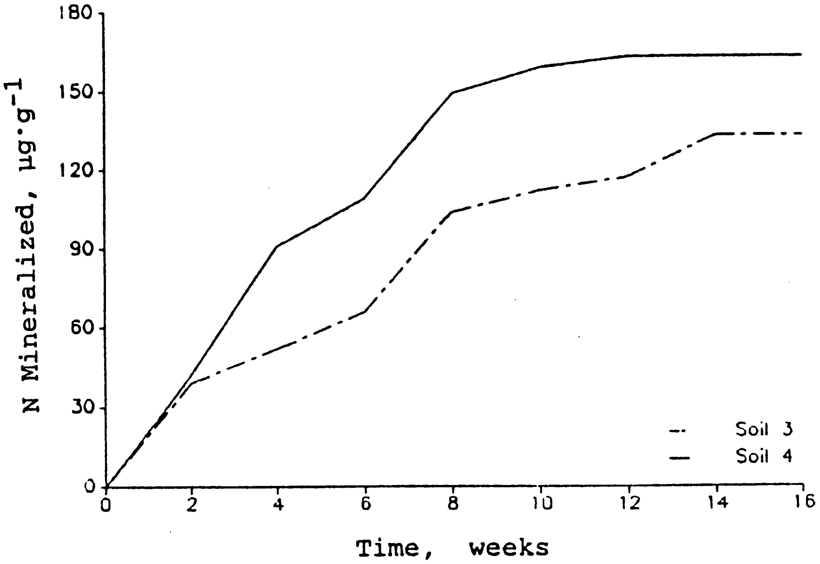

Fig 2. Cumulative N mineralization in Chromoxerert soils.

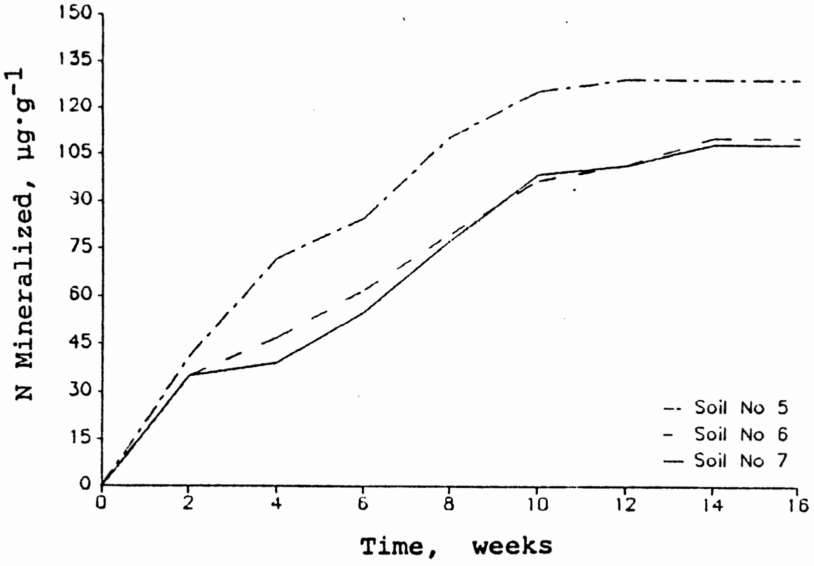

Fig 3. Cumulative N mineralization in Rendoll soils.

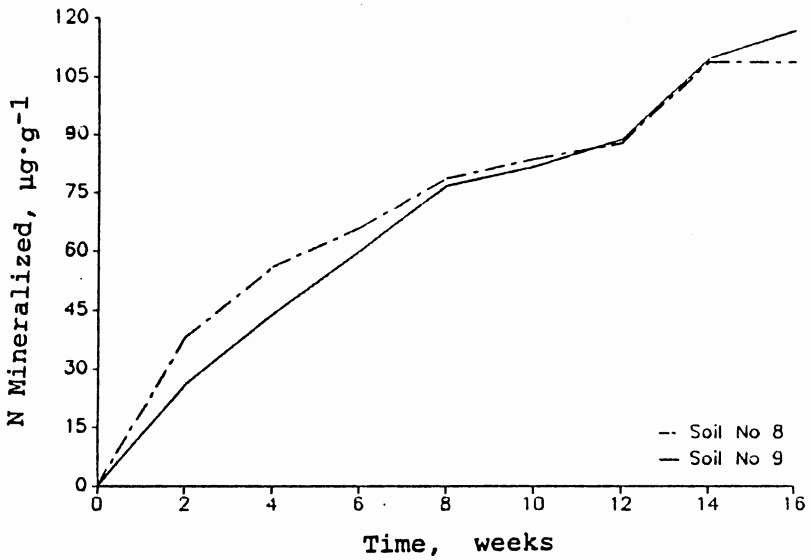

Fig 4. Cumulative N mineralization in Palexeroll soils.

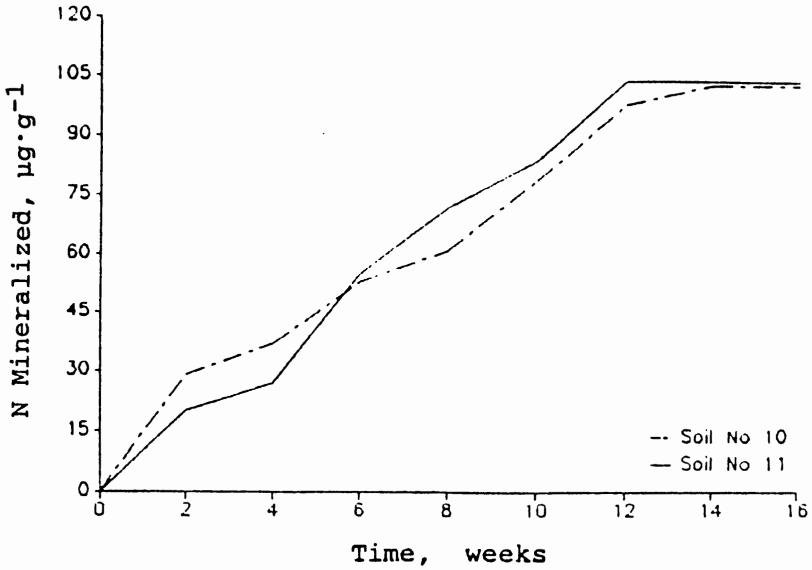

Fig 5. Cumulative N mineralization in Aridisol soils.

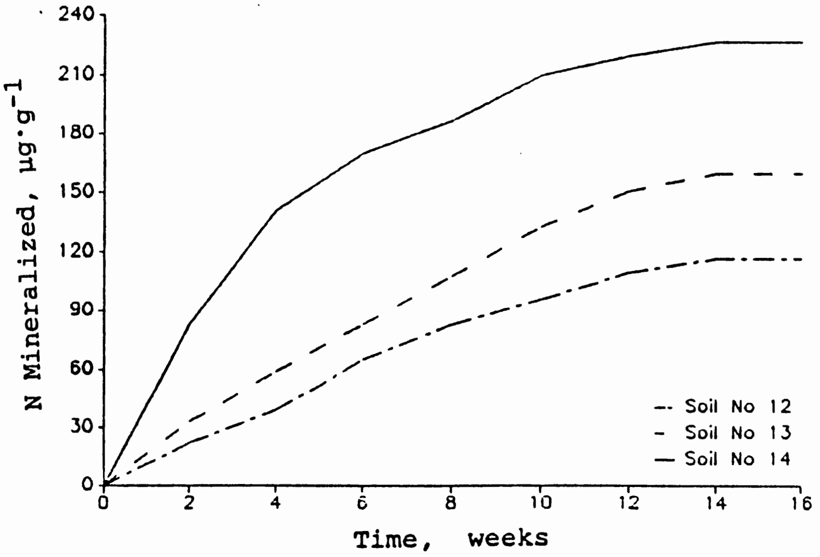

Fig 6. Cumulative N mineralization in Xerochrept soils.

Mineralization Potential (N_0) Estimates

Based on data in literature (Standford and Smith, 1972) it has been commonly assumed that N mineralization reactions follow first-order kinetics. This assumption will be used here as well.

First-order kinetics for N mineralization can be described by the equation:

$$dN/dt = -kN \tag{1}$$

where N is mineralization substrate, k is the rate constant for the mineralization, and t is time.

Upon integration from time equal zero to time t of equation (1), equation (2) is obtained:

$$N_t = N_0 \cdot \exp(-kt) \tag{2}$$

where N_0 is the substrate at the beginning and N_t is the substrate at time t.

Since N_0 and N_t as well as k are unknown, it is convenient to eliminate one unknown using the following relation:

$$N_t = N_0 - N \tag{3}$$

where N is the N mineralized in time period t.

Using the substitution in equation (2), equation (4) is obtained:

$$N = N_0 \cdot (1 - \exp(-kt)) \tag{4}$$

The hyperbolic equation which was generally used to determine the size of the first approximation of N mineralization potential (N_0) in soils for the first-order kinetic equation was also used to estimate N_0 for the different soils studied. This equation simultaneously computes N_0 and the time required for half of N_0 to mineralize (Juma et al., 1984):

$$N = N_0 \cdot t/(T_c + t) \qquad (5)$$

where T_c is the time required for half N mineralization potential (N_0) to mineralize (weeks).

Using a nonlinear computer program (Wilkinson, 1986), N_0 and the rate constant (k) were estimated in the case of equation (4), and N_0 and half time (T_c) in the case of equation (5).

The correlation coefficients (r^2) for the models of the different soils using equation (4) varied from 0.92 to 0.98, and those for the models using equation (5) varied from 0.94 to 0.98 (Table III).

Both models have higher r^2 which means that both models were suitable to estimate the N mineralization (N_0) and the rate constant (k) for the different soils studied.

The N_0 of the 14 soils estimated with equation (5) ranged from 164 to 390 $\mu g \cdot g^{-1}$ of soil. These N_0 values were larger than those estimated with equation (4) and which ranged from 119 to 241 $\mu g \cdot g^{-1}$ of soil (Table IV).

The N mineralization potential values obtained by both models are within the range that Standford and Smith (1972) found in the 39 soils studied.

The N mineralization potential of the soils studied are about the same except one soil from the Xerochrepts great group (soil no. 13) and one soil from the Palexerolls great group (soil no. 8).

TABLE III

CORRELATION COEFFICIENTS (r^2)FOR THE FIRST-ORDER AND HYPERBOLIC MODELS FOR N MINERALIZATION

Soil great group	Soil number	r^2	
		First-order	Hyperbolic
Orthents	1	0.97	0.97
"	2	0.97	0.96
Chromoxererts	3	0.96	0.95
"	4	0.96	0.95
Rendolls	5	0.97	0.96
"	6	0.98	0.98
"	7	0.95	0.94
Palexerolls	8	0.92	0.94
"	9	0.97	0.97
Aridisols	10	0.96	0.96
"	11	0.95	0.95
Xerochrepts	12	0.98	0.97
"	13	0.96	0.96
"	14	0.96	0.98

TABLE IV

NITROGEN MINERALIZATION POTENTIAL (N_0) FOR DIFFERENT SOILS STUDIED

Soil great group	Soil number	N_0 ($\mu g \cdot g^{-1}$) Exponential	Standard error	Hyperbolic	Standard error
		------------ $\mu g \cdot g^{-1}$ of soil ------------			
Orthents	1	157	6.8	235	18.2
"	2	178	35.1	262	23.2
Chromoxererts	3	174	6.6	264	25.6
"	4	184	5.5	255	14.6
Rendolls	5	145	4.0	199	9.7
"	6	144	4.8	208	11.1
"	7	145	11.7	223	22.4
Palexerolls	8	120	6.7	164	10.3
"	9	169	15.4	266	8.7
Aridisols	10	164	12.5	266	40.8
"	11	184	17.8	317	62.4
Xerochrepts	12	165	9.1	266	23.1
"	13	241	14.4	391	31.9
"	14	172	1.7	210	3.5
LSD (0.05)		17.3		35.5	
LSD (0.01)		23.3		47.9	

Soil no. 13 has the highest N_0 because this soil is an exception. The soil sampled in this site has been uncultivated for many years because this site was used for a cemetery. In contrast, soil no. 8 has the lowest N_0. It is assumed that the lowest N_0 of this soil is certainly due to the effect of erosion.

For instance, in the 12 soils left it is worth noting that the Rendolls (soil nos. 5, 6 and 7) have low N mineralization potentials compared to the others. The Rendolls in the arid and semi-arid regions of Morocco are shallow soils with a depth varying from 15 to 35 cm. They are also stony and hard to work, thus, they have low production potential in spite of their high organic matter content.

The analysis of variance and application of the least significant difference (LSD 0.01) divided the soils studied into two groups if soil nos. 8 and 13 are omitted. The first group contained soils with N_0 values from 144 to 164 $\mu g \cdot g^{-1}$ of soil and the second group included soils that have N_0 from 168 to 184 $\mu g \cdot g^{-1}$ of soil. This subdivision was not related to soil type, total N in soil, or organic matter.

The Rate Constant (k)

The rate constant of the different soils estimated with the first-order equation are considerably higher than those obtained by Standford and Smith (1972) or Campbell et al. (1981) for example, but they generally agree with those of Smith et al. (1980) (Table V).

Smith et al. (1980) and Talpez et al. (1981) demonstrated that the nonlinear least square approach generally resulted in higher k values.

Juma et al. (1984) suggested that N_0 and k values obtained by fitting the experimental data to a first-order model by a nonlinear least square regression technique are more precise and less ambiguous than those obtained by the reciprocal plot approach of Standford and Smith (1972).

The k values obtained in this study using the first-order equation ranged from 0.060 to 0.274 per week. Those obtained using the hyperbolic equation ranged from 0.024 to 0.212. Contrary to N mineralization potential (N_0), the rate constants estimated by the hyperbolic equation are lower than those estimated by the exponential equation. The mean of the k values was found to be equal to 0.119 ± 0.015 per week for the exponential model; however, the k value the hyperbolic equation was found to be equal to 0.063 ± 0.008 per week.

In general, the k values obtained in this study from the exponential equation are in or above the upper part of the range obtained by Juma et al. (1984), and in or below the lower part of the range obtained by Beauchamp et al. (1986). However, those obtained with the hyperbolic equation are within the range of Standford and Smith (1972).

This large variation in the k values obtained by different researchers leads, however, to a conclusion that a universal value of k does not exist and it is important to determine the rate constant for different soils or a group of soils under a specified climatic condition.

TABLE V

MINERALIZATION RATE CONSTANT (k) FOR DIFFERENT SOILS STUDIED

Soil great group	Soil number	k Exponential	Standard error	Hyperbolic	Standard error
		----------------	week^{-1}	----------------	
Orthents	1	0.109	0.009	0.054	0.008
"	2	0.123	0.086	0.063	0.005
Chromoxererts	3	0.100	0.007	0.049	0.008
"	4	0.168	0.013	0.095	0.013
Rendolls	5	0.164	0.012	0.099	0.012
"	6	0.127	0.009	0.068	0.007
"	7	0.096	0.014	0.046	0.009
Palexerolls	8	0.139	0.017	0.083	0.010
"	9	0.073	0.010	0.034	0.006
Aridisols	10	0.068	0.008	0.030	0.006
"	11	0.060	0.008	0.024	0.007
Xerochrepts	12	0.082	0.007	0.037	0.009
"	13	0.076	0.007	0.035	0.008
"	14	0.274	0.004	0.212	0.016
LSD (0.05)		0.019		0.014	
LSD (0.01)		0.026		0.020	

Providing an overall mean of N_0 and k might be ambiguous. However, a mean for each soil great group shows that Rendolls and Palexerolls have the lowest N_0 and Xerochrepts have the highest one. Aridisols with Chromoxererts and others have about the same N mineralization potential but the rate constant (k) is about the same for all soil great groups studied except for Aridisols, where it is low (Table VI).

TABLE VI

NITROGEN MINERALIZATION POTENTIAL (N_0) AND RATE CONSTANT (k) AS ESTIMATED BY THE FIRST-ORDER EQUATION FOR DIFFERENT SOIL GREAT GROUPS

Soil great groups	N_0	k
	$\mu g \cdot g^{-1}$	$week^{-1}$
Orthents	167	0.12
Chromoxererts	179	0.14
Rendolls	145	0.13
Palexerolls	144	0.11
Aridisols	174	0.06
Xerochrepts	193	0.14

Half Time for N Mineralization Potential (N_0)

The weeks of incubation required for 50% of the potentially mineralizable N were also determined by both equations (Table VII).

The range of the half N_0 as determined by the first-order equation is from 2 to 12 weeks and it is from 3 to 28 weeks as determined by the hyperbolic equation. As a general observation, the half time determined by the hyperbolic equation is about two times the one determined by the first-order equation.

The half life ($T_c = Ln2/k$) where T_c is the time required to mineralize 50% of N_0; did not show any consistent changes with soil type. But generally, the soil studied mineralized 50% of N_0 within 10 weeks when N_0 was estimated with the exponential model or within 20 weeks when N_0 was estimated with the hyperbolic model.

The Active Fraction of Total N

The active fraction of total N (N_0/N_t) of the 14 soils varied from 7 to 21% (Table VIII). These values are of the same order as those reported in other countries (Allison and Sterling, 1949; Standford and Smith, 1972; Feingin et al., 1974; Herlihy, 1979; and Campbell and Souster, 1982).

Again, the amount of the active fraction as determined by the hyperbolic model was larger than that of the exponential model. However, according to the N_0/N_t of the exponential model the soils were divided into two groups: one group with an active fraction below 10% and the second group with N_0/N_t from 10 to 20%.

TABLE VII

TIME REQUIRED TO MINERALIZE HALF OF N MINERALIZATION POTENTIAL (N_0) IN DIFFERENT SOILS STUDIED

Soil great group	Soil number	Half time Exponential	Standard error	Hyperbolic	Standard error
		weeks			
Orthents	1	6.39	0.58	12.85	1.84
"	2	5.70	0.62	11.13	1.91
Chromoxererts	3	6.94	0.90	14.21	2.43
"	4	4.13	0.34	7.28	0.97
Rendolls	5	4.13	0.29	7.03	0.82
"	6	5.46	0.39	10.25	1.11
"	7	7.23	0.98	15.02	2.59
Palexerolls	8	5.06	0.65	8.45	1.08
"	9	9.62	1.30	20.62	1.13
Aridisols	10	10.40	1.80	23.04	5.29
"	11	11.64	3.66	28.41	7.90
Xerochrepts	12	8.69	0.93	18.97	2.72
"	13	8.92	1.29	20.76	2.61
"	14	2.53	0.18	3.28	0.19
LSD (0.05)		1.56		4.39	
LSD (0.01)		2.10		5.92	

Rendolls and Palexerolls belong to the first group. However, the second group contains Orthents, Chromoxererts, Aridisols and Xerochrepts. It was also observed that 80% of the soils belonging to the first group have a loamy texture and 67% of the soils belonging to the second group have a clay texture.

TABLE VIII

ACTIVE FRACTION OF TOTAL N IN DIFFERENT SOILS STUDIED

Soil great group	Soil number	Active N fraction	
		Exponential	Hyperbolic
		------------- %	--------------
Orthents	1	14.23	21.38
"	2	19.75	29.15
Chromoxererts	3	17.39	26.41
"	4	16.77	23.22
Rendolls	5	7.26	9.93
"	6	7.57	10.92
"	7	10.36	15.91
Palexerolls	8	8.54	11.72
"	9	9.93	15.67
Aridisols	10	11.74	19.00
"	11	15.29	26.31
Xerochrepts	12	11.80	19.03
"	13	21.87	35.52
"	14	12.27	14.97
LSD (0.05)		3.27	5.55
LSD (0.01)		4.41	7.48

Campbell and Souster (1982) reported that the fraction of total N consisting of N_0 was generally higher in the finer-textured soils, which agrees with the findings of this study.

Losses of the active N fraction are greater in the coarser-textured soils because such soils tend to erode more easily (Bisal and Hsieh, 1966); having low clay content, they are less protected from aggregate disruption upon cultivation (Voroney et al., 1981).

Cropping systems and fertilization practices, affect the net balance of soil N, and may also affect the active fraction of total N in soil. Nevertheless, in this study a linear relationship between total N in soil and the inverse of the active fraction of soil N was found. The slope and the intercepts were found to be equal to 0.725 and -0.015, respectively, with a coefficient of determination (R^2) of 0.90 (Fig. 7).

The variability of the rate constant (k) and half life of potentially mineralizable N (T_c) certainly did not indicate that the composition of mineralizable N was similar in all soils. Therefore, the suggestion of Molina et al. (1980), who assumed that at least two groups of compounds decompose at two different rates, was also tested. The labile fraction of organic N varied quite randomly among the different soils and did not show any consistent pattern (Table IX).

Nitrogen mineralization potential (N_0) and the rate constant (k) estimated by the double exponential model were not different from those estimated by the single exponential model (Table IV and V).

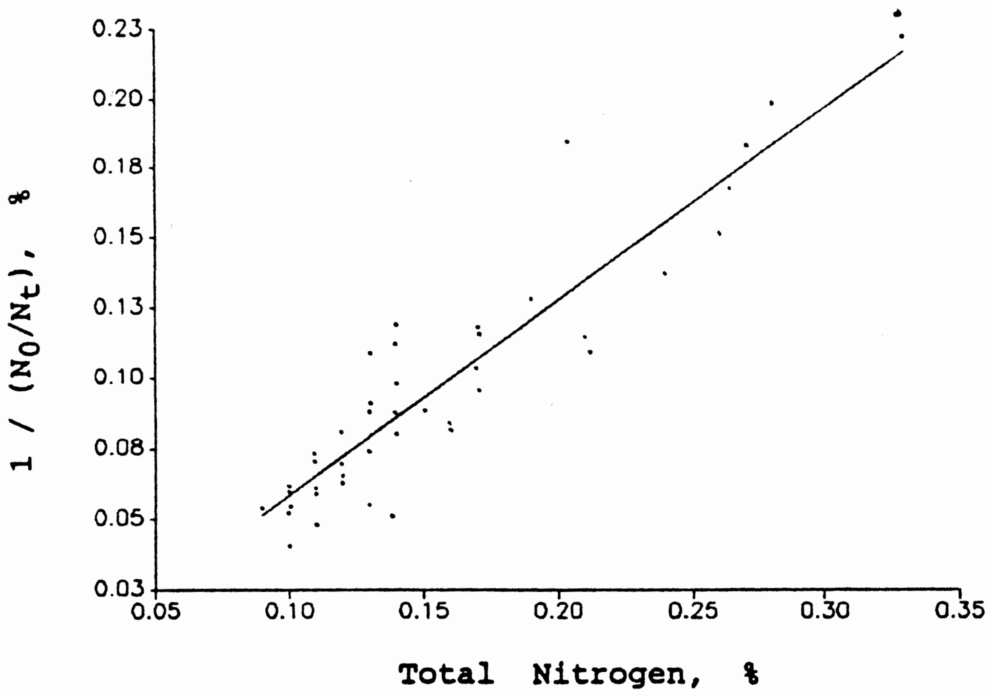

Fig 7. Relationship between total N and the inverse of the active N fraction.

Estimated and Observed Values of Mineralized N

It is important to verify if the models developed are valid. To do so a person can select a set of new independent variables, determine the predicted values and then compare them with the observed ones.

In this study, the validation of the models was done by comparing the observed values to the adjusted predicted ones. The adjusted predicted values were obtained by removing the effect of each case from the regression coefficients (Havlin and Soltanpour, 1984). For instance, the first dependent value was predicted wiht an equation that did not contain the effect of the corresponding independent value. and the second dependent value was estimated with another equation that did not contain the effect of the second independent value and so on. In other words, to estimate the mineral N in the sixteen weeks of incubation, eight different regression coefficients were used. For example, regression coefficients used to estimate mineral N produced during the first two weeks, were obtained from data of 4, 6, up to 16 weeks of incubation. However, regression coefficients used to estimate mineral N for the fourth week were developed from data of 2, 6, 8, up to 16 weeks of incubation and so on.

The trend of the observed and the estimated values as determined by the first-order equation for the Orthents is shown in Figs. 8 and 9. The correlation coefficients between the estimated and the observed in these soils were 0.99 and 0.96. The trend in the Chromoxererts is shown in Figs. 10 and 11 and the r^2 were also highly significant and they were equal to 0.94 and 0.94. Figs. 12, 13, and 14 show the trend in the Rendolls and the r^2 were equal to 0.96, 0.99 and 0.91 for

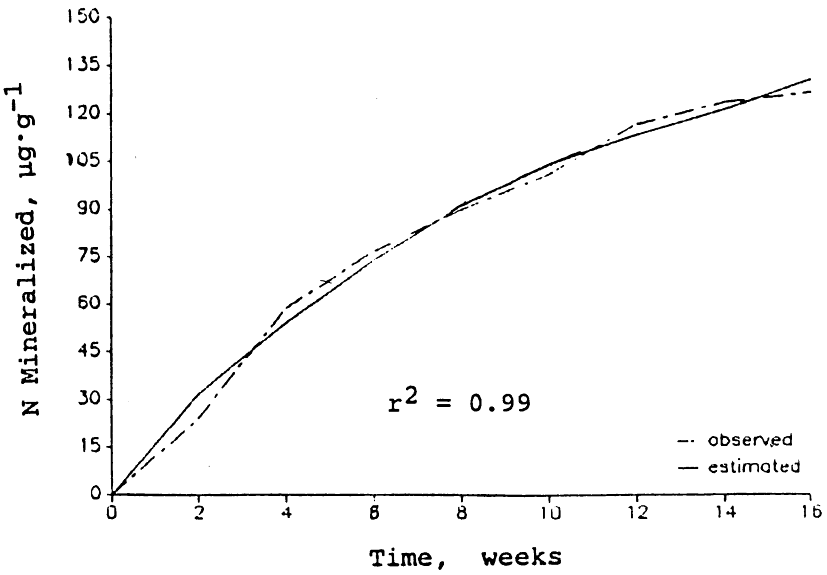

Fig 8. Observed and estimated mineralization values in relation to time for soil no. 1.

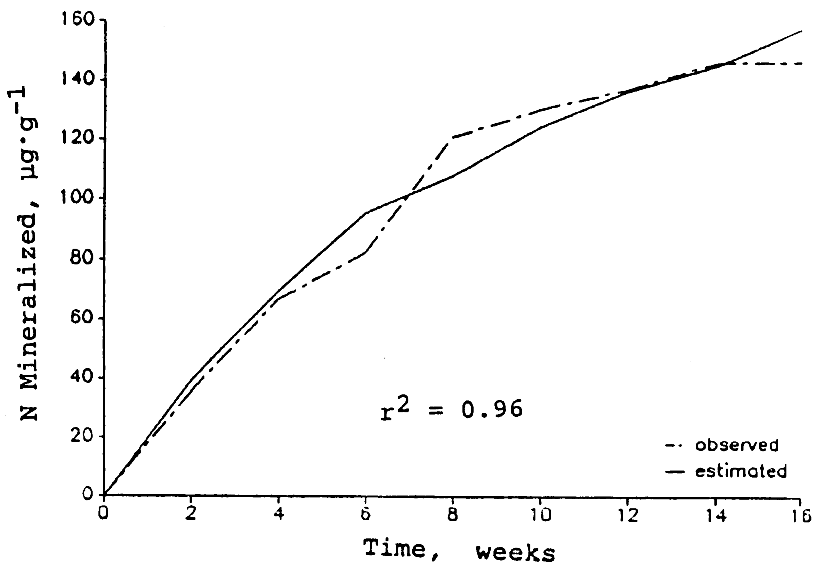

Fig 9. Observed and estimated mineralization values in relation to time for soil no. 2.

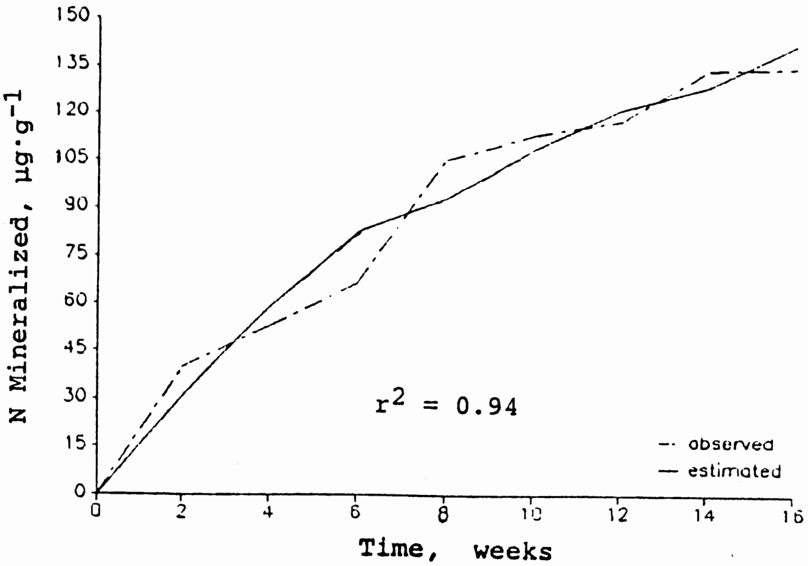

Fig 10. Observed and estimated mineralization values in relation to time for soil no. 3.

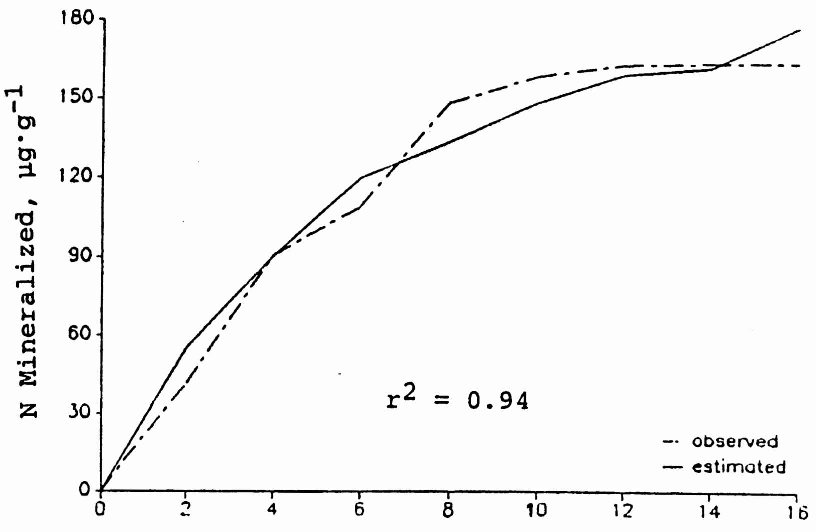

Fig 11. Observed and estimated mineralization values in relation to time for soil no. 4.

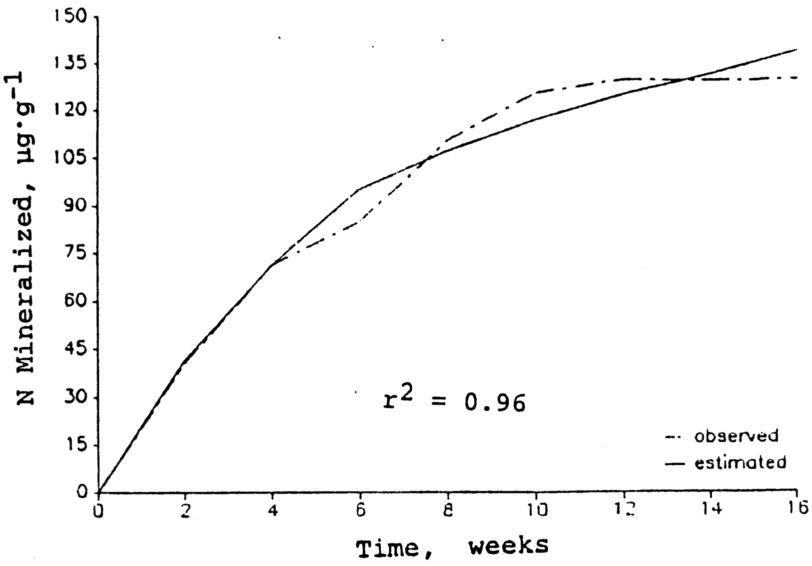

Fig 12. Observed and estimated mineralization values in relation to time for soil no. 5.

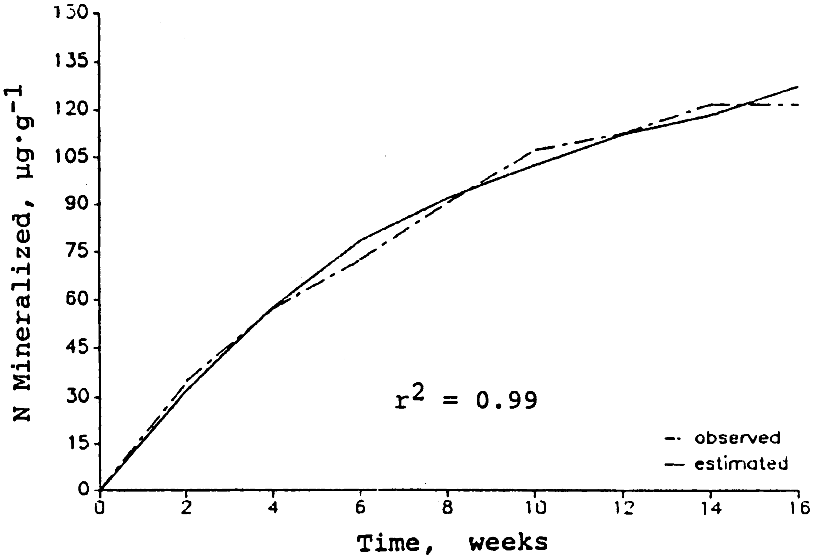

Fig 13. Observed and estimated mineralization values in relation to time for soil no. 6.

TABLE IX

ESTIMATION OF N MINERALIZATION POTENTIAL (N_0), 1 - S, k, AND h FOR DIFFERENT SOILS STUDIED [a]

Soil great groups	Soil number	N_0	1 - S	k	h
		$\mu g \cdot g^{-1}$		----- $week^{-1}$	----
Orthents	1	157	0.566	0.109	0.109
"	2	178	0.962	0.123	0.123
Chromoxererts	3	174	0.800	0.100	0.100
"	4	184	0.242	0.168	0.168
Rendolls	5	145	0.856	0.169	0.169
"	6	144	0.677	0.127	0.127
"	7	145	0.944	0.096	0.096
Palexerolls	8	- [b]	-	-	-
"	9	-	-	-	-
Aridisols	10	164	0.472	0.068	0.068
"	11	183	0.761	0.060	0.060
Xerochrepts	12	165	0.483	0.082	0.082
"	13	241	0.878	0.076	0.076
"	14	-	-	-	-

[a] (1-S) is the slow decomposable organic N, k and h are the rate constants

[b] Convergence was not reached.

soil nos. 5, 6 and 7, respectively. The trend in the Palexerolls, the Aridisols and the Xerochrepts is shown in Figs. 15 through 21. Again,

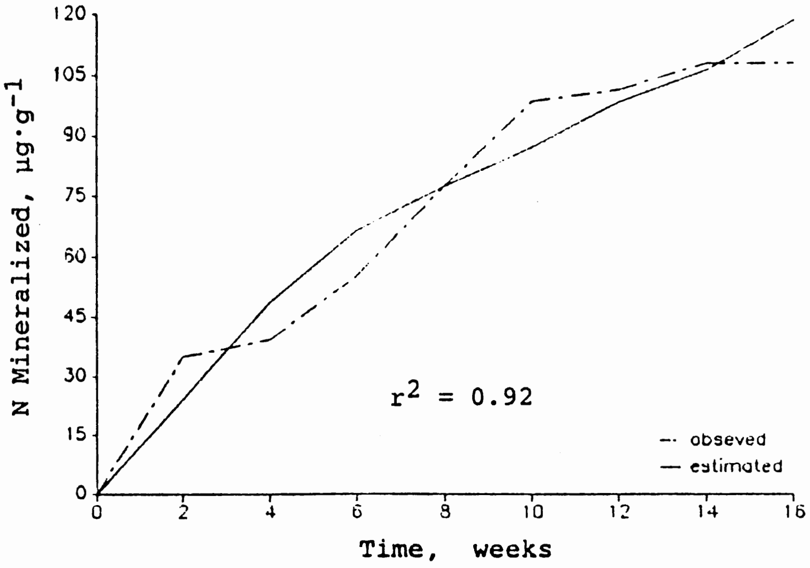

Fig 14. Observed and estimated mineralization values in relation to time for soil no. 7.

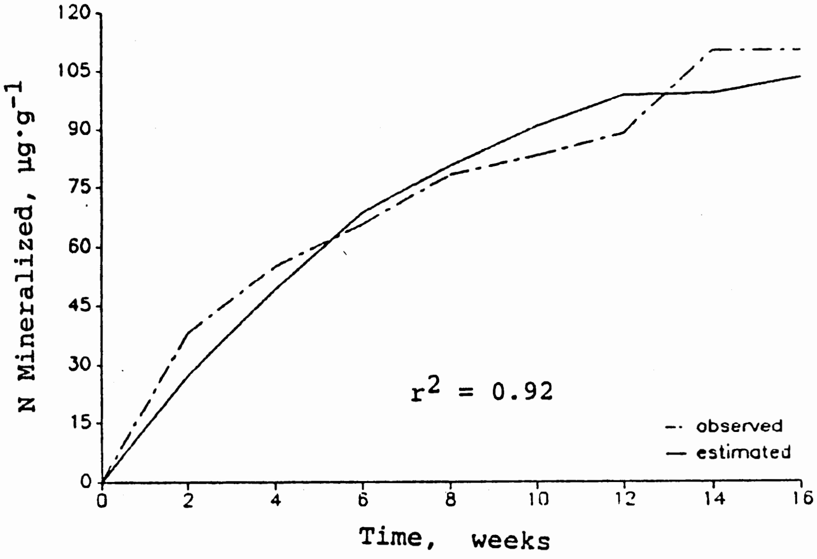

Fig 15. Observed and estimated mineralization values in relation to time for soil no. 8.

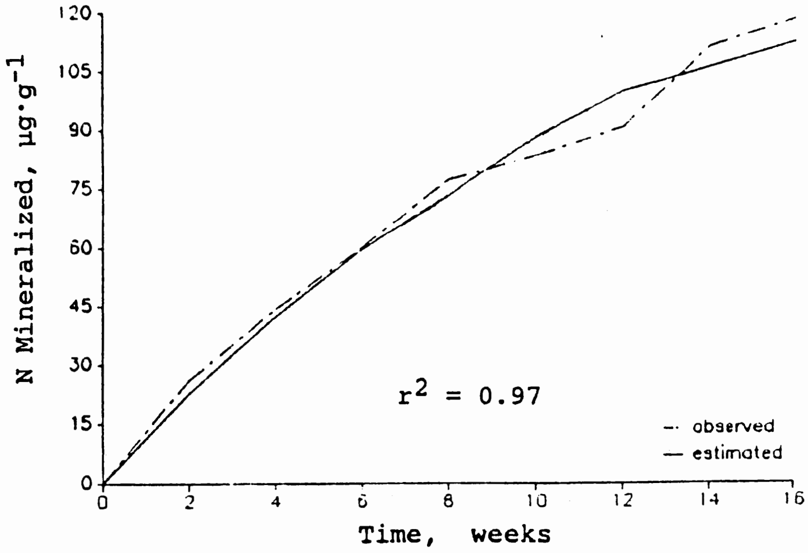

Fig 16. Observed and estimated mineralization values in relation to time for soil no. 9.

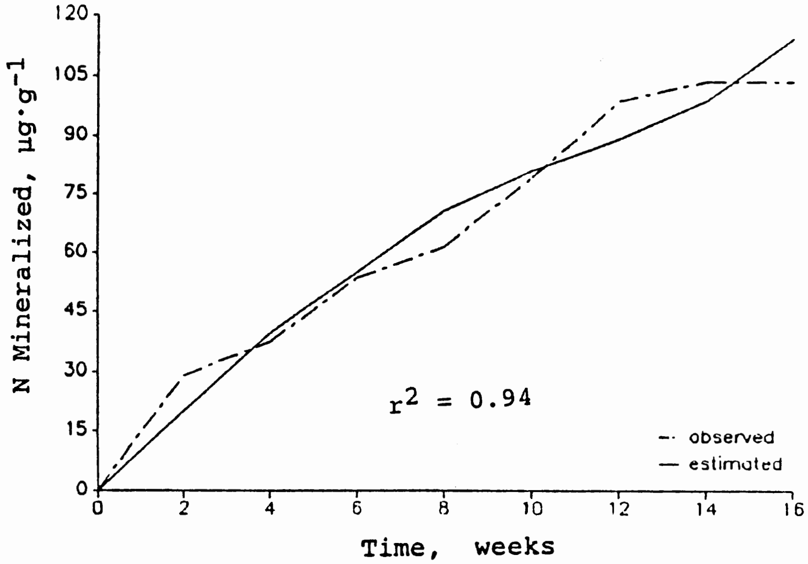

Fig 17. Observed and estimated mineralization values in relation to time for soil no. 10.

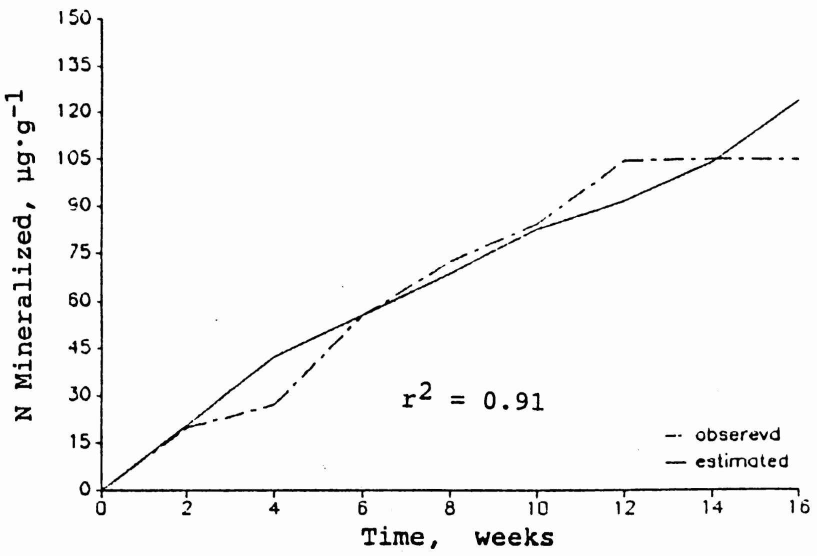

Fig 18. Observed and estimated mineralization values in relation to time for soil no. 11.

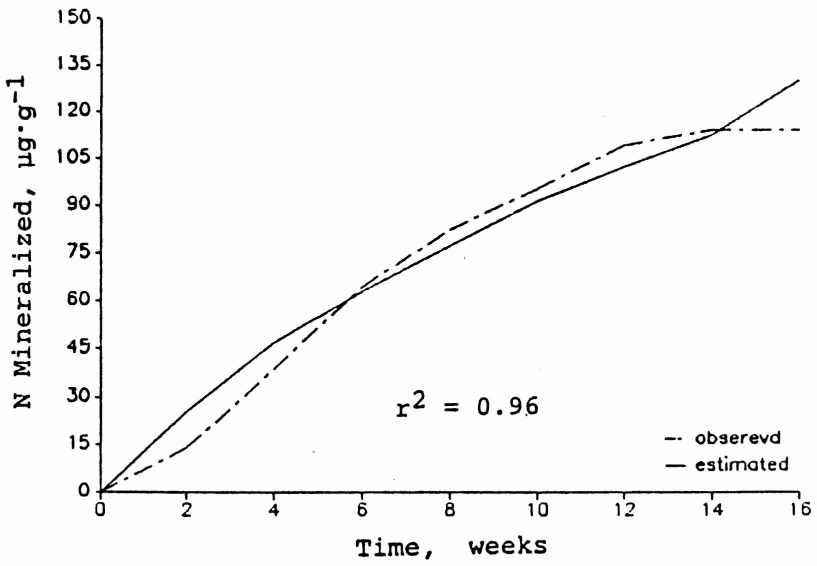

Fig 19. Observed and estimated mineralization values in relation to time for soil no. 12.

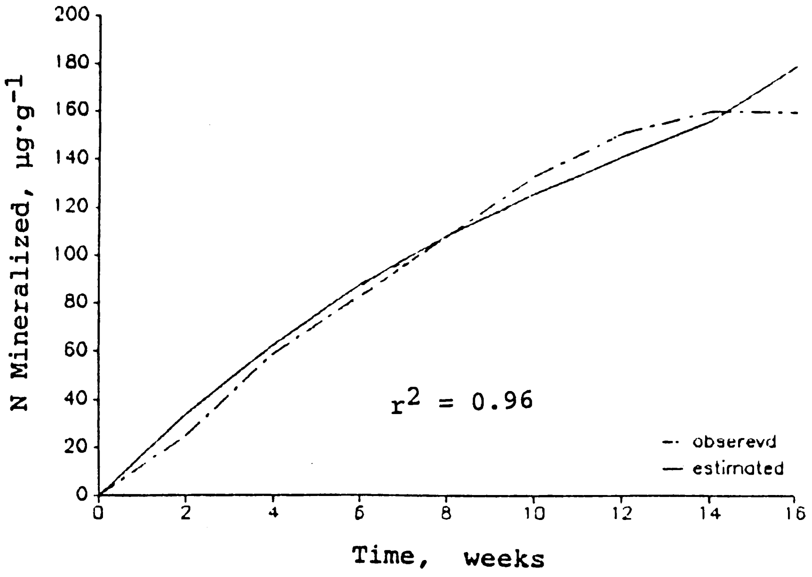

Fig 20. Observed and estimated mineralization values in relation to time for soil no. 13.

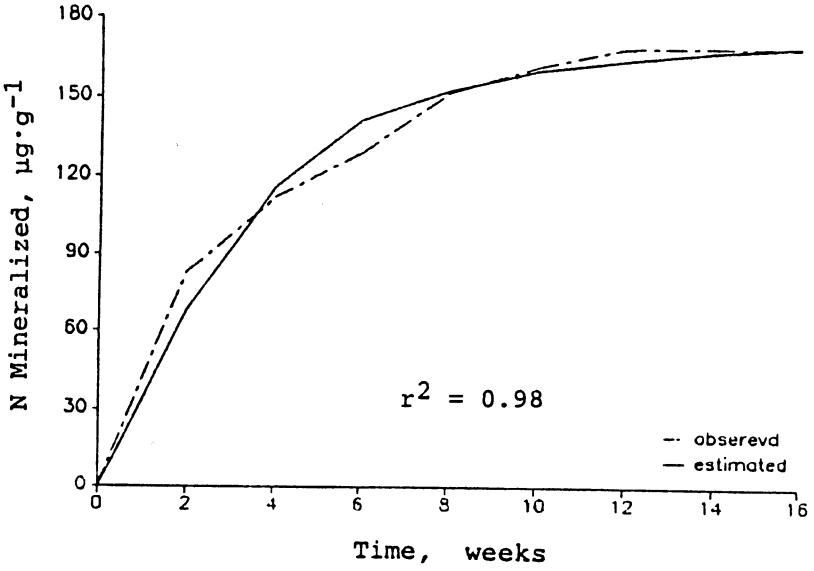

Fig 21. Observed and estimated mineralization values in relation to time for soil no. 14.

the r^2 in these soils were highly significant and were equal to 0.92, 0.97, 0.94, 0.91, 0.96, 0.96, and 0.98 for soils 8 through 14, respectively.

Correlation Between Actual N Mineralization Potential (N_0) and Soil Parameters

Developing an index for N availability to plants has proven to be relatively difficult compared with success in testing for plant available phosphorus. Ratio of C:N has been used to predict N availability, and it is generally reported that C:N ratios of decomposing materials have to be below 20 to 25 to obtain appreciable net mineralization (Harmsen and Kolenbrander, 1965). The weakness of this assumption is that organic fractions are relatively resistant to decomposition. The general rule that net mineralization of organic N depends primarily on N content of the substrate, holds only for the readily mineralizable part of the decaying materials.

Considering the limitation of C:N ratio and total N as indices for available N, N_0 would be a better index. A major disadvantage of using N_0, however, is that it is time-consuming and does not take into consideration the environmental effect. Being a time dependent process, the rate of N mineralization or mineral N supplied by the soil as a function of time should be considered for N fertilization requirements.

For practical purposes, a chemical index or a soil parameter correlated with N_0 should be found rather than determining the value of N_0 from a lengthy incubation experiment.

In this study the correlation between N_0 obtained from the incubation experiment and other soil parameters was evaluated. Using the multivariate analysis; pH (1:1) in water, organic carbon (%), and clay content (%) were found to contribute the most to the N mineralization potential.

The regression coefficients as determined by the use of multiple regression are shown in Table X.

Soil pH was found to be one of the soil parameters that contributes to soil N mineralization potential. The regression coefficient for the pH was found to be positive, which agrees with the findings of Gilmour (1984) and Weier and Gilliam (1986) that nitrate production in soils increases as pH increases. Organic carbon was also found to contribute positively to N mineralization potential.

The estimated and the actual N_0 for the 42 samples used to derive the regression equation are presented in Fig. 22.

The high r^2 and the wide range of soils in this study suggest that the regression coefficients obtained could be used to estimate N_0.

The multiple regression analysis approach, utilizing soil physical and chemical analysis, such as pH and clay content, can simplify estimation of N_0.

The regression coefficients needed to estimate the rate constant k from soil parameters are presented in Table XI.

In spite of the lower squared multiple r, the regression equation gives a significantly better prediction of k than does the overall mean of k for all soils.

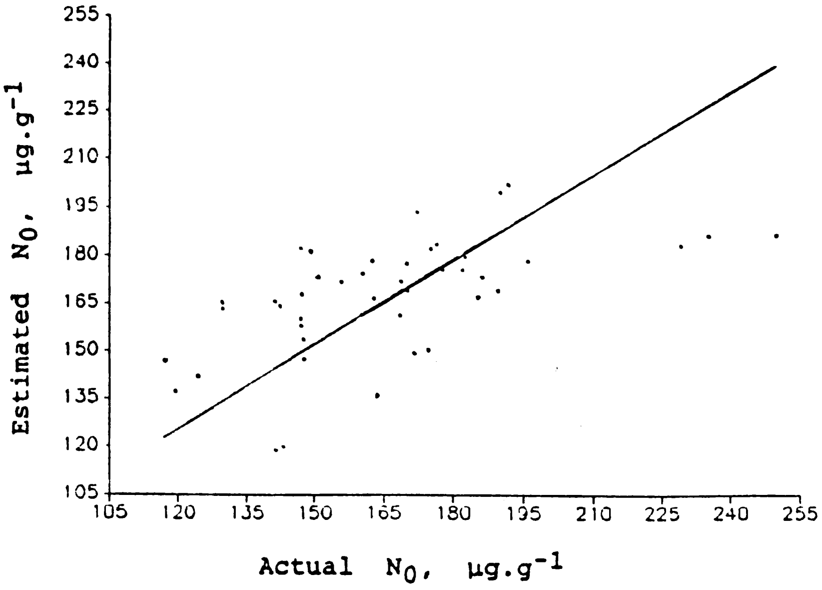

Fig 22a. Relationship between laboratory measurements of N mineralization potential N_0 and estimates of N_0 by multiple regression (model without an intercept).

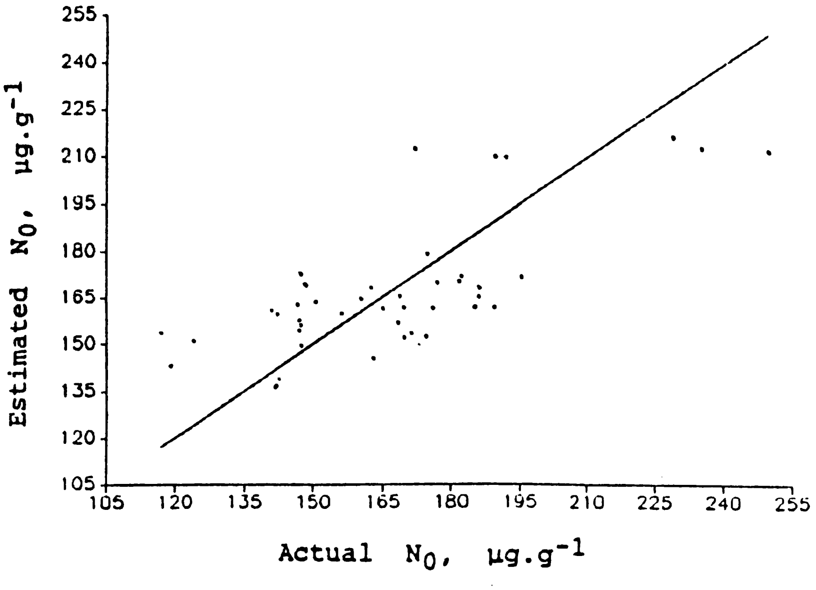

Fig 22b. Relationship between laboratory measurements of N mineralization potential N_0 and estimates of N_0 by multiple regression (model with an intercept).

TABLE X(a)

REGRESSION COEFFICIENTS USED TO ESTIMATE N MINERALIZATION POTENTIAL (N_0) FROM pH, ORGANIC CARBON AND CLAY CONTENT (MODEL WITHOUT AN INTERCEPT)

Independent variable	Regression coefficient	Std. error	Probability P (2 tails)
Intercept	0	-	-
pH_W	24.126	1.339	0.000
Organic carbon	626.531	106.890	0.000
Organic carbon x pH	-80.395	13.666	0.000
Organic carbon x clay content	-10.034	3.353	0.005
Organic carbon x clay content x pH	1.243	0.423	0.006

Multiple squared R = 0.99; N = 42.

TABLE X(b)

REGRESSION COEFFICIENTS USED TO ESTIMATE N MINERALIZATION POTENTIAL (N_0) FROM pH, ORGANIC CARBON AND CLAY CONTENT (MODEL WITH AN INTERCEPT)

Independent variable	Regression coefficient	Std. error	Probability P (2 tails)
Intercept	192.729	10.725	0.000
Organic carbon	511.351	107.777	0.000
Organic carbon x pH_W	-65.974	13.742	0.000
Organic carbon x clay content	-10.580	3.364	0.003
Organic carbon x clay content x pH_W	1.310	0.424	0.004

Multiple squared R = 0.63; N = 42.

TABLE XI

REGRESSION COEFFICIENTS USED TO ESTIMATE RATE CONSTANT (k) FROM pH, ORGANIC CARBON, AND CLAY CONTENT

Independent variable	Regression coefficient	Std. error	Probability P (2 tails)
Intercept	0	-	-
pH_W	0.007	0.004	0.053
Organic carbon	-0.509	0.288	0.086
Organic carbon x pH_W	0.064	0.037	0.093
Organic carbon x clay content	0.025	0.009	0.010
Organic carbon x clay content x pH_W	-0.003	0.001	0.014

Multiple squared R = 0.88; N = 42.

CHAPTER V

SUMMARY AND CONCLUSIONS

Nitrogen mineralization (N_0) and the rate constant for mineralization (k) of different soil types of the Chaouia region of Morocco were estimated from aerobic incubation using different computation models.

This study supported earlier findings that a single exponential or a hyperbolic model can both be used successfully to estimate soil N mineralization potential and the rate constant using a nonlinear least square fitting technique. The double exponential model, was not satisfactory for all soils studied, but for the ones where it worked the output was not different from that of the single exponential model.

This study also provided the estimates of N_0 and k for 14 different soil types of the Chaouia region of Morocco. Soils of the area were divided into three groups based on N mineralization potential. The first group had a low potential and included two soil great groups, Rendolls and Palexerolls. The second group, however, had a high potential and contains mainly Xerochrepts. The third group had a medium potential of N mineralization and included Orthents, Chromoxererts, and Aridisols. Estimations of N mineralization potential were not related to either soil type or total soil N.

The rate constant for mineralization was found to be about the same in most soils studied, except in Aridisols where it was low. In addition, the active fraction of total N in soils was found to be higher in finer-textured soils.

A model to estimate N mineralization potential and the rate constant for mineralization from soil pH, organic carbon and clay content was developed and after validation it could used to assess N_0 and k of the soils of the region.

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