LONG-TERM N FERTILIZATION EFFECTS ON N MINERALIZATION POTENTIAL IN SOILS UNDER DIFFERENT CROPPING SYSTEMS AND DIFFERENT ENVIRONMENTS

BY

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PREFACE

Mineral N is essential for plant growth and development. The Nitrogen cycle in soil and plants is thus an area of fundamental importance for both basic and applied science. Impressive progress has been made in our understanding of N transformation in soil and in plants; at the same time, there have been advances in increasing crop yields by the supply of N fertilizer. The objective of this document is to evaluate the amount of mineral N that can be produced by soils through mineralization under different soil management, different cropping systems and different environments, and to provide a reliable N availability index.

The contribution, though small, convinced the author that the soil nitrate test widely used nowadays is an adequate N availability index for dryland agriculture. This study could not have been accomplished without the excellent support and guidance of my major advisor, Dr. Robert L. Westerman. I am very much indebted to him. Dr. W. R, Raun helped in statistical analyses and especially determination of the linear plateau. He is, therefore, urged to accept full gratitude and respect. The author wishes to express his appreciation to Drs. G.V. Johnson, B. Martin, E. Allen, and W.D. Warde for their valuable advice and time while serving as advisory committee members.

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CHAPTER I

INTRODUCTION

INTRODUCTION

The biological availability of N, P and K is of considerable economic importance because these are the major plant nutrients derived from the soil. Of the three, N stands out as the most susceptible to microbial transformations. The element is a key building block of the protein molecule on which all life is based, and thus an indispensable component of the protoplasm of plants, animals, and microorganisms. Because of the critical position of the N supply in crop production and soil fertility, a deficiency markedly reduces yield as well as quality of crops; and because this is one of few soil nutrients that is lost by volatilization as well as by leaching, it requires continual conservation and maintenance.

More than 90% of the N in most agricultural soils is in organic form, and the C:N ratio of soil organic matter usually falls within the range of 10 to 12 (Stevenson, 1982). The dynamics of soil N is therefore closely related to the dynamics of soil organic matter. In models of soil N dynamics the terms pool and turnover time are often used. A pool is defined as the amount of material behaving similarly enough to be grouped together in the model. The turnover time for a pool of organic matter is defined for a steady state system as the time required for addition and decomposition of an amount of organic matter equal to that in the pool. For pools of slowly changing systems it has been suggested that calculations of turnover time should be based on an average pool size and average decomposition rate (Frissel and Van Veen, 1981). For pools containing old organic matter, the turnover time is approximately the same as the average age determined by carbon dating (Van Veen and Paul, 1981).

Increasing attention has been given to scientifically justified N fertilization advice during the last decades. Recommendation for N fertilizer requirements for cereals are presently based on the level of NO_3^- in the top 60 cm of the soil before planting (Campbell et al., 1988; Soltanpour et al., 1989). The assumption is that N mineralized from the soil during the growing season is either not important or is closely correlated to the initial soil NO_3^- content (Campbell et al., 1988). In Oklahoma, N fertilizer recommendations for cereals are presently based on the levels of NO_3-N in the top 15 cm of the soil before planting, deep sampling is considered when unusual cropping conditions arise. However, the N liberated through mineralization of soil humus and incorporated fresh organic material during the growing season, is an important parameter in N fertilization recommendation (Westermann and Crothers, 1980) and it is variable depending on soil moisture, temperature and inherent N supplying power of the soil (Campbell, 1978)

New approaches to the measurement of the amount of mineral N that a soil can provide from organic N during the course of the year or a cropping season should assist in developing better practices. These practices will conserve N in agricultural systems and maximize economic returns by the efficient use of N fertilizer and its conversion into plant and animal protein.

This report is divided into four parts. The first part is a general literature review concerning soil N mineralization. The other three parts are related subjects, and for convenience literature review, materials and methods and results are presented separately for each subject. Extensive literature citations are listed so they can be used by coworkers.

CHAPTER II

LITERATURE REVIEW

LITERATURE REVIEW

Origin of Soil Nitrogen

The atmosphere was the original source of combined N in the soil. This N, in turn, is believed to have originated from fundamental rocks of the earth crust (Fairbridge 1972). One popular theory is that the atmosphere arose through the gradual evolution of gases from the interior as the newly formed earth warmed up from the heat generated by compression, by decay of radioactive elements, and possibly by other exothermic processes. Nitrogen, which is believed by many geochemists to have consisted mostly of ammonia, was ejected largely during the early stages of the existence of the earth. Small quantities have been liberated during the course of geological times, and the process is continuing today. As the atmosphere became enriched with oxygen, reduced N (ammonia) became oxidized to molecular nitrogen N_2. Small additions of N have been made to the atmosphere over geologic times by volatilization of N compounds from meteorites during entry into the earth's atmosphere.

Nitrogen Cycle

In all soils there is a very considerable intake and outgo of mineral N during the course of the year. Nitrogen passes repeatedly through its various forms as it moves from the soil into the bodies of living organisms and back to the soil again. The reactions may be viewed in term of a cycle in which the element is shuttled back and forth at the discretion of microflora. The source of soil N is the atmosphere, where the strongly bound gaseous molecule (N_2) is the predominant gas (Thompson and Troeh, 1978). The significance of N arises from the fact that, after C, H and O no other element is so intimately associated with the reactions carried out by living organisms. The cycling of other nutrients, notably P and S, is closely associated with biochemical N transformations.

Although considered as a sequence, a "N cycle" as such does not exist in nature. Rather, any given N atom moves from one form to another in an irregular or random fashion. A key feature of the N cycle in soil is the turnover of N through mineralization-immobilization.

Gain in soil N occurs through fixation of molecular N by microorganisms, mineralization of organic N from plant and animal residue and from the return of NH_4^+ and NO_3^- in rainwater; losses occur through crop removal, leaching, and volatilization. The conversion of molecular N_2 to combined forms occurs through biological N_2 fixation. Organic forms of N, in turn, are converted to NH_4^+ and NO_3^- by a process called mineralization. The conversion to NH_4^+ is termed ammonification; the oxidation of this compound to NO_3^- is termed nitrification. The utilization of NH_4^+ and NO_3^- by plants and soil organisms constitutes assimilation and immobilization, respectively. Combined N is ultimately returned to the atmosphere as molecular N through biological denitrification, thereby completing the cycle.

Not all transformations of N in soil are mediated by microorganisms. Ammonia and NO_3^- produced as products of the microbial decomposition of nitrogenous organic materials, are capable of undergoing chemical reactions with organic substances, in some cases leading to the evolution of N gases. Through the association of humic material with mineral matter, organo-clay complexes are formed whereby the N compounds are protected against attack by microorganisms. The positively charged NH_4^+ ion undergoes substitution reactions with other cations on the exchange complex, and it can be fixed by clay minerals.

The basic feature of biological N transformations centers on oxidation and reduction. In the oxidized state, the outer electrons of N serve to complete the electron shells of other atoms; in the reduced state, the three electrons required to fill the outer shell are supplied by other atoms.

Internal Cycle of N in Soil

In recent years, a concept of internal N cycle in soil has evolved, which is distinct from the overall cycle of N but that interfaces with it. A key feature of the internal cycle is the biological turnover of N through mineralization-immobilization process.

The biological turnover through mineralization-immobilization leads to the interchange of inorganic forms with the organic forms of N. In a system closed to net gain or loss, a decrease in mineral N levels with time indicates net immobilization; an increase suggests net mineralization. The fact that levels of mineral N remains unchanged does not necessarily mean that an internal cycling is not operating but that mineralization-immobilization rates, even though vigorous, are equal. (Jansson and Persson 1982).

Several interrelated organic matter fractions must be taken into account when considering N-organic matter interactions in soil. As plant residues undergo decay in soil, inorganic N is incorporated into microbial tissue (biomass), a portion of which is converted to newly formed humic substances and ultimately into stable humus. The mean residence time of the N in any given pool can range from a few days or weeks for some components of the biomass to thousand or more years for the stable humus fraction. Under conditions where steady-state levels of organic matter have been attained, mineralization of native humus is compensated for by synthesis of new humus (Jansson and Persson, 1982).

Biochemical processes such as ammonification, nitrification, denitrification, and assimilation are responsible for many of the transformations that occur within the soil. Fixation reactions of NH_4^+ by clay minerals and ammonia by the soil organic matter also play a prominent role.

Nitrogen as Plant Nutrient

Nitrogen occupies a unique position among the elements essential for plant growth because of the rather large amounts required by most agricultural crops. Plants absorb nitrogen whenever they are actively growing but not always at the same rate. A deficiency of N is shown by yellowing of the leaves and by slow and stunted growth. Other factors being favorable, an adequate supply of N in soil promotes rapid plant growth and the development of dark-green color in the leaves. Major roles of N in plant nutrition include: (1) component of chlorophyll; (2) component of amino-acids, the building blocks of proteins; (3) essential for carbohydrate utilization; (4) component of enzymes, vitamins, and hormones; (5) stimulative of root development and activity; and (6) supportive to uptake of other nutrients (Olsen and

Kurtz, 1982).

Nitrate is the main form of N used by most crop plants, the most notable exception being lowland rice. The first step in NO_3^- utilization by plants is reduction to the ammonia form. The NO_3^- is first reduced to nitrite (NO_2^-) is an enzymatic step carried out by NO_3^- reductase. Nitrite is then reduced to NH_4^+ by NO_2^- reductase.

The NH_4^+ produced by NO_2^- reductase seldom accumulates in plants but is rapidly metabolized and incorporated into glutamic and aspartic acids, the two main compounds from which other amino acids and N-containing biochemicals are formed.

The amount of N consumed by plants varies greatly from one species to another, and for any given species, the amount varies with genotype and the environment. Also considerable variation exists in the relative amount of N contained in the different plant parts (grains, stems, leaves, roots).

Mineralization

The soil nutrient that plants require in greatest quantities is nitrogen. Yet, despite its critical role in plant nutrition, N is assimilated almost entirely in the inorganic state, as NO_3^- and NH_4^+. On the other hand, the bulk of the nitrogenous materials found in soil or added in the form of plant residues is organic and, hence, largely unavailable for plant nutrition. The release of the bound element and the mobilization of organically combined nitrogen are essential to the recycling of the nutrient and therefore to soil fertility.

The conversion of organic N to more mobile, inorganic state is known as N mineralization. The process of mineralization is brought about by the joint activities of a wide range of macro- and microfaunal organisms. The first step is ammonification, in which NH_4^+ is formed from organic compounds, the second step is nitrification, a term that usually is taken to indicate the oxidation of NH_4^+ to NO_3^-. Ammonium accumulation represents the quantity of substrate N in excess of microbial demand. Nitrification, however, is usually associated with the energy-yielding reactions in the metabolism of autotrophic bacteria. Mineralization is nearly always accompanied by immobilization, and for this reason results obtained from NH_4^+ and NO_3^- accumulations cannot be used to calculate a mineralization rate, nor can increase in NO_3^- levels be used to determine a nitrification rate.

Both aerobic and anaerobic microorganisms are involved in the ammonification process, whereas only aerobic microorganisms oxidize NH_4^+ to NO_3^-. Thus, conditions that restrict the supply of O_2 permit NH_4^+ to accumulate, such as in rice paddy fields. Nitrate is the predominant available form of N in cultivated soils that are well aerated.

Ammonification

Organic nitrogenous compounds, when incorporated in the soil are immediately attacked, if conditions are favorable, by a great variety of microorganisms. Ammonification is an enzymatic process in which the N of nitrogenous organic substances is liberated as NH_4^+. The initial substrate is often a macromolecule (protein, nucleic acid, amminopolysacharide), from which simpler N-containing biochemicals are formed (amino acids, purine, pyrimidine, amino sugars). The biochemical compounds are then attacked by other enzymes, with formation of ammonia (Ladd and Jackson, 1982).

Nitrification

Except for poorly drained or submerged soils, the NH_4^+ formed through ammonification is readily converted to NO_3^-. The biological nature of nitrification is related to the metabolism of two groups of autotrophic bacteria, one group Nitrosomonas spp bringing about the oxidation of NH_4^+ to NO_2^- and the other group Nitrobacter spp the oxidation of NO_2^- to NO_3^-.

In addition to autotrophic bacteria, several heterotroph have been shown to produce NO_2^- or NO_3^- from NH_4^+ and organic N compounds in pure culture. They include a number of bacteria, and fungi. Several algae have also been reported to produce NO_2^- or NO_3^- from NH_4^+.

The ecological importance of heterotrophic nitrification has yet to be established with certainty. Nitrification occurs in soil under a broader range of environmental conditions than has been predicted from biochemical and physical studies of the autotrophic nitrifier, suggesting the participation of heterotrophs in the process. For example, nitrification proceeds in soils at pH values well below the optimum observed for Nitrosomonas and Nitrobacter in pure culture.

Immobilization

Some and often all of the NH_4^+ and NO_3^- formed through ammonification and subsequent nitrification is simultaneously consumed by the heterotrophic microflora and converted into microbial tissue, that is, the inorganic N is said to be immobilized. The biochemical pathway of immobilization is the reverse of those of ammonification and nitrification.

Since both mineralization and immobilization occur simultaneously in soil, the amounts of mineral N (NH_4^+ and NO_3^-) formed at any one time represent the difference in the magnitude of the two opposing processes. In a system without net gains or losses, a decrease in mineral N levels with time indicates net immobilization; and an increase indicates net mineralization.

C:N ratio

The decay of organic residues in soil is accompanied by conversion of carbon and N into microbial tissue. As the C:N ratio is lowered, and as microbial tissues are attacked, a portion of the immobilized N is released through net mineralization.

The N content of organic residues, as reflected through the C:N ratio is of primary importance in regulating the magnitude of the two opposing processes of N transformations, mineralization and immobilization. Residues that have C:N ratio greater than about 30 results in lowering of mineral N reserves because of net immobilization by microorganisms. On the other hand, residues with C:N ratio below 20 lead to an increase in mineral N levels through net mineralization (Thompson and Troeh, 1978).

Under conditions suitable for microbial activity, rapid decomposition occurs with the concurrent liberation of considerable quantities of C as CO_2. To meet the N requirements of microorganisms, mineral N is consumed; that is, there is net immobilization of N. However, when the C:N ratio of the decomposing material has been lowered to about 20, NO_3^- levels once again increase because of net mineralization.

The time required for microorganisms to lower the C:N ratio of carbonaceous plant residues to the level where mineral forms of N accumulate will depend on such factors as application rate, lignin content, degree of pulverization, and level of respiration of the soil microflora. Nitrogen will eventually be mineralized even though the organic material added has a wide C:N ratio, but a lengthy waiting period is required. The higher the C:N ratio, the longer the period of net immobilization. The lower C:N ratio of freshly added decomposable materials, the sooner N will be mineralized.

A prime objective of studies on N transformation in soil is to assign quantitative values for mineralization rate. Mineralization is an important component of many N-cycle models. Several pools for organic matter are often included in these models, such as native humus, the soil biomass, and component of plant residues. Various substrates decompose at different rates, with the order of decomposition for plant residue components from the fastest to the slowest being proteins, carbohydrates, cellulose, hemicellulose, and lignin respectively.

Factors Affecting Mineralization

Mineralized plant N is a by-product of microbial metabolism. Anything that affect the microbial activities will eventually affect N mineralization. Among the important factors that affect mineralization in soil are temperature, aeration, moisture, soil reaction, mineral nutrient status, and the nature of organic matter. Production of NO_3^- decreases with decreasing temperature. Below 5°C very little NO_3^- is formed. As one might expects nitrification proceeds at a very slow rate in cold, wet soils.

The O_2 and CO_2 required by the nitrifying organisms are contained in the solution phase of the soil, consequently, moisture content is of major importance. Depletion of O_2 is favored by (i) the presence of easily decomposed organic matter, which increases O_2 demand by heterotrophic organisms; (ii) excess moisture, which saturates soil pores and restricts recharge of O_2 from the gaseous phase; and (iii) high soil temperatures, which reduce the solubility of O_2.

Temperature

Temperature governs all biological processes, and it is thus a prime factor of concern to the microorganisms. An association between microorganism population size and temperature has been shown (Alexander, 1977). Each microorganism has an optimum temperature for growth and a range outside of which development ceases. The temperature range and the optimum for proliferation serve as means of delineating microorganism groups. Most microorganisms have an optimum in the vicinity of 25 to 35°C and the ability to grow from 15 to 45°C.

Soil N mineralization rate is affected profoundly by temperature within the range that is normally encountered under field conditions (Kowalenko and Cameron, 1976). 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 NH_4^+ to NO_3^- 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. Mayers (1975), based on work done in tropical Australia, suggested that the optimum temperature for nitrogen mineralization would not be less than 37°C. But this temperature may, in fact, depend on geographical locations.

Stanford 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 across all temperatures. However, Q_{10} is not constant for all soils (Campbell et al., 1984) nor constant across all temperatures encountered under soil conditions (Campbell et al., 1981). Burger and Pritchett (1984), using Q_{10} of approximately 2, developed an equation to adjust the rate constant k to a desired temperature. This equation is:

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

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.

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

Aeration

The oxidation of NH_4^+ requires the presence of oxygen in soil. However, any procedure that increases the aeration of the soil should, up to a certain level, enhance NH_4^+ oxidation. Plowing and cultivation are recognized to promote nitrification. Miller and Johnson (1964) reported that a minimum of aeration is necessary for the oxidation of NH_4^+ in the soil because the aerobic microorganisms responsible for the reaction are dependent on having adequate O_2 supply. Amer and Bartholomew (1951) found the optimal O_2 concentration for nitrification to be about equal to that in ordinary air.

Moisture

Moisture governs the microbial activity in two ways. Since water is the major component of protoplasm, an adequate supply must be available for vegetative development. But, where moisture becomes excessive, microbial proliferation is suppressed not by the over abundance of water, which is not deleterious per se, but rather because the oversupply limits gaseous exchange and lowers the available O_2 supply, creating therefore an anaerobic environment. The maximum bacterial density is found in regions of fairly high moisture content, and the optimum level for the activities of aerobic bacteria often is at 50 to 75 percent of the soil's moisture-holding capacity (Alexander, 1977). Microbial activity ceases when the soil water content is near the wilting point. It proceeds again almost immediately when the soil water is renewed. The rate of mineralization is most rapid shortly after the soil is re-moistened and then slows down.

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 0.015 to 0.05 MPa (Miller and Johnson 1964). Cassman and Munns (1980) found that a moisture tension of 0.03 MPa gave the maximal mineralization rate. Stanford and Epstein (1974) found the optimum moisture tension to be from 0.01 to 0.033 MPa. Similar results were also reported by others (Reichman et al., 1966; Chiang et al., 1983; and Myers et al., 1982).

Robinson (1957) reported the optimum range of moisture content for nitrification to be between the wilting point and the field capacity. Also, it was found that addition of moisture to the soil increased the uptake and utilization of N fertilizer by grass (Power, 1967).

Soil Reaction

Highly acid or alkaline conditions tend to inhibit many common soil microorganisms as the optimum for most species is near neutral. The greater the H ion concentration, the smaller generally is the soil microorganism population. It follows, therefore, that liming of acid soil would greatly increase the bacterial population in soils. It is a very common observation that lime stimulates nitrification in soils, even those that may already contain a fair amount of active calcium. This accounts for the feeble nitrification in acid mineral soils and the apparent sensitivity of the microorganisms to low pH. The beneficial effect of liming on N mineralization has been shown by many laboratory studies (Alexander, 1977; 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, 1985). 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

Although organic C is the major constituent of the food supply, inorganic nutrients are required, and it is not surprising that the flora is sometimes affected by the application of inorganic fertilizer. These inorganic fertilizer serve dual function since they supply both the plant and the microorganisms with the needed inorganic nutrients. Nitrogen in some form is needed for the decomposition of organic matter by heterotrophic 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. Stanford 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 NH_4^+ 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, 1985).

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).

Nature of Organic Matter

Soil organic matter has a dynamic nature, whenever environmental conditions permit biological activity, soil organic matter is decomposed, and during the growing season period there is a continuous input of new organic matter to the soil, dead roots and root exudates. Organic matter is also introduced periodically into agricultural soils by plowing plant residues or applying farmyard manure and other organic waste products. If the rates of addition and decomposition are equal, the soil organic matter remains at equilibrium; otherwise, the amount of soil organic matter changes with time.

The existence of two general pools of organic N in soils have been reported (Stanford, 1968). The first pool undergoes relatively rapid transformation through microbiological action. The second pool (labile) 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. Therefore, the ability of soil organic matter to deliver N to growing crops depends on the size and turnover rate of these two conceptual pools of organic N. The labile pool comprises about half of the N in soil and has a turnover of 30 to 40 years. This turnover time depends on soil characteristics, and the control mechanisms are not adequately understood. The size of this pool influences the response of soil organic matter to changes in management practices and determines the amount of mineralizable N in the soil. The active pool comprises less than 10% of the N in most soils and has a higher turnover rate.

Nitrogen Availability Indexes

Soils contain several thousand kilograms of N per hectare but only a small fraction of this N becomes available to the plant during any given growing season. Various soil tests have been proposed in attempts to predict the soil's contribution of N to the crop, but in general, these tests have not been as successful as those for available P and K (Campbell, 1978; Harmsen and Van Shereven, 1955; Stanford, 1982).

A variety of chemical tests (Stanford and Smith, 1978; Paul and Juma, 1981) and microbiological tests (Stanford and Smith, 1972, Richter et al., 1982) have been proposed as indexes of soil N availability, including soil NO_3^- levels, hot water or hot salt extractable total N or NH_4^+, amount of ammonia recovered by soil distillation with alkaline $KMnO_4$, total N or organic matter content, and aerobic and anaerobic incubations.

Chemical Methods

A number of chemical tests have been proposed for estimating soil N availability, but they are empirical in nature and for the most part are too expensive and time consuming for routine use. They range in severity of extraction from drastic (total organic N and hydrolyzable N) to intermediate (alkaline $KMnO_4$ distillation) to mild (hot water and hot salt extractions).

Incubation methods

The incubation methods involve short term incubation of the soil under aerobic or anaerobic conditions. Most soil test correlation with yield or plant N uptake has been done under greenhouse conditions. Modifications in the incubation methods include pre-leaching of the soil to remove residual NO_3^-, the use of vermiculite or sand to improve aeration and leachability, and addition of a nutrient solution which does not contain N.

Stanford and Smith (1972) have developed an incubation approach designed to define the mineralizable soil N. In this approach, measurements are made for the amounts of N mineralized from the soil over a time period, with inorganic N being removed at various time intervals in order to describe the relationship between cumulative N and time of incubation. The N mineralization potential (N_0) is assumed to follow first order kinetics ($dN/dt = -kN$).

Limitations of incubation methods are (1) the results are affected by conditions prevailing in the soil at the time of sampling, (2) high results are attained with soils of poor structure, and (3) reliable results, sufficiently correlated with the N requirement of field crops, can only be expected when technique is calibrated to a given soil type in a given climate zone and when all samples are collected at the same time during the season. (Harmsen and Van Shereven, 1955).

Modeling of N mineralization

Modeling is an attempt to describe the dynamic aspect of the soil N mathematically. Many models are simulation models that attempt to forecast how a system will behave without actually using the physical system or its prototype. Mathematical models, on the other hand, use empirical or observational data to provide quantitative values for gains, losses, and transfer of N, as well as, the amount of N contained in one or more pools as a function of time. Mathematical models can be divided into three groups; (i) Stochastic Models, which are based on the assumption that the process to be modeled obey the law of probability; (ii) Empirical Models, which are based on observational data, in which the input and output processes are expressed in terms of regression equations; and (iii) Mechanistic Models; these are more versatile than other types and are based on well-established physical, chemical, and biological processes.

The major objectives of modeling are (1) to obtain a better understanding and increased insight into complex problems, (2) to test existing as well as new concepts and hypotheses, (3) to obtain a better evaluation or prediction of an observed phenomenon (4) to identify research needs, and (5) to help develop guidelines for best management practices.

Considerable interest has been stimulated in recent years on the mathematical description of the N mineralization process. Stanford and Smith (1972) proposed that cumulative N mineralization could be described by an exponential equation of the form;

$$Nm = N_0(1 - e^{-kt})$$

where N_0 is the potentially mineralizable N, Nm is the cumulative N mineralized in time t, and k is a rate constant. A number of workers have used this equation to characterize the N mineralization process (Smith et al.,1980; Talpaz et al., 1981; El Gharous et al.,1990). In order to obtain realistic results, soil organic matter has been divided into two or more components (biomass active, non-biomass active, slow, and passive; and usually two litter components, labile and structural) (Bonde and Rosswall, 1987). Several workers have expanded on the Stanford and Smith (1972) model by assuming two or more soil pools each of which can be described by an exponential term (Molina et al., 1980; Richter et al., 1982; Nuske and Richter, 1981; Lindemann and Cardenas, 1984; Deans et al., 1986). These models take the form;

$$Nm = S.N_0(1-e^{-kt}) + (1-S).N_0(1-e^{-ht})$$

where S is the proportion of N mineralization potential with fast turnover, $S.N_0$ and $(1-S).N_0$ are the rapidly mineralizing sub-fraction and a more slowly mineralizing sub-fraction respectively, and h and k are the respective rate constants of mineralization. An intermediate model between the one proposed by Stanford and Smith (1972) and that proposed by Molina et al. (1980) was proposed by Lindemann et al. (1988). This model takes the following form;

$$Nm = N_o.S.(1-e^{-kt}) + N_o.(1-S)$$

where N_o, S, and k are as described above. On the other hand, some workers found that N mineralization can be described by parabolic equations of the form;

$$Nm = A.t^B$$

where A and B are constant and t is time, and which in its simplest form (B=1) is a straight line (Stanford and Smith, 1972; Tabatabai and Al-Khafaji, 1980; Addiscott, 1983; Broadbent, 1986). Juma et al. (1984) have shown that N mineralization can also be described by a hyperbolic equation of the form

$$Nm = N_o.t/(T_c + t)$$

where T_c is the half time of mineralization and other terms are as described above. Half time for mineralization is related to the rate constant, k, by the following equation:

$$T_c = \ln(2)/k$$

Other models proposed to describe net N mineralization are summarized in Table 1.

Relationship between potentially and net mineralizable N

The validation of the soil N mineralization potential approach to predict N mineralization under field conditions has been the subject of study by a number of scientists (Stanford et al., 1973; Stanford and Epstein, 1974; Westermann and Crothers, 1980; Campbell et al., 1988; Cabrera and Kissel, 1988). In order to calculate the correct N fertilizer rate for a crop, it is necessary to estimate the amount of nitrogen that mineralizes from soil organic matter during the growing season. Accurate methods for making such estimates, however, are not presently available. A method proposed by Stanford and Smith (1972) involves the incubation of soil samples to determine the soil's mineralization potential, N_o, and its first order rate constant of mineralization, k. To predict N mineralized in the field, the rate constant of mineralization is adjusted by soil temperature (Stanford et al. 1973), and the amount of N mineralized predicted with the N mineralization potential and adjusted rate constant is further adjusted by soil water content as described by Stanford and Epstein (1974). Cabrera and Kissel (1988) used a temperature correction factor for the rate constant (k), an average Q_{10} of 2 between 15 and 35°C and the predicted amount of N mineralized was then corrected for soil water content with a factor W=soil water content/optimum soil water content.

The relation between the rate constant k and temperature has been well established (Stanford et al., 1973; Mayers, 1975; Campbell et al., 1981; Campbell et al., 1984) but no similar relationship has been established between k and soil moisture content. The relationship between nitrogen mineralization and soil moisture content, however, has been documented. Mayers et al. (1982) reported that the relationship between relative net N mineralization and relative available soil moisture content could be assessed by the following

$$y = bx + (1-b)x^2$$

where y is the net N mineralized expressed as a fraction of the maximum rate which occur at about 0.001 to 0.03 MPa moisture tension and

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

where M, M_{max}, and M_o refer to the actual moisture content and b is a coefficient that depends on the soil.

Griffin and Laine (1983) assumed that k was linearly related to the fraction of optimum available water. The same assumption was made by Campbell et al. (1984). However, Smith et al. (1977) and Marion et al. (1881) combined the moisture and temperature effects by assuming that the relative cumulative N mineralization was linearly related to the fraction of optimum available moisture.

Statistical analyses

Most net mineralization models in the literature are nonlinear with respect to their parameters. Iterative numerical techniques are required to estimate the parameters, because closed solution to the minimizing functions defining the best fit do not generally exist (Draper and Smith, 1981).

Statistical tests used to evaluate the fit of equation which are linear in parameters are inappropriate for nonlinear regression, because parameter estimates rarely follow a normal distribution, and confidence intervals are asymmetrical. Most nonlinear regression programs, including NLIN in SYSTAT, employ an approximate linearization of the nonlinear function, and output standard errors of parameters calculated from the linearization of the final iteration. However, the standard errors are valid only if the final linearization closely approximates the nonlinear model (Draper and Smith, 1981; Robinson, 1985). The total uncorrected sum of square (SS) is divided between the model SS and the residual SS which shows the remaining variation of points about the curve. The residual SS, which is the true measure of error inherent in the data, and lack-of-fit, which is the difference between the residual and pure error SS need to be computed. The smaller the ratio of the lack-of-fit mean square to the pure error mean square (F lack of fit) the better the model fits a particular mineralization curve.

References

Addiscott, T.M. 1983. Kinetics and temperature relationships of mineralization and nitrification in Rothamsted soils with differing histories. J. Soil Sci. 34: 343-353.

Alexander, M. 1977. Soil Microbiology. John Wiley and Sons Inc. New York. pp. 16-35.

Amer, F. M., and W. V. Bartholomew. 1951. Influence of oxygen concentration in soil air on nitrification. Soil Sci. 71:215.

Awad, A. S., and D. G. Edwards. 1977. Reversal of adverse effects of heavy ammonium sulfate application on growth and nutrient status of a Kikuyu pasture. Plant and Soil 48:169-183.

Bonde, T.A. and T. Rosswall. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. Soil Sci. Soc. Am. J. 51:1508-1514.

Broadbent, F.E. 1986. Empirical modeling of soil nitrogen mineralization. Soil Sci. 141:208-213.

Broadbent, F. E., and F. Clark. 1965. Denitrification In: W. V. Bartholomew and F. E. Clark (eds.) Soil Nitrogen. Am. Soc. of Agron., Madison, WI. Agron. 10: 344-59.

Burger, J. A., and W. L. Pritchett. 1984. Effects of clearfelling and site preparation on nitrogen mineralization in a southern pine stand. Soil Sci. Soc. Am. J. 48: 1432-37.

Brunner, W., and D.D. Focht. 1984. Deterministic three-half order kinetic model from microbial degradation of added carbon substrates in soil. Appl. Environ. Microbiol. 47:167-172.

Cabrera, M.L., and D.E. Kissel. 1988. Evaluation of a method to predict nitrogen mineralized from soil organic matter under field conditions. Soil Sc. Soc. Am. J. 52:1027-1031.

Campbell, C.A. 1978. Soil organic carbon, nitrogen, and fertility. in M. Schnitzer and S.U. Khan, eds. Soil organic matter developments in soil science. Vol. 8. Elsvier Scientific Publ. Co. Amsterdam, The Netherlands. pp.173-272.

Campbell, C.A., R.J.K. Mayers, and K.L. Weier. 1981. Potentially mineralizable nitrogen decomposition rates and their relationship to temperature for five Queensland soils. Aust. J. Soil Res. 19:323-332.

Campbell, C.A., Y. W.Jame, and G.E. Winkleman. 1984. Mineralization rate constants and their use for estimating nitrogen mineralization in some Canadian prairie soils. Can. J. Soil Sci. 64:333-343.

Campbell, C.A., Y.W.Jame, and R. DeJones. 1988. Predicting net nitrogen mineralization over a growing season: Model verification. Can. J. Soil Sci. 68:537-552.

Campbell, C. A., V. O. Beiderbeck, and F. G. Warder. 1971. Influence of simulated fall and spring conditions on the soil system: II. Effect on soil nitrogen. Soil Sci. Soc. Am. Proc. 35:480-83.

Cassman, K. G., and D. N. Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. Am. J. 44: 1233-37.

Chang, F. M., and F. E. Broadbent. 1982. Influence of trace metals on soil nitrogen transformations. J. Environ. Qual. 11: 1-4.

Chiang, C., B. Soudi and A. Moreno. 1983. Soil nitrogen mineralization and nitrification under Moroccan conditions. In Proc. 17th Coll. Int. Potash Institute, p. 77-87.

Deans, J.R., A.E. Molina, and C.E. Clapp. 1986. Models for predicting potentially mineralizable nitrogen and decomposition rate constants. Soil Sci. Soc. Am. J. 50:323-236.

Draper, N.R., and H. Smith. 1981. Applied Regression Analysis. 2nd edition. John Wiley and Sons, Inc. New York.

Edmeades, D. C., M. Judd, and S. V. Sarathchandra. 1981. The effect of lime on nitrogen mineralization as measured by grass growth. Plant and Soil 60:177--86.

El Gharous, M., R.L. Westerman, and P.N. Soltanpour. 1990. Nitrogen mineralization potential of arid and semiarid soils of Morocco. Soil Sci. Soc. Am. J. 54:438-443.

Fairbridge, R.W. 1972. Ed., Encyclopedia of Geochemistry and Environmental Science. Vol. IVA, Van Nostrand and Reinhold, New York. 795-849.

France, J., and J. H. M. Thornley. 1984. Mathematical Models in Agriculture. Butterworth and Co. Ltd., London.

Frissel, M.J., and J.A. Van Veen. 1981. Simulation model for nitrogen immobilization and mineralization. In Modeling Waste Water Renovation. Ed. I.K. Iskander, pp.359-381. John Wiley and Sons, New York.

Griffin, G.F., and A.F.Laine 1983. Nitrogen mineralization in soil previously amended with organic wastes. Agron. J. 75:124-129.

Haas, H. J., C. E. Evans, and E. F. Miles. 1957. Nitrogen and carbon changes in Great Plains soils as influenced by cropping and soil treatments. USDA Tech. Bull. No. 1164.

Harmsen, G. W., and G. J. Kolenbrander. 1965. Soil inorganic nitrogen. In W. V. Bartholomew and F. E. Clark (eds.) Soil Nitrogen. Am. Soc. of Agron. Madison, WI. Agron. 10: 43-92.

Harmsen, G.W., and D.A. Van Shereven. 1955. Mineralization of organic nitrogen species in soil. Adv. Agron. 7: 299-398.

Jansson, S.L., and J. Persson. 1982. Mineralization and immobilization of Soil Nitrogen. In F.J.Stevenson, (ed.) Nitrogen in Agricultural Soils, American Society of Agronomy, Madison, WI. pp. 229-252.

Jones, C.A. 1984. Estimation of an active fraction of soil nitrogen. Comm. Soil Sci. Plant Anal. 15:23-32.

Juma, N. G., E. A. Paul, and B. Mary. 1984. Kinetic analysis of net nitrogen mineralization in soils. Soil Sci. Soc. Am. J. 48:753-757.

Kowalenko, C. G., and D. R. Cameron. 1976. Nitrogen transformations in an incubated soil as affected by combinations of moisture content and temperature and adsorption fixation of ammonium. Can. J. Soil Sci. 56:63-70.

Ladd, J. N., and R. B. Jackson. 1982. Biochemistry of Ammonification. In F. J. Stevenson, (ed.). Nitrogen in Agricultural Soils, American Society of Agronomy, Madison, WI. 173-228.

Liang, C. N., and M. A. Tabatabai. 1977. Effect of trace elements on nitrogen mineralization in soils. Environ. Pollut. 12: 141-47.

Lindemann, W.C., and M. Cardenas. 1984. Nitrogen mineralization transformations of sludge-amended soil. Soil Sci. Soc. Am. J. 48:1072-1077.

Lindemann, W.C., G. Connell, and N.S.Urquhart. 1988. Pervious sludge addition effect on nitrogen mineralization in freshly amended soil. Soil Sci. Soc. Am.

J. 52:109-112.

Marion, G.M., J. Kummerow, and P.C. Miller. 1981. Predicting nitrogen mineralization in chaparral soils. Soil Sci. Soc. Am. J. 45:956-961.

Mayers, R.J.K. 1975. Temperature effects on ammonification and nitrification in tropical soil. Soil Biol. Biochem. 7:83-86.

Mayers, R.J.K., C.A. Campbell, and K.L. Weier. 1982. Quantitative relationship between net nitrogen mineralization and moisture content of soil. Can. J. Soil Sci. 62:111-124.

Miller, R. D., and D. D. Johnson. 1964. The effect of soil moisture tension on carbon dioxide evolution, nitrification, and nitrogen mineralization. Soil Sci. Soc. Am. Proc. 28: 644-647.

Molina, J. A. E., C. E. Clapp, and W. E. Larson. 1980. Potentially mineralizable nitrogen in soil: The simple exponential model does not apply for the first 12 weeks of incubation. Soil Sci. Soc. Am. J. 44:442-443.

Noggle, J. H. 1985. Physical Chemistry. Little Brown and Company, Boston.

Nuske, A. and J. Richter. 1981. N mineralization in loss parabrown earths Incubation experiments. Plant Soil 59:237-247.

Olsen, R.A., and L.T. Kurtz. 1982. Crop nitrogen requirements, utilization and fertilization. In F.J. Stevenson, (ed.) Nitrogen in Agricultural Soils, American Society of Agronomy, Madison, WI. pp. 567-604.

Paul, E.A., and N.G. Juma. 1981. Mineralization and immobilization of soil nitrogen by microorganisms. In F.E. Clarck and T. Rosswall (eds.). Terrestrial Nitrogen Cycles. Ecol. Bull. Stockholm, 33:179-195.

Power, J. F. 1967. The effect of moisture on fertilizer N immobilization in grasslands. Soil Sci. Soc. Am. Proc. 31:223-26.

Reeder, J. D., and W. A. Berg. 1977. N mineralization and nitrification in a cretaceous shale and coal mine spoils. Soil Sci. Soc. Am. J. 41: 922-27.

Reichman, G. A., D. L. Grunes, and F. G. Viets, Jr. 1966. Effect of soil moisture on ammonification and nitrification in two northern plains soils. Soil Sci. Soc. Am. Proc. 30:363-366.

Richter, J.A., W.H. Nuske, and J. Bauer. 1982. Optimized N mineralization parameters of loess soils from incubation experiments. Plant Soil 68:379-388.

Robinson, J. B. D. 1957. The critical relationship between soil moisture content in the region of the wilting point and mineralization of native soil nitrogen. J. Agr. Sci. 49: 100-05.

Robinson, J.A. 1985. Determining microbial kinetics parameters using nonlinear regression analysis. Advantages and limitations in microbial ecology. Micro. Ecol. 8:61-114.

Smith, J.S., L.B. Young, and G.E. Miller. 1977. Evaluation of soil nitrogen mineralization potential under modified field conditions. Soil Sci. Soc. Am. J. 42:74-76.

Smith, J.L., R.R. Schanbel, B.L. McNeal, and G.S. Campbell. 1980. Potential errors in the first-order model for estimating soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 44:996-1000.

Smith, S. J., and L. B. Young. 1984. Mineralization of soil nitrogen in the presence of different metallic and organic solids. Commun. in Soil Sci. Plant Analy. 15:125-34.

Soltanpour, P.N., M. El Gharous, A. Azzaoui, and M. Abdelmonum. 1989. A soil test based N recommendation model for dryland wheat. Comm. Soil Sci. Plant Anal. 20:1053-1068.

Stanford, G. 1968. Effect of partial removal of soil organic N with sodium pyrophosphate in sulfuric acid solution on subsequent mineralization of nitrogen. Soil Sci. Soc. Am. Proc. 32:679-82.

Stanford, G. 1982. Assessment of soil N availability. In F.J. Stevenson. (ed.) Nitrogen in Agricultural soils. Am. Soc. of Agronomy, Madison, WI. pp.651-688.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization- water relations in soils. Soil Soc. Am. Proc. 38:103-107.

Stanford, G. and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., and S.J. Smith. 1978. Oxidative release of potentially mineralizable soil nitrogen by acid permanganate extraction. Soil Sci. 126:210-218.

Stanford, G., M.H. Frere, and D.H. Schwaninger. 1973. Temperature coefficient of soil nitrogen mineralization. Soil Sci. 115: 321-323.

Stevenson, F.J. 1982. Origin and distribution of nitrogen in soil. In F.J. Stevenson (ed.) Nitrogen in Agricultural Soils. Am. Soc. of Agron., Madison, WI. Agorn. 22:1-39.

Tabatabai, M.A., and A.A. Al-Khafaji. 1980. Comparison of nitrogen and sulfur mineralization in soils. Soil Sci. Soc. Am. J. 44: 1000-1006.

Talpaz, H., P. Fine, and B. Bar-Yasef. 1981. On the estimation of N-mineralization parameters from incubation experiments. Soil Sci. Soc. Am. J. 45:993-996.

Tisdale, S. L., and W. L. Nelson. 1985. Soil Fertility and Fertilizers. 4rd ed. New York: MacMillan Publishing Co, Inc. p. 112-183.

Thompson, M.L., and R.F. Troeh. 1978. Nitrogen. Soils and Soil Fertility. 235-258 Fourth ed. McGraw-Hill Inc.

Van Veen, J.A., and E.A.Paul. 1981. Organic carbon dynamics in grassland soils. I. Background information and computer simulation. Can. J. Soil Sci. 61: 185-201.

Westermann, D.T., and S.E. Crothers. 1980. Measuring soil nitrogen mineralization under field conditions. Agron. J. 72:1009-1012.

Table 1. Different Mathematical Models Proposed by Different Authors.

Models[a]	References
$Nm/t = N_o.k\text{-}0.5.N_o.k^2.t$	Addiscott, 1983.
$Nm = N_o.(1\text{-}e^{-kt})+N_e$	Jones, 1984.
$Nm = N_o\text{-}N_o.e^{-kt}).(kt+1)$	Noggle, 1985.
$Nm = N_o.e^{-he-kt} - N_o.e^{-h}$	France and Thornley, 1984.
$Nm = N_o.(1\text{-}e^{-kt\ -\ o.5ht2})$	Brunner and Focht, 1984.

[a] Symbols definitions: Nm=cumulative mineral N (mg kg^{-1}); t=time; N_o=potentially mineralizable N (mg kg^{-1}); k and h are proportionality constants specific to the model in which they appear; N_e=easily mineralizable fraction (mg kg^{-1}).

CHAPTER III

EFFECT OF CROPPING AND FERTILIZER MANAGEMENT ON SOIL NITROGEN MINERALIZATION

EFFECT OF CROPPING AND FERTILIZER MANAGEMENT ON SOIL NITROGEN MINERALIZATION

Abstract

Nitrogen mineralization of soil organic matter has long been recognized to be very important in meeting plant N needs. Recommendations for N fertilizer requirements for cereals are presently based on the level of nitrate in the soil before planting. Nitrogen mineralization potentials (N_0) were determined on soils collected from four long term continuous wheat (Triticum aestivum) experiments and one long term continuous cotton (Gossypium Hirsutum) experiment. Soils were classified as Kirkland silt loam soil (fine, mixed, thermic, udertic paleustolls), Grant silt loam soil (fine-silty, mixed, thermic udic argiustolls), and Tillman clay loam soil (Fine, mixed, thermic, typic paleustolls at Stillwater, Lahoma and Altus locations respectively. The purpose of this study was to evaluate the N supplying capacity of these soils under different soil management practices and to determine the long-term effect of N fertilization on soil N mineralization potential. Soil samples were collected to a depth of 15 cm from wheat experiments at Stillwater, Lahoma, and Altus and from a cotton experiment at Altus, OK. The samples were incubated under optimum moisture and temperature for a period of 12 weeks. The incubated soil samples were leached with 100 ml 0.01 M $CaCl_2$ and 25 ml of nutrient solution void of N before and during the incubation period. Leachates were analyzed for mineral N (NH_4-N,

NO_3-N plus NO_2-N). The N mineralization potential and the rate constant were determined from a first order exponential model using a non-linear least squares iterative statistical method.

Cumulative N mineralized during the incubation period increased with increasing N rates 27 and 76% respectively for soils cropped to cotton and wheat. The highest increase in cumulative mineral N in the Magruder plots at Stillwater was due to manure application, (32%).

Nitrogen fertilizer increased N mineralization potential (N_0) by 37% to 78% in the 0 to 15 cm depth in soils cropped to continuous wheat and by 61% in soils cropped to continuous cotton. The increase in N mineralization potential (N_0) over a check plot ranged from 21 to 39% depending on past fertilizer applications.

The effect of fertilizer N on the decomposition rate constant (k) was not consistent and was dependent on soil type and crop management.

Grain N uptake and grain yield exhibited a quadratic relationship with N mineralization potential in fertilized plots and a linear relationship in check plots (no N fertilization) ($P=0.0001$).

Introduction

The biological availability of N, P, and K is of considerable economic importance because they are the major plant nutrients derived from the soil. Of the three, N is the most susceptible to microbial transformations. Because of the critical position of the N supply in crop production and soil fertility, a deficiency markedly reduces yield as well as the quality of crops. Nitrogen is one of the few soil nutrients that is lost by volatilization, denitrification as well as by leaching and it requires continual conservation and maintenance.

Soils have been increasingly used for organic waste deposition and since most soil N is in organic form, quantification of N release during mineralization of organic material is recommended.

Soil N mineralization potential is affected by many complex interactions of moisture, temperature, aeration, nature of organic matter, soil nutrient status and other soil physical, chemical, and biotic properties. N mineralization can be studied by several methods (Paul and Juma, 1981). Laboratory experiments (Stanford and Smith, 1972; El Gharous et al. 1990) used to estimate N mineralization supply, generate useful data about qualitative composition of the organic material and the soil N mineralization potential. The soil N mineralization potential is then corrected to soil moisture and temperature and correlated to crop N uptake and/or yield to provide an estimate of the actual amount of N mineralized during a growing season.

The crop fertilizer N requirement is a function of many factors. Among these are residual and mineralizable soil N and those elements of crop and soil management that influence the fraction of total N that is in a readily mineralizable form (Stanford and Smith, 1972; 1976). Crop residue management also affects the availability of N. When crop residues low in N are incorporated, there is a net immobilization of residual mineral N remaining in the soil after harvest. After immobilization, mineralization of the previously immobilized N occurs, resulting in a net release of N (Allison and Klein, 1962). When fertilizer N is added to soil, a portion is immobilized, but the mineralization rate of the recently immobilized fertilizer N is greater than that of indigenous organic N for the same period (Freney and Simpson, 1969). Studies on N interactions with cropping and fertilizer practices are needed to establish crop N requirement and to determine management practices that promote the efficient use of N.

The objectives of this research were (i) to determine the N mineralization potential of soils that have been cultivated to continuous wheat and cotton for more than twenty years, (ii) to determine the effect of long-term N fertilizer applications on the N supplying capacity of soils and (iii) to evaluate the relationship of N_0 and crop N uptake or crop yield.

Materials and Methods

Soil

Soil samples were collected from five long-term soil fertility experiments in Oklahoma. Four of these experiments were continuous wheat and one was continuous cotton. Continuous wheat experiment locations included two at Stillwater, one at Lahoma, and one at Altus. The long term continuous soil fertility experiment on cotton was located at Altus. The Stillwater experiments were initiated in 1892 and 1968 for Magruder Plots and a NPK study (No. 222) respectively on a Kirkland silt loam soil (fine, mixed, Thermic Udertic Paleustolls); the Lahoma experiment (No. 502) was initiated in 1970 on Grant silt loam soil (fine-silty, mixed, Thermic Udic Argiustolls), and the Altus experiments (Nos. 406 and 439) were initiated in 1964 and 1972 for continuous wheat and continuous cotton respectively on Tillman clay loam soil (Fine, mixed, thermic, typic paleustolls . All experiments have different N rates combined with different P and K rates as treatments except the Magruder Plots where treatments are check plot, barnyard manure, P, N plus P, N plus P plus K, and N plus P plus K plus lime. The average manure application rate was 2.52 tons per hectare every four years which supplied four times the annual N rate that was supplied by commercial fertilizer in other N treatments. Nitrogen was applied annually at a rate of 34 kg N ha^{-1} as ammonium nitrate through 1967 at which time the annual rate was increased to 67 kg N ha^{-1} applied in fall. Phosphorus and K were applied at the annual rate of 33 kg ha^{-1} as superphosphate and potash respectively. Lime was applied when soil analysis indicate a pH of 5.5 or less. Selected chemical characteristics of the soils studied are shown in Table 1.

Soil pH was measured by a pH electrode using a 1:2(w/v) soil water suspension ratio. Total N and organic C were determined by Kjeldahl (Bremner, 1965) and Walkley and Black procedure (Allison, 1965), respectively.

The treatments selected for these studies were different levels of N at constant P and K levels in all experiments but the Magruder plots where all treatments were considered (Table 2).

A soil probe was used to remove 0.05 m diameter core samples to a depth of 0.15 m from each treatment in all experiments cited above. The samples were air dried after checking for carbonate (using 10% HCl solution), ground and stored for further analyses.

Incubation

The N mineralization procedure followed the method used by Stanford and Smith (1972). Triplicate samples of 30 g of air dried soil from each treatment were uniformly mixed with an equal amount of pre-acid washed sand, moistened with distilled water and gently mixed. The mixtures were transferred to a 250 ml Corning disposable sterile filter/storage system and the soil was covered with a thin (0.25 cm) glass wool pad to avoid dispersing the soil when solutions were poured into the tubes.

Mineral N initially present was removed by leaching with 100 ml 10 mM $CaCl_2$ in 10 to 20 ml increments, followed by 25 ml of N-free nutrient solution (2.0 mM $CaSO_4$; 2.0 mM $MgSO_4$; 5.0 mM $Ca(H_2PO_4)_2.H_2O$; and 2.5 mM K_2SO_4). Excess water was removed under vacuum (0.02 MPa). The tubes were then incubated at 35±1°C. After two weeks, mineral N was recovered by leaching with 100 ml of 10 mM $CaCl_2$ and 25 ml of N-free nutrient solution, followed by applying suction as described above. The sample-sand mixtures were returned to the incubator for periods of 2, 4, 6, 8, 10, and 12 weeks cumulative, with intermittent leaching of mineral N. Optimum soil water content was maintained at approximately 0.02 MPa throughout the incubation period.

Mineral N Determination

The leachates were then immediately analyzed for NH_4-N and NO_3-N plus NO_2-N colorimetrically using the Lachat continuous flow automated Ion Analyzer (Lachat, 1988 and 1991).

Estimation of N Mineralization Potential

The N mineralization potential and the decomposition rate constant were determined from the first-order exponential model to describe net N mineralization proposed by Stanford and Smith (1972).

$$N = N_0(1 - e^{-kt})$$

where N is mineralized nitrogen in time t, N_0 is the N mineralization potential and k is the decomposition rate constant. A nonlinear least-squares iterative regression program was used to evaluate N_0 and k (Wilkinson, 1990).

Results and Discussion

Effect of N management and cropping systems on mineral N

Cumulative N mineralization during the incubation period exhibited the same general trend for all experiments (Fig. 1). The rate of mineralization was rapid during the first 4 to 6 weeks and then declined with the length of the incubation period.

Nitrogen fertilizer applications resulted in a significant increase in mineralization of soil N for all sites. The percent increase with respect to check plot varied from 27 to 76% (Table 3). The increase in mineralization of N due to fertilizer management was more related to soil type (texture) and climatic conditions than to crop management (Campbell and Souster, 1982). It was also observed that chemical fertilizer N enhance the mineralization of soil organic matter more than the farmyard manure.

Effect of fertilizer N and cropping systems on N_0 and k

The N mineralization potential (N_0) of soils cropped to continuous wheat ranged from 14 to 81 mg kg^{-1} of soil in check plots and from 25 to 122 mg kg^{-1} of soil in plots receiving N fertilizer (Table 4). The highest N_0 was obtained at Lahoma in experiment 502, and the lowest one was obtained at Altus in experiment 406. In soils cropped to continuous cotton, N_0 was 57 mg kg^{-1} of soil in check plots and 89 mg kg^{-1} of soil in plots receiving fertilizer N (Table 4). These values are lower than the ones reported by El Gharous et al. (1990) but fall within the range reported by Torben et al. (1988). The low N_0 values obtained in this study and that of Torben et al (1988) are probably due to the nature of soils studied. Both studies utilized long term experiments (20 to 100 years old cropping systems) where organic matter decline had probably reached a steady state. In contrast, the soils studied by El Gharous et al. (1990) were farmer's fields with different management practices. In fact the active fraction (N_0/N total) of the soil studied varied from 1.5 to 10%, which was much lower than that reported by El Gharous et al. (1990).

Nitrogen fertilizer increased N mineralization potential in all sites studied, however, this effect was quantitatively different from site to site and apparently was affected by both soil type and crop management. For instance, at Lahoma (experiment 502) and Altus (experiment 406) under continuous wheat the significant increase in N_0 was observed at lower rate of N (45 and 67 kg ha^{-1} for Altus and Lahoma respectively). At Stillwater (experiment 222) under continuous wheat and at Altus (experiment 439) under continuous cotton the effect of N fertilizer was not observed until the rate of 134 kg N ha^{-1} (Table 4). The observed increase in N_0 due to N fertilizer over a check plot was about 37% at all location except experiment 406 at Altus where the increase was 78%. Experiment 406 had the lowest N_0 compared to the others but grain yield and grain N uptake were comparable to the ones obtained at other locations. This is probably due to the significant NO_3-N accumulation in the soil profile of this experiment (Westerman et al. 1993).

Yield responses to fertilizer N applications enhance the return of organic substrate in the form of shoot, root, and exudate material returned to the soil and probably explain the positive effect of fertilizer N on N_0. The positive effect of fertilizer N on N mineralization was also reported by others (Haas et al., 1957; El Haris et al., 1983; Fisher et al., 1987). Fertilizer N serves a dual function by supplying both plants and microorganisms with their N needs. Nitrogen in some form is, however, needed for the decomposition of organic matter by heterotrophic soil microorganisms.

Nitrogen mineralization potential was also increased by the application of manure and lime in combination with chemical fertilizer applications in the Magruder Plots (Table 4). The increase in N_0 with respect to the check was 39 and 21% for manure and NPK plus lime applications respectively. The positive effect of lime may be attributed to its effect on soil pH and thus on the activity of soil microorganisms responsible of organic matter decomposition (Awad and Edwards, 1977; Edmeades et al. 1981).

The various sites exhibited large differences in N mineralization potential even when rotations and treatments were comparable. These differences did not appear to be attributed to soil organic N or soil organic carbon content but mainly is a reflection of the variations in environmental factors, such as moisture and temperature, which exert a strong influence on decomposition rates (Parton et al. 1987).

The decomposition rate constant (k) was also affected by fertilizer N application, however, the effect was not consistent at all sites (Table 5). At Lahoma (experiment 502) under continuous wheat, the decomposition rate decreased with the application of 45 kg N ha^{-1}. The decomposition rate constant (k) increased significantly with the application of manure and NPK plus lime in the Magruder plot and in soils with increasing N rate under continuous cotton (experiment 439). It was not affected by N fertilizer in continuous wheat cropping system at Stillwater (experiment 222) (Table 5).

These discrepancies in response to N fertilizer may be attributed to a number of factors: the variation in environmental factors, such as moisture and temperature, the quantity and quality of organic matter, to soil type and soil physical and chemical characteristics (Parton et al., 1987; Janzen et al. 1992).

Relationship between N_0 and grain yield and grain N uptake

Efficient use of N fertilizer in crop production requires the correct N fertilizer rate for a crop. This, in turn, requires the knowledge of the amount of N needed by the crop and the amount of N supplied by the soil. In this study both linear and quadratic regression analyses were used in wheat grain to correlate both average wheat grain yield and average grain N uptake at different locations to both N mineralization potential (N_0) and the product of N_0 and the decomposition rate (N_0k). The linear and the quadratic models for each site and all sites combined are shown in Tables 6 and 7. The results showed that the relationship between N_0 and grain N uptake was not the same for all the experiments. For instance, at Altus (experiment 406) and at Lahoma (experiment 502) the best fit was obtained by the quadratic equation but at Stillwater (experiment 222) N uptake was linearly related to both N_0 and N_0k. Grain yield, on the other hand, was best estimated by the quadratic equation (Table 6). The analyses of check plots (no N fertilization) and plots receiving N fertilizer separately have shown that the quadratic regression equation fit best the data from plots receiving N fertilizer and the linear regression those from check plots (Table 7). Using these models we estimated the amount of N mineralized in soils to be 50% of the N mineralization potential (N_0). Based on this hypothesis, the amount of N coming from the soil through mineralization of organic matter would be 30, 40 and 7 mg kg^{-1} of soil or 78, 104 and 18 kg N ha^{-1} (0-15 cm) in check plots and 44, 60 and 13 mg kg^{-1} of soil or 114, 156 and 34 kg N ha^{-1} (0-15 cm) in plots receiving the highest N rate for experiment 222, 502 and 406 respectively. The high values of estimated

N mineralized in soils of experiments 222 and 502 may be explained by the low N fertilizer recovery reported by Raun et al. (1993). These authors found that the percent fertilizer N in grain was less than 20% in experiment 222 and less than 50% in experiment 502.

The quadratic equations were used to determine the N mineralization potential at which optimum grain yield or N uptake occurred, the first derivative of the quadratic equation was set equal to zero and solved. Solutions for this calculation were 164, 27 and 190 mg kg^{-1} for N uptake and 147, 21.5 and 90 mg kg^{-1} for grain yield for experiment 502, 406 and 222 respectively. These values were found to be 101 and 17 mg kg^{-1} of soil using a linear plateau analysis for experiment 502 and 406 respectively. The estimates for all sites combined were about 100 mg kg^{-1} of soil for both N uptake and grain yield. When all sites were combined, both the linear and the quadratic relationships were found to be significant for both grain yield and N uptake (Fig.2 and 3). However, the quadratic model accounted for more of the variability when compared to the linear model. These models were further improved when the data of experiment 406 were removed (Fig. 4 and 5). Experiment 406 had a lower N mineralization potential with about the same range of N uptake and grain yield when compared to the other experiments. This has caused the model to be shifted to the right.

The use of the product N_0 and k instead of N_0 in the regression analyses did improve the coefficient of determination of all equations discussed above but this improvement did not account for more variability.

The relationship between grain yield or crop N uptake with N_0 or N_0k found in this study were also reported by other authors (Gasser and Jephcott, 1964;

Robinson, 1968a,b). These relationships emphasize once more the importance of N supplied by the soil in crop production and the necessity of taking it into consideration when making N fertilizer recommendations. However, this relationship does not solve the problem of estimating the actual amount of N supplied by the soil but could be used to estimate the amount of N that might be mineralized from soil organic matter if a long term average grain yield or N uptake is available.

Summary and Conclusions

The Grant silt loam soil was found to have high potential of mineralizing soil organic N compared to Kirkland silt loam and Tillman clay loam. The Tillman clay loam, on the other hand, had the lowest N mineralization potential. The long term N fertilization application has increased the capacity of mineralizing soil organic N in all soil types and cropping systems.

The data of this research also showed that soil N mineralization potential was linearly related with grain N uptake or grain yield when no N fertilizer was applied. However, when N fertilizer was applied, this relationship became quadratic.

The quantitative estimates of N mineralized in soil reported here will provide a valid basis for the estimates of annual mineral N produced by the soil through mineralization in continuous wheat cropping system under Oklahoma conditions. However, and due to the complexity of the steps that N goes through in the soil (N cycle) more investigations are required.

References

Allison, F.E., and C.J. Klein. 1962. Rates of immobilization and release of nitrogen following additions of carbonaceous material and nitrogen to soils. Soil Sci. 93:383-386.

Allison, L.E. 1965. Organic carbon. In C.A. Black et al. (ed) Methods of soil analysis. Part 2. Agronomy 9:1367-1378.

Awad, A.S., and D.G. Edwards. 1977. Reversal of adverse effects of heavy ammonium sulfate application on growth and nutrient status of Kikuyu pasture. Plant and Soil 48:169-183.

Bremner, J.M. 1965. Total nitrogen. In C.A. Black et al. (ed) Methods of soil analysis. Part 2. Agronomy 9:1149-1176.

Campbell, C.A., and W. Souster. 1982. Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils to cropping. Can. J. Soil Sci. 62:651-656.

Edmeades, D.C., M. Judd, and S.V. Sarathchandra. 1981. The effect of lime on nitrogen mineralization as measured by grass growth. Plant and Soil 60:177-186.

El Gharous, M., R.L. Westerman, and P.N. Soltanpour. 1990. Nitrogen mineralization potential of arid and semiarid soils of Morocco. Soil Sci. Soc. Am. J. 54:438-443.

El Haris, M.K., V.L. Cochran, L.F. Elliott, and D.F. Bezdicek. 1983. Effect of tillage, cropping, and fertilizer management on soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 47:1157-1161.

Fisher, F.M., L.W. Parker, J.P. Anderson, and W.G. Whitford. 1987. Nitrogen mineralization in a desert soil: Interacting effects of soil moisture and nitrogen fertilizer. Soil Sci. Soc. Am. J. 51:1033-1041.

Freney, J.R., and J.R. Simpson. 1969. The mineralization of nitrogen from some organic fractions in soil. Soil Biol. Biochem. 1:241-251.

Gasser, J.K.R., and B.M. Jephcott. 1964. Soil nitrogen: VIII. Some factors affecting correlations between measurements of soil-N status and crop performance. J. Sci. Food Agric. 15:422-428. Cited by Goh, K.M., and R.J. Haynes. 1986. Nitrogen and agronomic practice. IN R.J. Haynes (ed.) Mineral nitrogen in the plant soil system. Academic Press Inc.

Haas, H.J., C.E. Evans, and E.F. Miles. 1957. Nitrogen and carbon changes in great plains soils as influenced by cropping and soil treatments. USDA Tech. Bull. No.1164.

Janzen, H.H., C.A. Campbell, S.A. Brandt, G.P. Lafond, and L.Townley-Smith. 1992. Light-fraction organic matter in soils from long-term crop rotations. Soil Sci. Soc. Am. J. 56:1799-1806.

Lachat. 1988. Ammonia (Phenolate) in 2M KCl soil extracts. QuikChem Method No. 12-107-06-1B. Lachat Instrument, 6645 West Mill Road, Milwaukee, WI 53218 USA.

Lachat. 1991. Nitrate and Nitrite in 2M KCl soil extracts. QuikChem Method No. 12-107-04-1A. Lachat Instrument, 6645 West Mill Road, Milwaukee, WI 53218 USA.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in great plain grasslands. Soil Sci. Soc. Am. J. 51:1173-1179.

Paul, A.E., and N.G.Juma. 1981. Mineralization and immobilization of soil nitrogen by microorganisms In F.J.Stevenson (ed.). Nitrogen in Agricultural Soils. American Society of Agronomy, Madison, WI. 567-604.

Raun, W.R., R.K. Boman, G.V. Johnson, and R.L. Westerman. 1993. Total nitrogen and organic carbon in the soil profile following 20 years of continuous wheat production in three long-term soil fertility experiments. Soil fertility research highlights 1993. Agronomy Department Oklahoma State University.

Robinson, J.B.D. 1968a. A simple available soil nitrogen index. I Laboratory and a greenhouse studies. J. Soil Sci. 19:269-279.

Robinson, J.B.D. 1968b. A simple available soil nitrogen index. II Field crop evaluation. J. Soil Sci. 19:280-290.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potential of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., and S.J. Smith. 1976. Estimating potentially mineralizable soil nitrogen from a chemical index of soil nitrogen availability. Soil Sci. 122:71-76.

Torben, A.B., J. Schnürer, and T. Rosswall. 1988. Microbial biomass as a fraction of potentially mineralizable nitrogen in soils from long-term field experiments. Soil Biol. Biochem. 20:447-452.

Westerman R.L.,R.K.Boman, W.R. Raun and G.V. Johnson. 1993. Accumulation of ammonium-N and nitrate-N in soil profiles of four long-term continuous wheat experiments. (in press, Agron.J.)

Wilkinson, L.S. 1990. The system for Statistics. SYSTAT Inc., Evanston, IL.

Table 1. Soil Chemical Properties as Affected by Fertilizer N at Different Locations.

N (kg ha^{-1})	pH	TOTAL N	ORGANIC C	CEC ($cmol_c$ kg^{-1})
		(g kg^{-1})	(g kg^{-1})	
		Experiment 222		
0	6.07	0.68	7.57	22.67
45	5.92	0.63	7.66	25.57
90	5.85	0.75	8.01	26.75
134	5.41	0.80	8.77	25.46
		Experiment 502		
0	5.43	0.97	6.04	9.22
22	5.36	0.95	6.06	
45	5.23	0.96	6.35	
67	5.18	0.99	6.59	
90	5.11	1.01	6.38	
112	5.05	1.10	6.57	8.00
		Experiment 406		
0	7.50	0.60	8.14	26.44
45	7.45	0.54	8.28	27.53
90	7.17	0.67	8.45	29.84
134	6.61	0.65	7.73	24.89
179	6.58	0.70	8.28	26.26
		Experiment 439		
0	7.70	0.81	9.00	30.60
45	7.68	0.77	8.21	29.68
90	7.52	0.66	9.29	30.60
134	7.33	0.67	8.61	33.41
179	7.32	0.68	9.26	25.06
224	7.11	0.74	9.14	24.68
		Magruder Plots		
Check	5.06	0.59	5.05	22.98
Manure	6.31	0.84	8.87	29.87
P	5.10	0.60	5.13	21.91
NP	4.67	0.77	7.39	26.00
NPK	4.82	0.87	9.90	23.51
NPK+lime	5.36	0.77	10.29	22.75

Table 2. Nitrogen Treatments Used for the Incubation Study.

Location	**Crops**	**N (Kg ha^{-1})**	**P (Kg ha^{-1})**	**K (Kg ha^{-1})**
Experiment 222	Wheat	0, 45, 90, and 134.	29	38
Magruder Plots	Wheat	0, 67 (manure, fertilizer N)	33	33
Experiment 502	Wheat	0, 22, 45, 67, 90, and 112.	20	56
Experiment 406	Wheat	0, 45, 90, 134, and 179.	20	38
Experiment 439	Cotton	0, 45, 90, 134, 179, and 224.	45	90

Table 3. Percent Increase in Mineral N Due to Fertilizer N.

Soil Type	**Experiment**	**Crop**	**% Increase**
KIRKLAND	Stillwater 222	WHEAT	46
KIRKLAND*	Magruder Plots	WHEAT	27
GRANT	Lahoma 502	WHEAT	33
TILLMAN	Altus 406	WHEAT	75
TILLMAN	Altus 439	COTTON	76

* Farmyard Manure

Table 4. Effect of Fertilizer N on N Mineralization Potential (N_0) in Soils Cropped to Continuous Wheat and Cotton.

Experiment 222		**Experiment 502**		**Experiment 406**	
N ($kg\ ha^{-1}$)	**N_0 ($mg\ kg^{-1}$)**	**N ($kg\ ha^{-1}$)**	**N_0 ($mg\ kg^{-1}$)**	**N ($kg\ ha^{-1}$)**	**N_0 ($mg\ kg^{-1}$)**
0	64.81	0	81.36	0	14.18
45	63.38	22	78.74	45	16.18
90	76.57	45	97.00	90	18.93
134	88.96	67	108.59	134	18.98
		90	121.76	179	25.26
		112	112.03		
LSD (5%)	**14.70**		**23.60**		**1.86**

Magruder Plots		**Experiment 439**	
N ($kg\ ha^{-1}$)	**N_0 ($mg\ kg^{-1}$)**	**N ($kg\ ha^{-1}$)**	**N_0 ($mg\ kg^{-1}$)**
Check	15.27	0	57.75
Manure	21.25	45	61.44
P	15.26	90	50.59
NP	10.86	134	75.52
NPK	9.98	179	89.64
NPK+lime	18.45	224	79.93
LSD (5%)	**2.97**		**6.92**

Table 5. Effect of Fertilizer N on the Decomposition Rate Constant in Soils Cropped to Continuous Wheat and Cotton.

Experiment 222		Experiment 502		Experiment 406	
N ($kg\ ha^{-1}$)	**k ($week^{-1}$)**	**N ($kg\ ha^{-1}$)**	**k ($week^{-1}$)**	**N ($kg\ ha^{-1}$)**	**k ($week^{-1}$)**
0	0.137	0	0.163	0	0.189
45	0.135	22	0.163	45	0.186
90	0.160	45	0.119	90	0.150
134	0.159	67	0.137	134	0.196
		90	0.136	179	0.188
		112	0.145		
LSD (5%)	**0.029**		**0.058**		**0.026**

Magruder Plots		Experiment 439	
N ($kg\ ha^{-1}$)	**k ($week^{-1}$)**	**N ($kg\ ha^{-1}$)**	**k ($week^{-1}$)**
Check	0.150	0	0.093
Manure	0.158	45	0.071
P	0.204	90	0.091
NP	0.182	134	0.107
NPK	0.144	179	0.113
NPK+lime	0.149	224	0.112
LSD (5%)	**0.013**		**0.019**

Table 6. Linear and Quadratic Models to Estimate Grain Yield and Grain N Uptake from N_0 at Different Locations.

MODELS	P value	RMSE
Experiment 222		
Uptake = $0.758*N_0-0.0020*N_0^2$	0.0001	9.967
Grain Yield = $0.416*N_0-0.0023*N_0^2$	0.0001	2.340
Uptake = $0.604*N_0$	0.0001	9.870
Grain yield = $0.233*N_0$	0.0001	3.425
Experiment 502		
Uptake = $0.786*N_0-0.0024*N_0^2$	0.0001	7.467
Grain yield = $0.398*N_0-0.0014*N_0^2$	0.0001	2.365
Uptake = $0.522*N_0$	0.0001	10.510
Grain yield = $0.246*N_0$	0.0001	4.926
Experiment 406		
Uptake = $4.086*N_0-0.0758*N_0^2$	0.0001	6.999
Grain yield = $1.870*N_0-0.0435*N_0^2$	0.0001	2.049
Uptake = $2.538*N_0$	0.0001	9.208
Grain yield = $0.982*N_0$	0.0001	4.075

Table 7. Linear and Quadratic Models to Estimate Grain Yield and Grain N Uptake from N_0.

MODELS	P value	RMSE
All sites combined		
Uptake = $1.171*N_0-0.0058*N_0^2$	0.0001	21.193
Grain yield = $0.482*N_0-0.0022*N_0^2$	0.0001	7.952
Uptake = $0.599*N_0$	0.0001	25.174
Grain yield = $0.261*N_0$	0.0001	9.538
All sites combined excluding experiment 406		
Uptake = $0.788*N_0-0.0024*N_0^2$	0.0001	8.454
Grain yield = $0.341*N_0-0.0009*N_0^2$	0.0001	3.310
Uptake = $0.548*N_0$	0.0001	10.664
Grain yield = $0.242*N_0$	0.0001	4.261
Check plots (no N fertilization)		
Uptake = $0.484*N_0$	0.0002	16.495
Grain yield = $0.248*N_0$	0.0001	7.578
Uptake = $1.539*N_0-0.0144*N_0^2$	0.0001	12.279
Grain yield = $0.698*N_0-0.0061*N_0^2$	0.0001	6.023
Fertilized Plots		
Uptake = $1.303*N_0-0.0067*N_0^2$	0.0001	21.086
Grain yield = $0.514*N_0-0.0024*N_0^2$	0.0001	8.015
Uptake = $0.617*N_0$	0.0001	26.854
Grain yield = $0.263*N_0$	0.0001	10.047

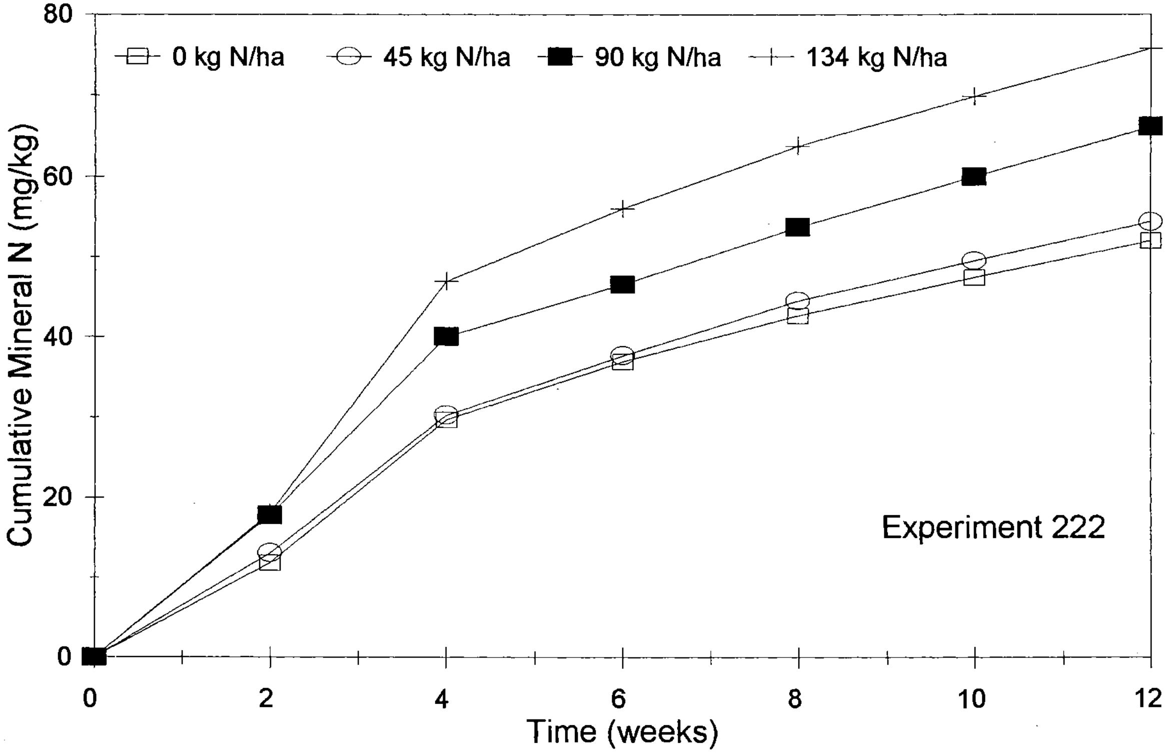
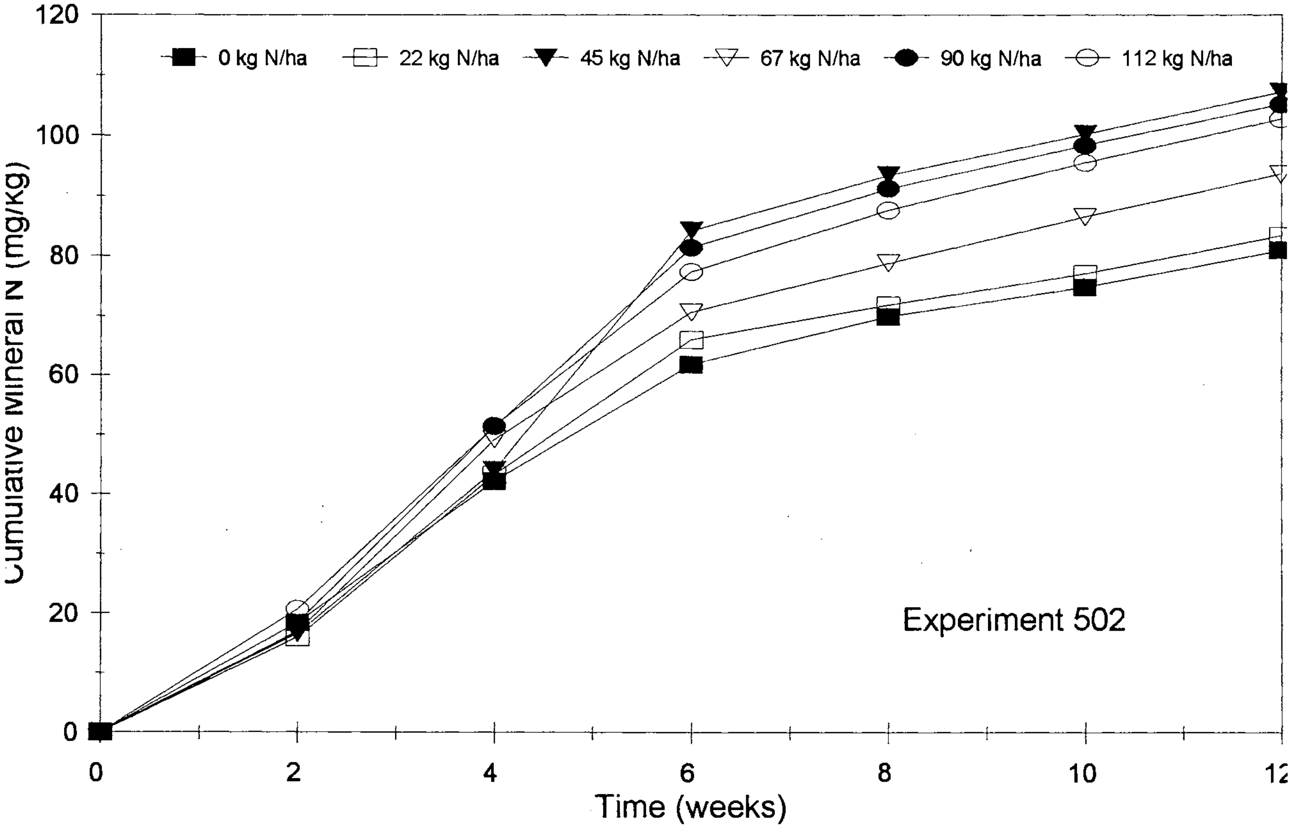


Fig. 1. Effect of Fertilizer N on N Mineralized at Different Locations.



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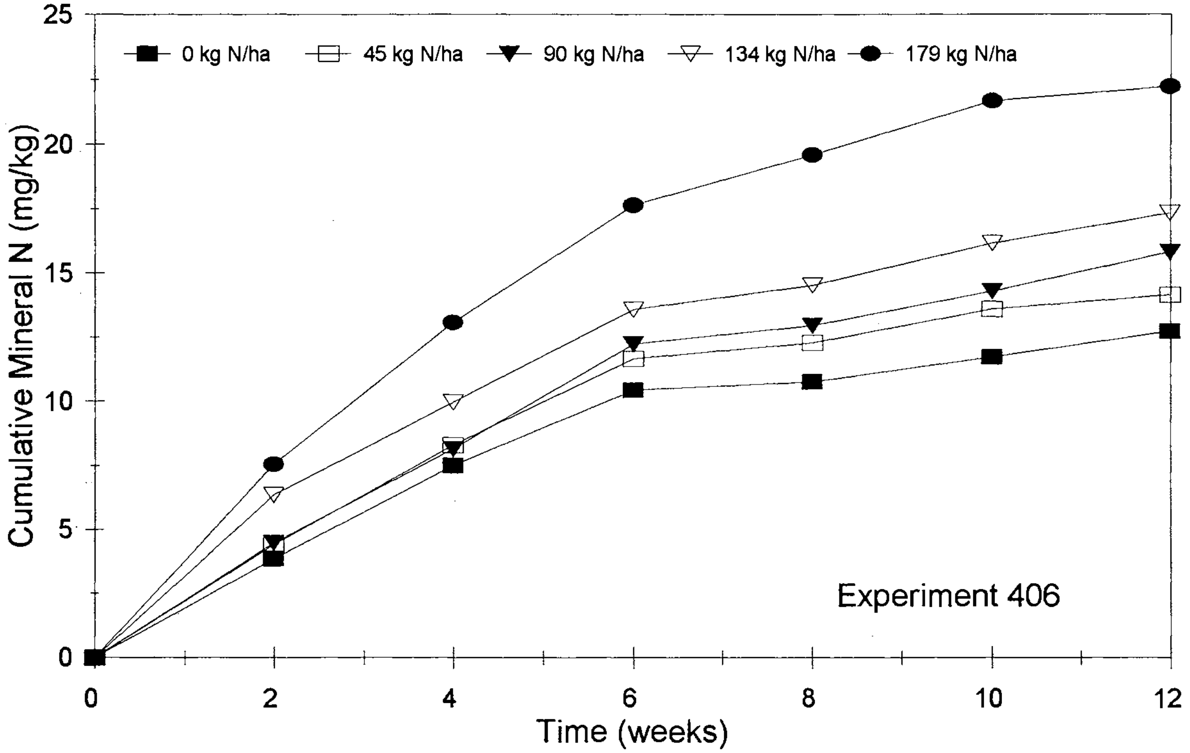

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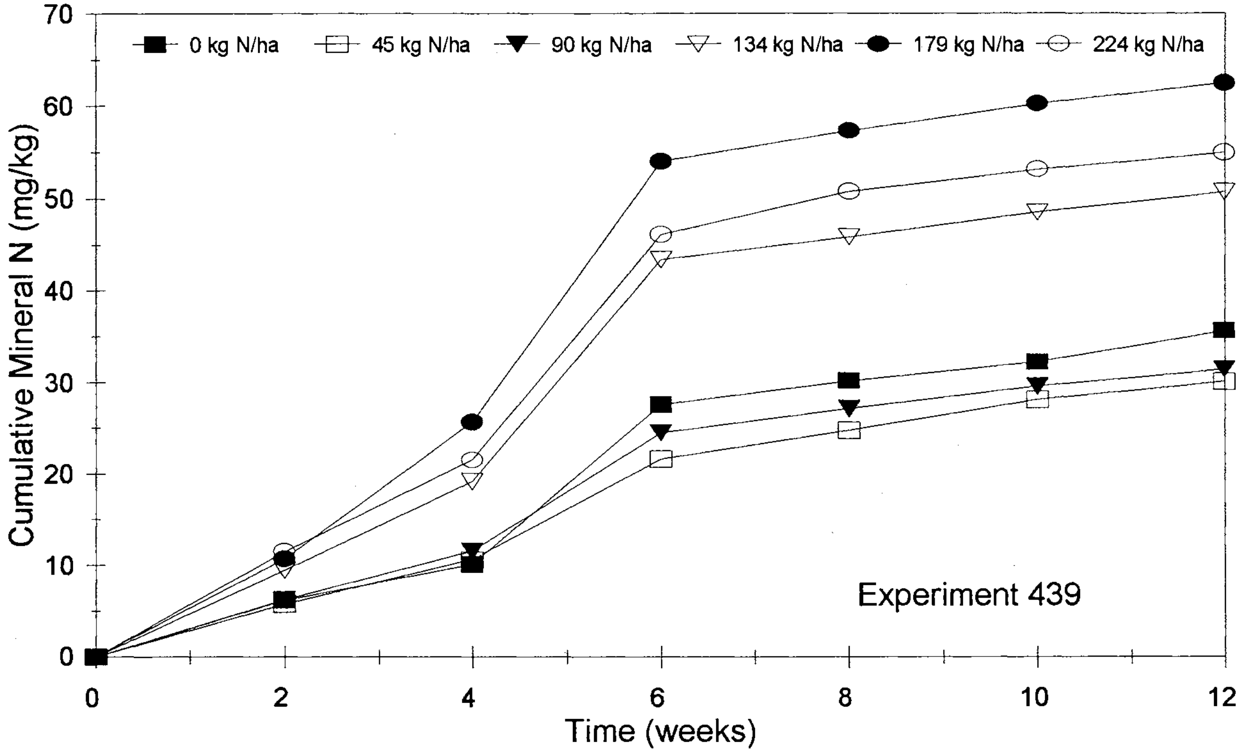

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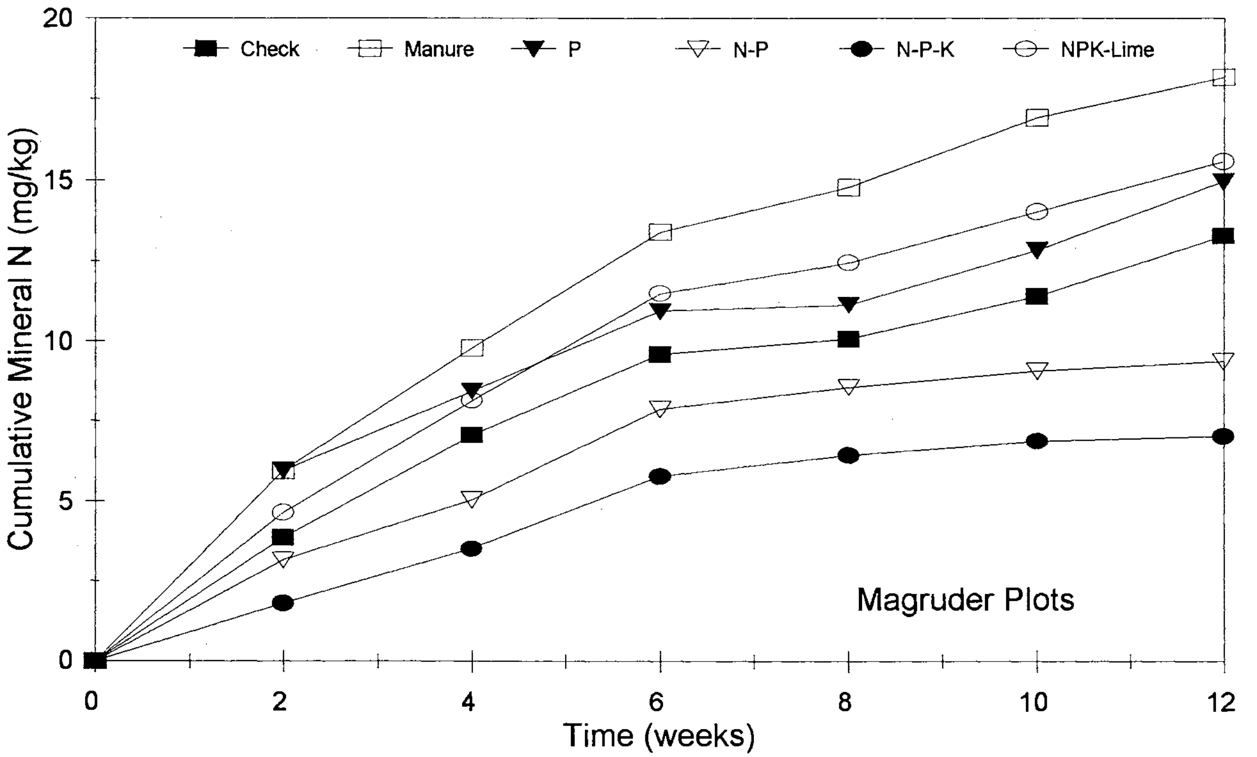

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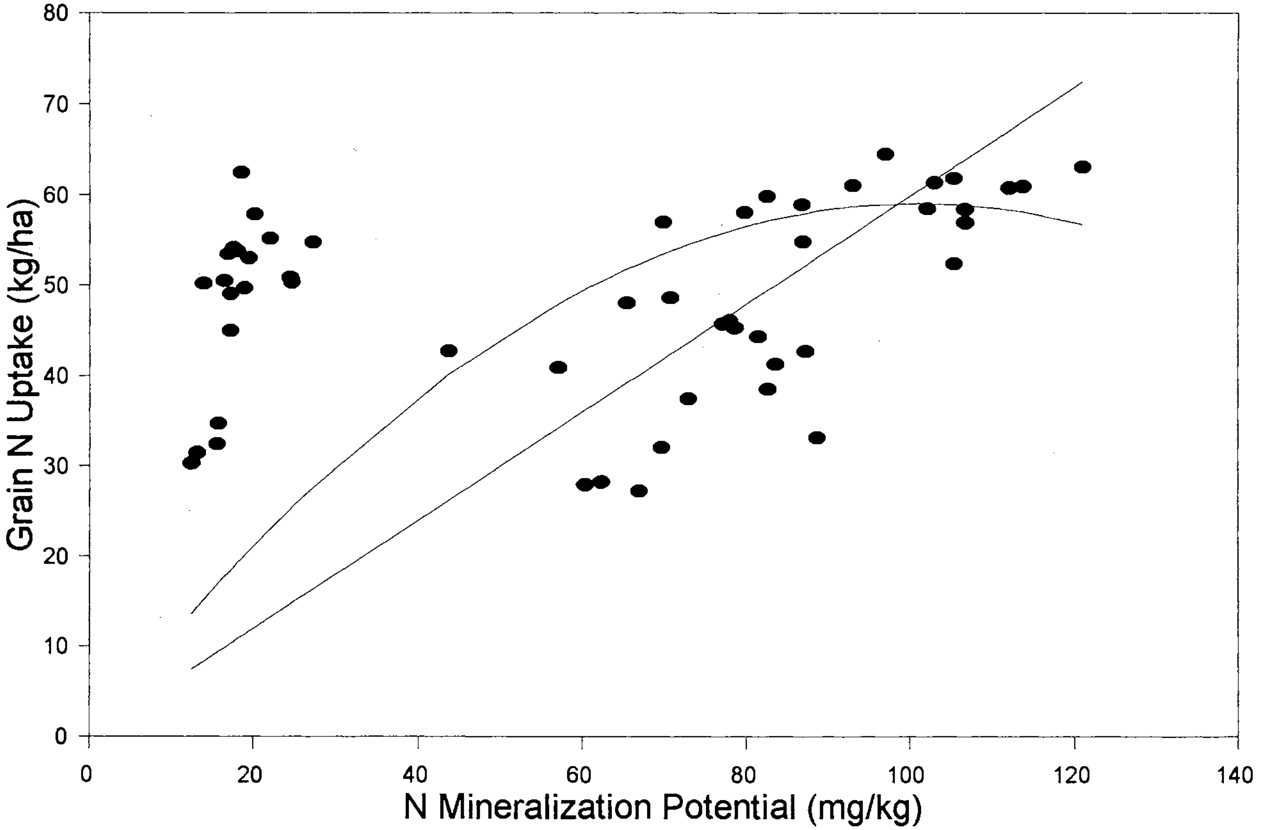


Fig. 2. N Mineralization Potential and Grain N Uptake Relationship in All Experiments Combined

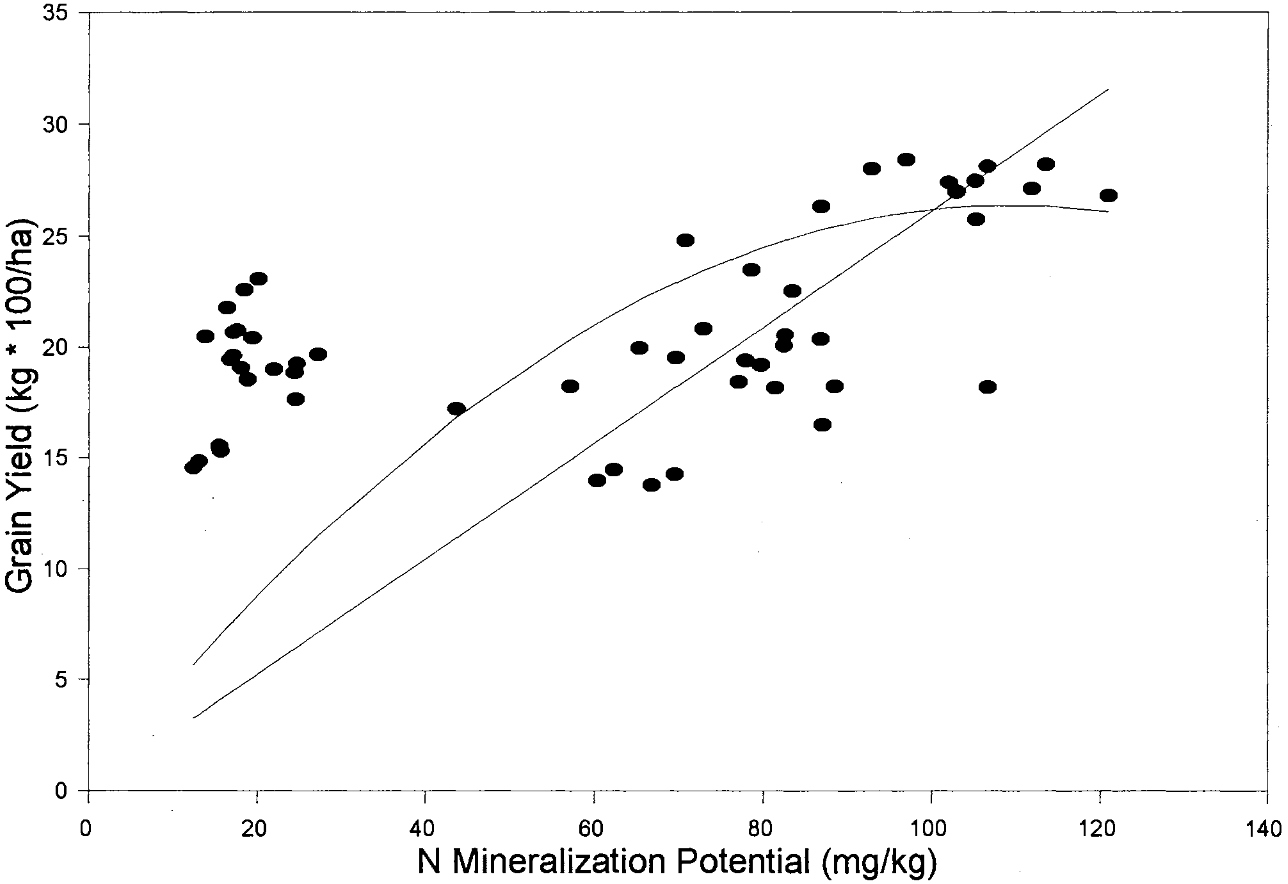


Fig. 3. N Mineralization Potential and Grain Yield Relationship in All Experiments Combined.

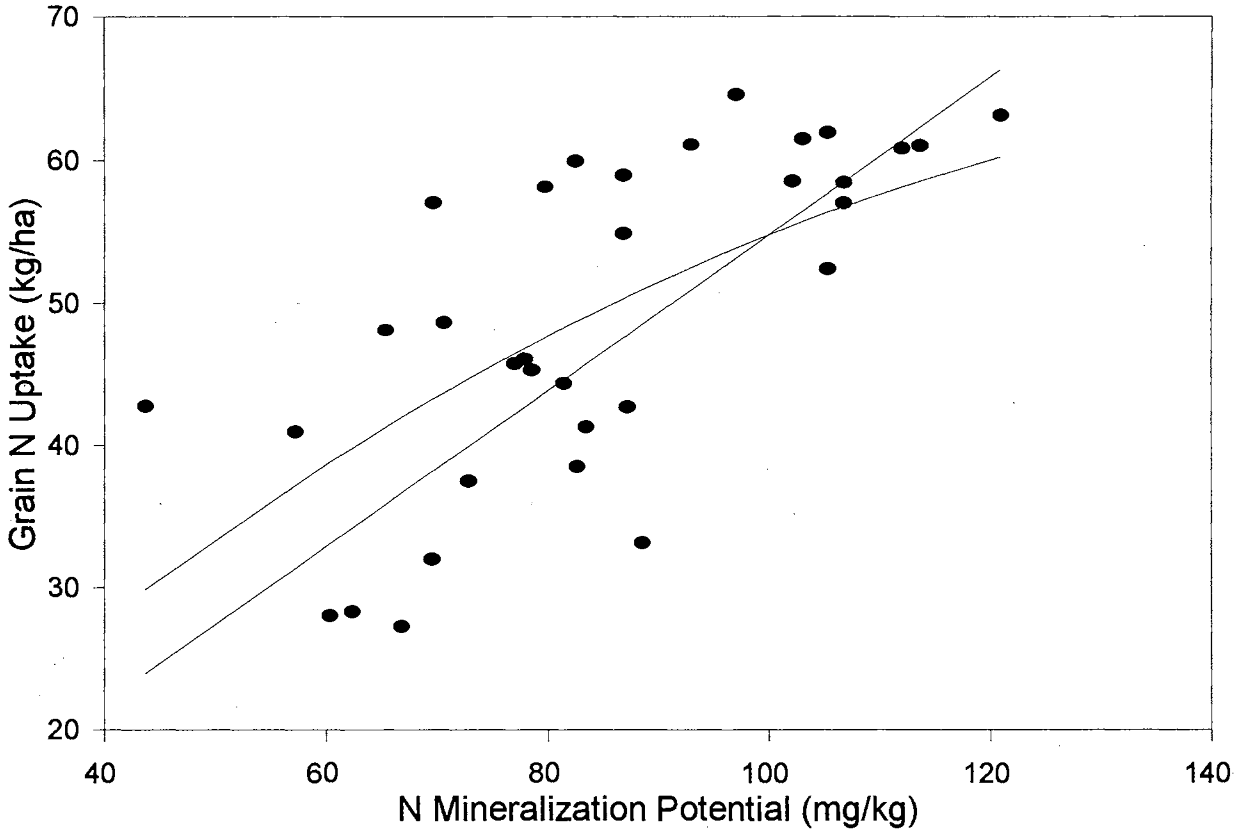


Fig. 4. N Mineralization Potential and Grain N Uptake Relationship in Experiments 502 and 222 Combined.

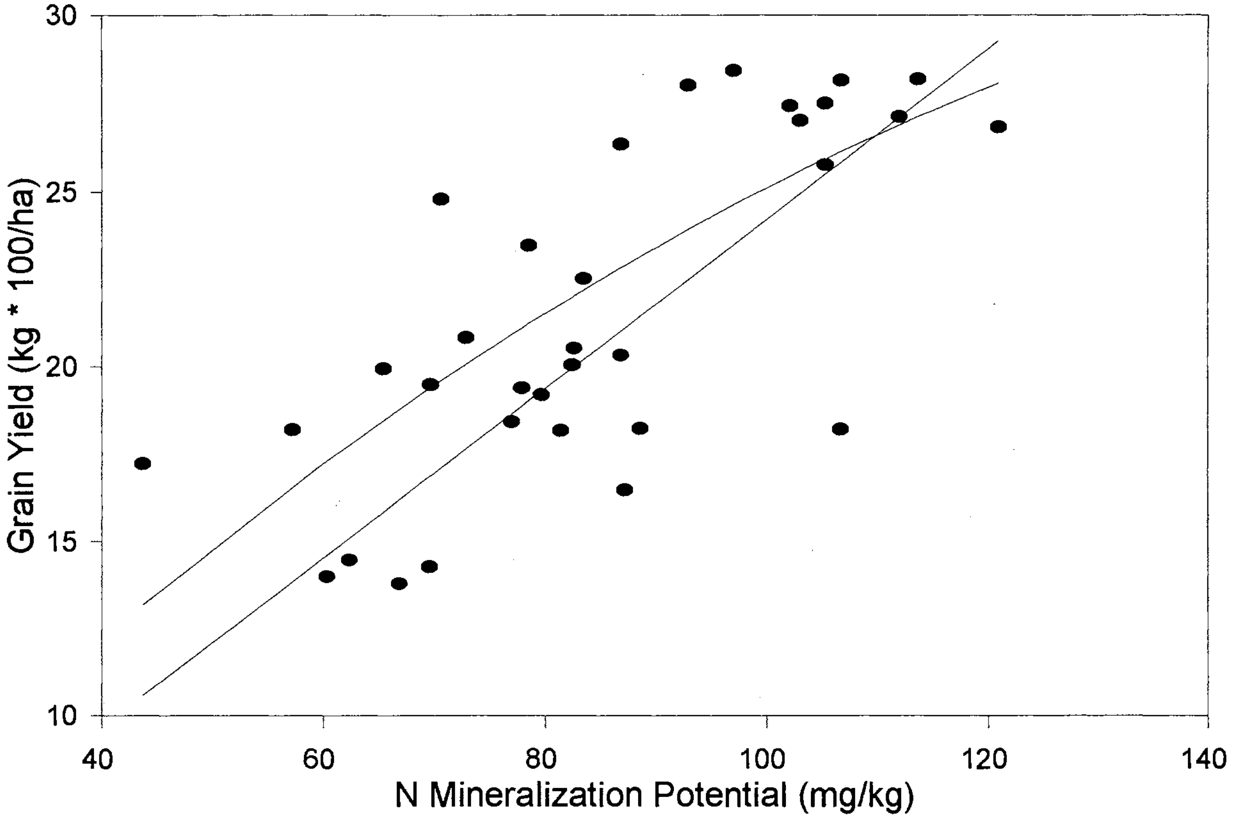


Fig. 5. N Mineralization Potential and Grain Yield Relationship in Experiment 502 and 222 Combined.

CHAPTER IV

POTENTIAL NITROGEN SUPPLYING POWER OF SOILS AT DIFFERENT DEPTHS OF LONG TERM FERTILITY EXPERIMENTS

POTENTIAL NITROGEN SUPPLYING POWER OF SOILS AT DIFFERENT DEPTHS OF LONG TERM FERTILITY EXPERIMENTS

Abstract

Development of good management practices for N use should increase crop production and reduce groundwater pollution. Nitrogen mineralization kinetics of different soil types have been studied mainly in surface soils. However, the contribution of N mineralized at lower depth to soil inorganic N in the soil profile may be significant. The objectives of this study were to determine N mineralization potential (N_0) at different soil depths, to evaluate the contribution of N supplied at different soil layers to mineral nitrogen (N) of the whole root zone and to evaluate the long-term effect of N fertilizer on both N_0 and the decomposition rate constant (k) at lower depths. Soil samples to a depth of 60 cm subdivided into three horizon of 15 cm each were collected from four long-term continuous wheat and one continuous cotton fertility experiments. Soil samples were then incubated at 35°C for a period of 12 weeks with intermittent leaching of mineral N every two weeks. Nitrogen mineralization potentials and the rate constant of mineralization were estimated by first-order exponential equation.

Nitrogen mineralization potential increased with application of fertilizer N and manure and decreased with depth at all experiments. The effect of fertilizer N was limited to the first 30 cm depth at experiment 222 and experiment 502 (silt loam

soils) but was observed up to 60 cm depth at experiments 406 and 439 (clay loam soils). The lower depths were found to contribute by more than 60% to the total soil mineral N in the profile.

Introduction

Good management practices for N use in crop production are required to protect both the environment and producers' profits. Among these practices is the knowledge of N fertilizer needed to achieve the most profitable yield. Insufficient applications of fertilizer N are costly in lost yields and over application increases the opportunity for fertilizers to end up in non-targeted area. Correct application amounts can be determined through the development of relationships between the nutrient supplying power of the soil, applied N fertilizer and crop yield or crop N uptake. Current fertilizer N recommendation for cereals are based on the level of nitrate N in the top 15 cm of the soil before planting, deep sampling (60 cm) is considered when unusual cropping conditions arise. The assumption is that significant N mineralization from wheat residue and soil organic matter occurs during the summer months prior to planting wheat and is estimated by the pre-plant nitrate test. Nevertheless, the mineralization of soil organic N in both the topsoil and the subsoil continues to occur throughout the growing season and is not accounted for in the pre-plant soil test. Nitrate levels in the subsoil (15-60 cm) represent more than 50% of that present in the topsoil (0-15 cm) calculated for the data of Boman et al. (1993) and Soltanpour et al. (1989). Little information is available regarding N mineralization as a function of depth. Yet, data presented by Cassman and Munns (1980), Powers (1980) and Hadas et al. (1986) indicate that the mineral N released at deeper layers may contribute by more than 40% to the total soil profile mineral N. Also, it was reported that almost all NO_3-N at risk to leaching over the winter period comes from mineralization of soil organic N (MacDonald et al. 1989).

The public concern has lead to the perception that NO_3-N contamination of surface and groundwater is closely related to the large increase in fertilizer N use. This accusation has lead the agricultural scientists to intensify their research on the fate of N fertilizer and the accumulation of NO_3-N in the soil profile and its relationship with ground and surface water contamination.

In this regard, Westerman et al. (1993) reported that the accumulation of NH_4-N and NO_3-N in soil profiles of four long-term winter wheat (Triticum aestivum L.) soil fertility experiments having received annual applications of N fertilizer for more than 18 years was not significant at recommended N rates where near maximum yields were obtained, citing research that showed no increase in residual soil NO_3-N in the soil profile (0-60 cm) when comparing 170 and 400 kg N ha^{-1} over a four year period experiment on corn. The objectives of this study were to determine the potential N supplying power (N_0) of soils at different depths of long-term continuous winter wheat (Triticum aestivum L.) and long-term continuous cotton (Gossypium Hirsutum) soil fertility experiments, to determine the effect of long-term fertilizer N application on N_0 and to evaluate the contribution of deeper soil layers to the N mineralized in the whole soil profile.

Materials and Methods

Five long-term wheat and cotton fertility experiments were sampled to a depth varying from 210 to 300 cm to evaluate the accumulation of NH_4-N and NO_3-N associated with N fertilizer application (Westerman et al. 1993) and to determine the optimum of N rates for maximum grain yield with less soil profile N accumulation (Raun et al. 1993). In this study we used only the top 60 cm to estimate the mineralization potential of soil organic N in the profile. The five experiments are identified as 222, 406, 502, and Magruder Plots for continuous wheat and 439 for continuous cotton. Soil type were Kirkland silt loam (fine, mixed, Thermic Udertic Paleustolls) for experiment 222 and Magruder Plots, Tillman clay loam (fine-mixed thermic Typic Paleustolls) for experiments 406 and 439, and Grant silt loam (fine-silty, mixed, Thermic Udic Argiustolls) for experiment 502. All experiments have different N rates combined with different P and K rates as treatments except the Magruder Plots where treatments are check plot (no fertilizer N added), barnyard manure, P, NP, NPK and NPK plus lime. At Magruder Plots, N was applied annually at a rate of 34 kg N ha^{-1} as ammonium nitrate through 1967 at which time the annual rate was increased to 67 kg N ha^{-1} applied in fall. The average manure application rate was 2.52 tons per hectare every four years. Phosphorus and K were applied at the annual rate of 33 kg ha^{-1} as superphosphate and potash respectively. Lime was applied when soil analysis indicate a pH of 5.5 or less. Selected chemical characteristics of the soils of each experiment are shown in Table 1 (a through e).

Soil pH was measured by a pH electrode using a 1:2(w/v) soil water suspension ratio. Total N and organic C were determined by Kjeldahl (Bremner, 1965) and Walkley and Black procedure (Allison, 1965), respectively.

The treatments selected for this study were different levels of N at constant P and K levels in all experiments but the Magruder plots where all treatments were considered.

Incubation

The N mineralization procedure followed the method used by Stanford and Smith (1972). Triplicate samples of 30 g of air dried soil from each treatment and 30 g of pre-acid washed sand were uniformly mixed, moistened with distilled water and transferred to a 250 ml Corning disposable sterile filter/storage system. The soil was covered with a thin (0.25 cm) glass wool pad to avoid dispersing the soil when solutions were poured into the tubes.

Mineral N initially present was removed by leaching with 100 ml 10 mM $CaCl_2$ in 10 to 20 ml increments, followed by 25 ml of N-free nutrient solution. Excess water was removed under vacuum (0.02 MPa). The tubes were then incubated at $35 \pm 1°C$. After two weeks, mineral N was recovered by leaching with 100 ml of 10 mM $CaCl_2$ and 25 ml of N-free nutrient solution, followed by applying suction as described above. The sample-sand mixture were returned to the incubator for periods of 2, 4, 6, 8, 10, and 12 weeks cumulative, with intermittent leaching of mineral N. Optimum soil water content was maintained at approximately 0.02 MPa throughout the incubation period.

Mineral N Determination

The leachates were then immediately analyzed for NH_4-N and NO_3-N plus NO_2-N colorimetrically using an automated flow injection analysis system (Lachat, 1988 and 1991).

Estimation of N Mineralization Potential

The N mineralization potential and the decomposition rate constant were determined from the first-order exponential model to describe net N mineralization proposed by Stanford and Smith (1972).

$$N = N_0(1 - e^{-kt})$$

where N is mineralized nitrogen in time t, N_0 is the N mineralization potential and k is the decomposition rate constant. A nonlinear least-squares iterative regression program was used to evaluate N_0 and k (Wilkinson, 1990).

Results and Discussion

The Amount of Mineral N Produced during a 12-week Incubation

The amount of N mineralized increased with increasing N rates and decreased with depth (Table 2). The highest amount of mineral N was produced in soils from experiment 502, where 71 mg kg^{-1} of soil was mineralized in check plots (no N fertilization) and 91 mg kg^{-1} in plots receiving 112 kg N ha^{-1} in the top 15 cm. The lowest amount was produced in experiment 406 and was 12 mg kg^{-1} of soil in check plots and 22 mg kg^{-1} in plots receiving 179 kg N ha^{-1} in the surface horizon (15 cm).

The amount of mineral N produced in Magruder Plots was also low in the top 15 cm and ranged from 7 to 18 mg kg^{-1} (Table 2).

The percentage of mineralized N to total organic N ranged from 4 to 9.5% in experiments 222, 502 and 439, and was less than 3% in experiment 406 and Magruder Plots (Table 3). These values can be compared with the estimates by Paul (1984), who reported that the microbial biomass accounted for 4 to 6% of total organic N, whereas the active non-biomass fraction accounts for 6 to 10% of total organic N.

The effect of N fertilization on the amount of mineralizable N agreed with the finding of Doran (1980), and El Haris et al. (1983). Increasing additions of fertilizer N increased the proportion of total N present in the more available form of soil N especially in experiment 439.

The percent of mineralized N to total organic N was also affected by depth. The proportion of total soil N present in the active form decreased by more than 50% to a depth of 60 cm in experiments 222, 502 and 439. In Magruder Plots this decrease was less than 20%, and in experiment 406, we observed no significant changes in this proportion with increasing depth (Table 3).

Cumulative N Mineralization Patterns

The time course of N mineralization obtained in the incubation experiments with intermittent leaching according to the method of Stanford and Smith (1972) for soil samples from experiment 222 at different N rate and different depth is shown in Fig. 1. Soil samples collected from other experiments were very similar to those shown in Fig. 1 and are not shown. Mineral N production was high during the first 6 weeks in the topsoil and during the first 2 to 4 weeks in lower depths in all experiments and declined to low fairly constant rate from then on, resulting in apparently linear increase in total cumulative inorganic N after about 4 weeks. These data agreed with those of Stanford and Smith (1972), Stanford et al. (1974), El Haris et al. (1983), and Cabrera and Kissel (1988a). El Haris et al. (1983) attributed the change in N mineralization rate to the greater amount of readily mineralizable N during the initial incubation period.

The effect of fertilizer N on cumulative mineralized N was significant in the top 15 cm and to some extent in the 15 to 30 cm depth (Table 2). However and below 30 cm depth, the long term fertilizer N application did not affect the 12 weeks cumulative mineral N (Table 2).

Effect of fertilizer N on N_0 and k at different depths

Nitrogen mineralization potential of soils studied (N_0) and the corresponding decomposition rate constant (k) are shown in Table 4 and 5. The effect of fertilizer N on N_0 and k at the top 15 cm depth was discussed in detail earlier in this document. The long-term N fertilizer applications have also increased the N supplying power of soils at lower depths. The statistical analyses showed a significant effect of both N fertilizer and depth on N_0 . It also showed a significant N x depth interaction in experiments 406, 439 and Magruder Plots. This significant interaction restricted interpretation to simultaneous evaluation of both variables. The N x depth interaction in experiments 222 and 502 was not significant. The increase in N_0 due to N fertilizer in experiment 222 was not observed below 134 kg N ha^{-1}, in contrast, N_0 was not significantly affected by N fertilizers in experiment 502. Yet, N_0 decreased significantly with depth in both experiments.

A significant increase in N_0 due to N fertilizer was observed up to a depth of 60 cm in experiment 406, and up to a depth of 45 cm in experiment 439. Both experiment 406 and 439 have the same soil type but different cropping systems, continuous wheat and continuous cotton respectively. Nitrogen fertilizer effect on N_0 at lower depths was more related to soil type than to cropping system. Westerman et al. (1993) in their study on the accumulation of NH_4-N and NO_3-N in soil profiles, reported a significant accumulation of NO_3-N in the soil profile of experiment 406 and no significant accumulation in other experiments. At Magruder Plots, the manure treatment has significantly increased the soil N supplying power to a depth of 45 cm and the effect of NPK plus lime treatment was limited to a depth of 15 cm (Table 4). The limited effect of long-term fertilizer N on N_0 throughout soil profiles observed in this study is, in fact, an evidence of the limited movement of N fertilizer down the soil profiles under Oklahoma conditions.

Nitrogen mineralization potential decreased significantly with depth at all locations. This decrease was quasi linear and ranged from 50% in check plots to about 70% in plots receiving N (Fig. 2). The same results were reported by other authors. A more than 50% decrease in N_0 in the 15 to 30 cm depth and about 30% decrease in the layer below 30 cm depth were calculated from data of Cabrera and Kissel (1988b). El Haris et al. (1983) determined N_0 of soil samples of 5 cm depth to a depth of 15 cm and found that N_0 decreases by 50% with depth in soils sampled in fall and by 33% in soils sampled in spring.

The decomposition rate constant was significantly affected by both N fertilizer and depth. As for N_0 the interaction effect of N fertilizer and depth on k was significant, therefore the interpretation of each variable was within each level of the other variable. For instant, in check plots at all locations, there was no significant difference between k values of the first two horizons (0-15 and 15-30 cm). The k values at depths below 30 cm were significantly smaller than those at the top 30 cm of soil. The decrease in k values with depth was also reported by Cabrera and Kissel (1988b). The application of N fertilizer, however, has masked the depth effect, and the k values were not significantly different from each other at all depths.

The effect of N fertilizer applications on k at different depth was not consistent (Table 5). In experiment 439, k increased with increasing N rates up to 45 cm depth, however in all other experiments, there was no significant effect of N fertilizer on k. The application of manure, on the other hand, decreased the decomposition rate constant significantly up to 45 cm depth. The decomposition rate constant (k) indicates how fast the soil organic N is decomposing. This rate seems to increase with increasing N rate under continuous cotton cropping system and not under continuous wheat cropping system and decreased with the application of manure. These results are, in part, in agreement with those reported by Jenkinson and Johnson (1977) cited by Stevenson (1982) who observed a decrease in soil organic N when fertilizer N and crop residue were added to the soil and an increase in soil N when manure was used instead.

It was concluded that the rate constant of mineralization is a universal value (Stanford and Smith, 1972). But our results, like others (Griffin and Laine, 1983; Hadas et al., 1986; Cabrera and Kissel, 1988b) indicate that k differs within soil profile, among soils, and with fertilizer N applications and crop management.

The product of N_0 and k represents the amount of mineral N a soil can mineralize under optimum conditions of moisture and temperature per week. In this study we used this product to evaluate the mineral N contribution of each soil layer to the total mineral N in the soil profile. The results showed that the proportion of N mineralized in the 15- to 60 cm layer out of 0- to 60 cm layer was very important and in many cases represented more than 60% (Table 6). The ratio of the N contribution of the 0- to 15 cm layer to that of 15- to 30 cm, 30- to 45 cm and 45- to 60 cm layers averaged 1.45, 1.85, and 2.6 respectively. These results are in a good agreement with those reported by Hadas et al. (1986) and Cabrera and Kissel (1988b).

Summary and Conclusions

Long-term N fertilizer application increased N mineralization potential of different soil types under different cropping systems. The effect of fertilizer N was limited to 45 cm depth at all experiments except in Tillman clay loam where it was observed up to 60 cm depth.

The rate constant of mineralization decreased with depth in soils receiving no N fertilizers and in soils with manure applications. The application of N fertilizer, however, did not show a consistent effect on k.

The contribution of deeper soil layers to the mineral N in the whole soil profile was very important and deserves more attention in N fertilizer recommendations.

References

Allison, L.E. 1965. Organic carbon. In C.A. Black et al. (ed) Methods of soil analysis. Part 2. Agronomy 9:1367-1378.

Boman, R.K., W.R. Raun, R.L. Westerman and M.E. Jojola. 1993. Effect of nitrogen rate and timing of application on yield and residual nitrate distribution in winter wheat. Soil Fertility Research Highlights. Agronomy Department, Oklahoma State University.

Bremner, J.M. 1965. Total nitrogen. In C.A. Black et al. (ed) Methods of soil analysis. Part 2. Agronomy 9:1149-1176.

Cabrera, M.L., and D.E. Kissel. 1988a. Potentially mineralizable nitrogen in disturbed and undisturbed soil samples. Soil Sci. Soc. Am. J. 52:1010-1015.

Cabrera, M.L., and D.E. Kissel. 1988b. Evaluation of method to predict nitrogen mineralized from soil organic matter under field conditions. Soil Sci. Soc. Am. J. 52:1027-1031.

Cassman, K.G., and D.N. Munns. 1980. Nitrogen mineralization as affected by soil moisture, temperature and depth. Soil Sci. Soc. Am. J. 44:1233-1237.

Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 44:756-771.

El Haris, M.K., V.L. Cochran, L.F. Elliott, and D.F. Bezdicek. 1983. Effect of tillage, cropping, and fertilizer management on soil nitrogen mineralization potential. Soil SCi. Soc. Am. J. 47:1157-1161.

Griffin, G.F., and A.F. Laine. 1983. Nitrogen mineralization in soils previously amended with organic wastes. Agron. J. 75:124-129.

Hadas, A., S. Feigenbaum, A. Feigin, and R. Portnoy. 1986. Nitrogen mineralization in profiles of differently managed soil types. Soil Sci. Soc. Am. J. 50:314-319.

Jenkinson, D.S., and A.E. Johnson. 1977. Soil organic matter in the Hoosfield continuous barley experiment. Rothamsted Exp. Stn. report for 1976, part 2. Harpenden, Herts, England, p.81-101.

Lachat. 1988. Ammonia (Phenolate) in 2M KCl soil extracts. Quickchem Method No. 12-107-06-1B. Lachat Instrument, 6645 West Mill Road, Milwaukee, WI 53218 USA.

Lachat. 1991. Nitrate and Nitrite in 2M KCl soil extracts. Quickchem Method No. 12-107-04-1A. Lachat Instrument, 6645 West Mill Road, Milwaukee, WI 53218 USA.

MacDonald, A.J., D.S. Powlson, P.R. Poulton, and D.S. Jenkins. 1989. Unused fertilizer nitrogen in arable soils - its contribution to nitrate leaching. J.Sci. Food Agric. 46:407-419.

Paul, E.A. 1984. Dynamics of organic matter in soils. Plant Soil. 76:275-285.

Powers, R.F. 1980. Mineralizable soil nitrogen as an index of nitrogen availability to forest trees. Soil Sci. Soc. Am. J. 44:996-1000.

Raun, W.R., G.V. Johnson, R.K. Boman, S.L. Taylor. E.A. Guertal, and R.L. Westerman. 1993. Estimation of inorganic nitrogen buffering from soil profile NO_3-N accumulation and maximum grain yield. Soil Fertility Research Highlights. Agronomy Department, Oklahoma State University.

Soltanpour, P.N., M. El Gharous, A. Azzaoui, and M. Abdelmonum. 1989. A soil test based N recommendation model for dryland wheat. Comm. in Soil Sci. Plant Anal. 20: 1053-1068.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stanford, G., J.N. Carter, and S.J.Smith. 1974. Estimates of potentially mineralizable soil nitrogen based on short-term incubations. Soil Sci. Soc. Am. Proc. 36:465-472.

Stevenson, F.J. 1982. Origin and distribution of nitrogen in soil. In: F.J. Stevenson (ed.) Nitrogen in agricultural soils. Am. Soc. of Agron., Madison, WI. Agron. 22:1-39.

Westerman, R.L.,R.K.Boman, W.R. Raun, and G.V. Johnson. 1993. Accumulation of ammonium-N and nitrate-N in soil profiles of four long-term continuous wheat experiments. (in press, Agron. J.).

Wilkinson, L.S. 1990. The system for Statistics. SYSTAT Inc., Evanston, IL.

Table 1a. Soil Chemical Properties as Affected by Fertilizer N and Depth in Experiment 222.

N (kg ha^{-1})	Depth (cm)	pH	TOTAL N	ORGANIC C (cmol$_c$ kg^{-1})	CEC
			-------------g kg^{-1} ---------------		
0	0-15	6.07	0.68	7.57	22.67
	15-30	6.61	0.65	6.57	29.93
	30-45	7.13	0.56	5.55	29.68
	45-60	7.40	0.47	5.09	32.26
45	0-15	5.92	0.63	7.66	25.57
	15-30	6.73	0.57	5.66	33.14
	30-45	7.20	0.49	4.21	30.11
	45-60	7.47	0.36	3.75	30.06
90	0-15	5.85	0.75	8.01	26.75
	15-30	6.55	0.70	6.38	32.78
	30-45	7.17	0.60	6.15	34.67
	45-60	7.62	0.38	4.95	32.19
134	0-15	5.41	0.80	8.77	25.46
	15-30	6.57	0.71	7.88	29.91
	30-45	7.61	0.63	6.84	30.64
	45-60	7.28	0.55	5.67	28.90

Table 1b. Soil Chemical Properties as Affected by Fertilizer N and Depth in Experiment 502.

N ($kg\ ha^{-1}$)	Depth (cm)	pH	TOTAL N	ORGANIC C	CEC ($cmol_c\ kg^{-1}$)
			------------g kg^{-1}	-------------	
0	0-15	5.43	0.97	6.04	9.22
	15-30	6.27	0.98	5.83	15.84
	30-45	6.99	1.01	5.48	22.09
	45-60	7.33	0.79	4.40	27.22
22	0-15	5.36	0.95	6.06	-
	15-30	6.38	1.02	5.94	-
	30-45	7.11	0.96	5.27	-
	45-60	7.36	0.86	4.41	-
45	0-15	5.23	0.96	6.35	-
	15-30	6.26	1.09	6.01	-
	30-45	6.88	0.93	5.22	-
	45-60	7.47	0.84	4.40	-
67	0-15	5.18	0.99	6.59	-
	15-30	6.22	0.99	6.14	-
	30-45	7.21	0.98	5.23	-
	45-60	7.50	0.95	4.28	-
90	0-15	5.11	1.01	6.38	-
	15-30	6.37	1.05	5.87	-
	30-45	7.14	1.01	4.98	-
	45-60	7.45	0.91	4.33	-
112	0-15	5.05	1.09	6.57	8.00
	15-30	5.64	1.01	6.18	14.26
	30-45	6.97	1.03	5.80	20.63
	45-60	7.37	0.86	4.59	25.01

Table 1c. Soil Chemical Properties as Affected by Fertilizer N and Depth in Experiment 406.

N ($kg\ ha^{-1}$)	Depth (cm)	pH	TOTAL N	ORGANIC C	CEC ($cmol_c\ kg^{-1}$)
			-------- g kg^{-1} --------		
0	0-15	7.50	0.60	8.14	26.44
	15-30	7.64	0.55	6.71	30.31
	30-45	8.14	0.38	4.97	30.61
	45-60	8.14	0.30	4.73	30.21
45	0-15	7.47	0.54	8.28	27.53
	15-30	7.68	0.49	6.94	31.74
	30-45	7.96	0.41	6.05	32.93
	45-60	8.23	0.34	4.59	31.45
90	0-15	7.17	0.67	8.45	29.84
	15-30	7.58	0.57	8.42	35.12
	30-45	8.08	0.39	5.44	33.39
	45-60	8.00	0.38	5.94	34.05
134	0-15	6.61	0.65	7.73	24.89
	15-30	7.26	0.54	6.52	29.72
	30-45	7.74	0.49	6.38	32.18
	45-60	7.93	0.36	5.40	31.80
179	0-15	6.58	0.70	8.28	26.25
	15-30	7.11	0.56	6.63	29.34
	30-45	7.72	0.44	5.61	31.90
	45-60	8.02	0.36	4.50	30.45

Table 1d. Soil Chemical Properties as Affected by Fertilizer N and Depth in Experiment 439.

N ($kg\ ha^{-1}$)	Depth (cm)	pH	TOTAL N	ORGANIC C	CEC ($cmol_c\ kg^{-1}$)
			-------- $g\ kg^{-1}$ --------		
0	0-15	7.70	0.81	9.01	30.60
	15-30	7.39	0.66	8.87	34.78
	30-45	7.21	0.56	8.28	35.09
	45-60	7.52	0.65	6.95	36.70
45	0-15	7.68	0.77	8.21	29.68
	15-30	7.44	0.84	9.24	33.68
	30-45	7.44	0.59	8.34	37.01
	45-60	7.52	0.54	6.72	37.16
90	0-15	7.52	0.66	9.29	30.60
	15-30	7.31	0.68	9.32	35.63
	30-45	7.31	0.59	8.25	36.67
	45-60	7.53	0.51	7.85	37.98
134	0-15	7.31	0.63	8.74	29.66
	15-30	7.33	0.67	8.61	33.41
	30-45	7.37	0.70	8.14	38.71
	45-60	7.66	0.53	7.53	36.05
179	0-15	7.32	0.68	9.26	25.06
	15-30	7.15	0.68	9.46	28.14
	30-45	7.19	0.62	8.27	30.44
	45-60	7.41	0.65	7.26	30.92
224	0-15	7.11	0.74	9.14	24.68
	15-30	7.11	0.70	9.11	29.44
	30-45	7.14	0.75	8.51	30.77
	45-60	7.27	0.52	7.35	30.84

Table 1e. Soil Chemical Properties as Affected by Fertilizer N and Depth at Magruder Plots.

Treatments	**Depth (cm)**	**pH**	**TOTAL N**	**ORGANIC C**	**CEC ($cmol_c\ kg^{-1}$)**
			--------- $g\ kg^{-1}$	-----------	
Check	0-15	5.06	0.59	5.05	22.97
	15-30	5.55	0.60	6.37	25.30
	30-45	5.97	0.54	5.12	21.99
	45-60	6.06	0.43	4.43	26.36
Manure	0-15	6.31	0.84	8.87	29.87
	15-30	5.66	0.72	7.71	21.17
	30-45	6.05	0.59	6.68	22.84
	45-60	6.35	0.45	4.80	24.49
P	0-15	5.10	0.60	5.13	21.91
	15-30	5.40	0.64	7.06	24.68
	30-45	6.02	0.61	6.03	28.24
	45-60	6.28	0.47	4.94	22.12
NP	0-15	4.67	0.77	7.39	26.00
	15-30	5.72	0.71	6.14	21.81
	30-45	6.09	0.57	5.09	32.56
	45-60	6.24	0.43	3.98	32.56
NPK	0-15	4.82	0.87	9.90	23.51
	15-30	5.42	0.70	8.27	26.87
	30-45	5.99	0.59	7.24	30.48
	45-60	6.31	0.44	4.87	20.67
NPK+lime	0-15	5.36	0.77	10.29	22.75
	15-30	6.16	0.67	8.82	26.33
	30-45	6.39	0.54	6.96	19.19
	45-60	6.61	0.69	4.92	30.97

Table 2. Total Mineral N Produced During a 12-week Incubation of Soils Collected From Different Cropping Systems at Different Depths.

N (Kg Ha^{-1})	Depths (cm)				LSD (5%)
	0-15	15-30	30-45	45-60	
	mg kg^{-1}				
			Experiment 222		
0	52.06	41.02	22.51	20.33	6.62
45	54.39	39.29	22.68	18.32	7.33
90	66.17	50.25	27.64	20.70	10.15
134	75.80	55.92	31.88	21.74	13.39
LSD (5%)	8.73	17.96	8.80	6.79	
			Experiment 502		
0	70.66	54.14	38.87	23.41	19.50
22	66.94	59.86	43.76	21.00	17.82
45	73.05	61.61	45.27	27.87	11.67
67	86.69	67.84	43.83	28.35	15.19
90	77.99	63.15	38.67	29.88	25.03
112	91.23	71.69	42.43	28.29	15.10
LSD (5%)	26.18	12.84	14.35	10.21	
			Experiment 406		
0	12.74	14.01	10.84	8.38	1.50
45	14.16	14.53	12.96	10.25	1.22
90	15.81	16.18	14.42	11.60	1.27
134	17.35	17.86	15.27	13.88	1.67
179	22.22	19.02	15.01	12.95	1.01
LSD (5%)	1.27	1.54	1.31	0.96	
			Experiment 439		
0	35.61	26.65	16.87	14.70	2.73
45	30.05	30.87	18.68	15.20	2.34
90	31.44	29.30	20.10	15.33	1.26
134	50.72	33.53	23.56	14.51	4.01
179	62.51	35.65	17.10	11.60	1.85
224	54.98	31.12	27.04	13.78	2.97
LSD (5%)	3.34	2.01	2.08	1.07	
			Magruder Plots		
Check	13.28	11.82	9.99	7.89	0.41
Manure	18.19	16.92	11.01	8.55	1.63
P	14.97	12.98	11.85	9.30	0.18
NP	9.37	14.09	9.66	9.52	0.69
NPK	7.04	12.47	9.12	8.10	0.17
NPK+Lime	15.58	12.87	9.59	8.06	0.48
LSD (5%)	0.39	1.15	0.57	0.35	

Table 3. Proportion of Total N Present in the Active Form in Different Experiments and at Different Depths.

N (Kg Ha^{-1})	Depths (cm)			
	0-15	15-30	30-45	45-60
	------------------------------ %		------------------------------	
		Experiment 222		
0	7.66	6.31	4.02	4.33
45	8.63	6.89	4.63	5.09
90	8.82	7.18	4.61	5.45
134	9.48	7.88	5.06	3.95
		Experiment 502		
0	7.28	5.52	3.85	2.96
22	7.05	5.87	4.56	2.44
45	7.61	5.65	4.87	3.32
67	8.76	6.85	4.47	2.98
90	7.72	6.01	3.83	3.28
112	8.37	7.10	4.12	3.29
		Experiment 406		
0	2.12	2.55	2.85	2.79
45	2.62	2.97	3.16	3.01
90	2.36	2.84	3.71	3.05
134	2.67	3.31	3.12	3.86
179	3.17	3.40	3.41	3.60
		Experiment 439		
0	4.40	4.04	3.01	2.26
45	3.90	3.68	3.17	2.81
90	4.76	4.31	3.41	3.01
134	8.05	5.00	3.37	2.74
179	9.19	5.24	2.76	1.78
224	7.43	4.45	3.61	2.65
		Magruder Plots		
Check	2.25	1.97	1.85	1.83
Manure	2.17	2.35	1.87	1.90
P	2.50	2.03	1.94	1.98
NP	1.22	1.98	1.69	2.21
NPK	0.81	1.78	1.55	1.84
NPK+Lime	2.02	1.92	1.78	1.17

Table 4. Nitrogen Mineralization Potential of Soils in Different Experiments and at Different Depths.

N (Kg Ha^{-1})	**Depths (cm)**				**LSD(5%)**
	0-15	**15-30**	**30-45**	**45-60**	
	----------	----------	mg kg^{-1}	----------	----------
			Experiment 222		
0	64.81	50.79	36.22	26.84	**4.93**
45	63.38	48.48	46.16	27.95	**14.85**
90	76.56	59.23	33.66	29.54	**10.55**
134	88.96	69.26	44.66	30.52	**17.36**
LSD(5%)	**14.70**	**20.50**	**14.77**	**7.05**	
			Experiment 502		
0	81.37	73.87	50.86	36.08	**24.85**
22	78.74	78.22	51.05	27.58	**17.35**
45	97.00	75.27	44.64	34.59	**23.64**
67	108.59	84.09	47.29	35.14	**18.64**
90	121.76	77.87	54.43	31.03	**39.06**
112	112.03	78.27	63.35	31.94	**32.03**
LSD(5%)	**37.53**	**22.65**	**23.83**	**19.05**	
			Experiment 406		
0	14.18	15.19	16.10	11.34	**2.33**
45	16.18	15.48	14.86	12.46	**1.67**
90	18.93	17.01	16.68	14.03	**2.08**
134	18.98	18.42	17.03	15.61	**2.40**
179	25.26	19.38	16.59	14.99	**1.01**
LSD(5%)	**1.87**	**1.77**	**1.96**	**1.38**	
			Experiment 439		
0	54.75	32.33	28.67	27.93	**5.66**
45	61.44	36.51	33.16	19.40	**13.21**
90	50.59	35.88	34.96	20.58	**6.88**
134	75.52	42.49	37.04	21.54	**8.68**
179	89.64	38.67	26.56	21.90	**5.03**
224	79.93	41.80	36.62	26.19	**7.23**
LSD(5%)	**11.53**	**2.22**	**5.78**	**4.53**	
			Magruder Plots		
Check	15.27	14.10	13.87	10.98	**5.62**
Manure	21.25	21.67	18.70	10.93	**6.04**
P	15.26	19.16	14.85	12.39	**0.30**
NP	10.86	24.20	12.00	12.15	**1.01**
NPK	8.98	14.30	11.84	10.16	**0.27**
NPK+Lime	18.45	15.42	10.70	9.89	**0.16**
LSD(5%)	**0.57**	**4.27**	**4.59**	**0.407**	

Table 5. Decomposition Rate Constant in Different Experiments and at Different Depths.

N (Kg Ha^{-1})	**Depths (cm)**				**LSD(5%)**
	0-15	**15-30**	**30-45**	**45-60**	
			week^{-1}		
			Experiment 222		
0	0.137	0.148	0.088	0.126	**0.044**
45	0.135	0.141	0.064	0.091	**0.041**
90	0.160	0.159	0.145	0.104	**0.032**
134	0.159	0.152	0.119	0.110	**0.034**
LSD (5%)	**0.030**	**0.036**	**0.043**	**0.040**	
			Experiment 502		
0	0.163	0.128	0.093	0.096	**0.044**
22	0.163	0.200	0.117	0.106	**0.105**
45	0.119	0.153	0.153	0.165	**0.039**
67	0.137	0.156	0.165	0.137	**0.036**
90	0.136	0.141	0.129	0.125	**0.099**
112	0.145	0.146	0.163	0.180	**0.071**
LSD (5%)	**0.036**	**0.083**	**0.059**	**0.059**	
			Experiment 406		
0	0.191	0.207	0.098	0.109	**0.031**
45	0.189	0.222	0.170	0.143	**0.032**
90	0.150	0.237	0.177	0.153	**0.032**
134	0.197	0.240	0.198	0.189	**0.036**
179	0.188	0.265	0.225	0.170	**0.018**
LSD (5%)	**0.024**	**0.025**	**0.031**	**0.018**	
			Experiment 439		
0	0.092	0.151	0.084	0.066	**0.022**
45	0.071	0.158	0.077	0.126	**0.018**
90	0.092	0.148	0.075	0.113	**0.023**
134	0.107	0.135	0.090	0.096	**0.030**
179	0.113	0.196	0.088	0.068	**0.019**
224	0.112	0.118	0.118	0.063	**0.018**
LSD (5%)	**0.021**	**0.015**	**0.022**	**0.023**	
			Magruder Plots		
Check	0.150	0.146	0.115	0.113	**0.011**
Manure	0.159	0.128	0.089	0.139	**0.030**
P	0.204	0.099	0.145	0.119	**0.004**
NP	0.183	0.072	0.154	0.139	**0.012**
NPK	0.145	0.170	0.128	0.152	**0.006**
NPK+Lime	0.149	0.157	0.210	0.152	**0.013**
LSD (5%)	**0.010**	**0.019**	**0.018**	**0.005**	

Table 6. Potential N Mineralized Contribution of each Layer to Total Soil Profile Potential N Mineralized in Different Experiments.

Depth (cm)	**Experiments**				
	222	**502**	**406**	**439**	**Magruder**
	%				
0 - 15	40.8	38.2	32.9	33.2	31.0
15 - 30	32.7	31.4	22.5	16.8	26.6
30 - 45	14.6	18.4	27.6	38.3	23.2
45 - 60	11.9	12.0	17.0	11.7	19.2
15 - 60	59.2	61.8	67.2	66.8	69.0

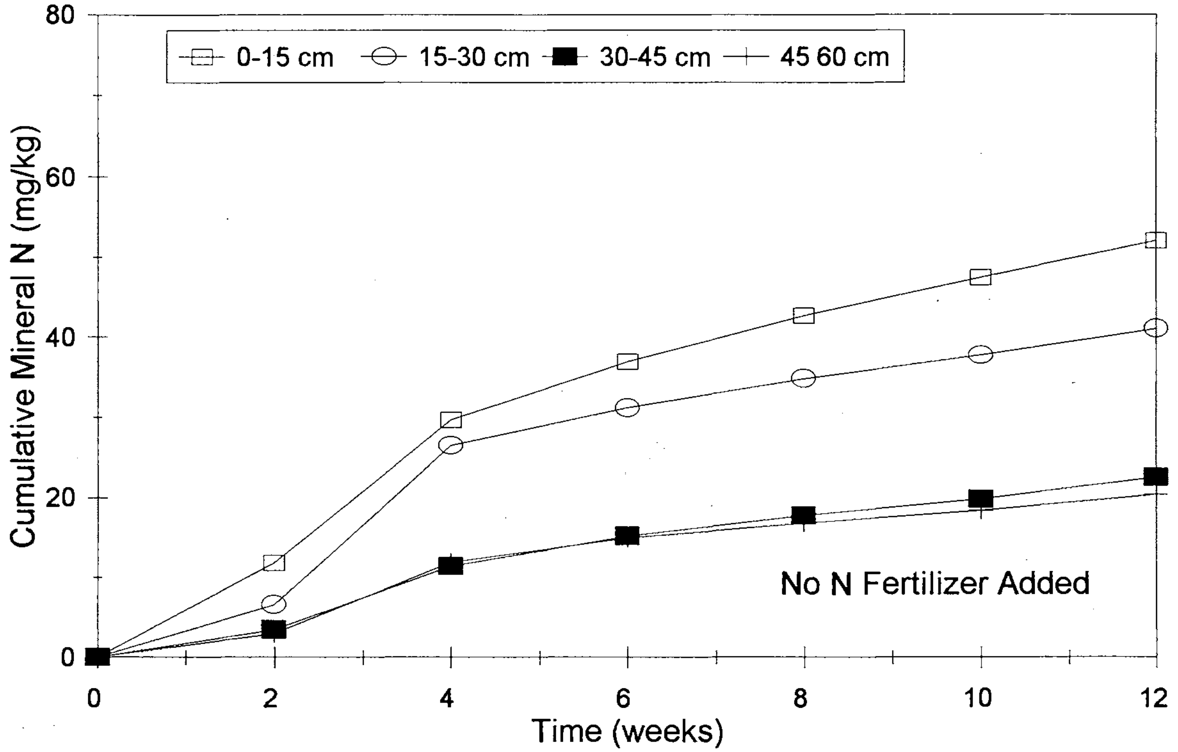


Fig. 1. Cumulative N Mineralized at Different N Rates and Different Depths at Experiment 222.

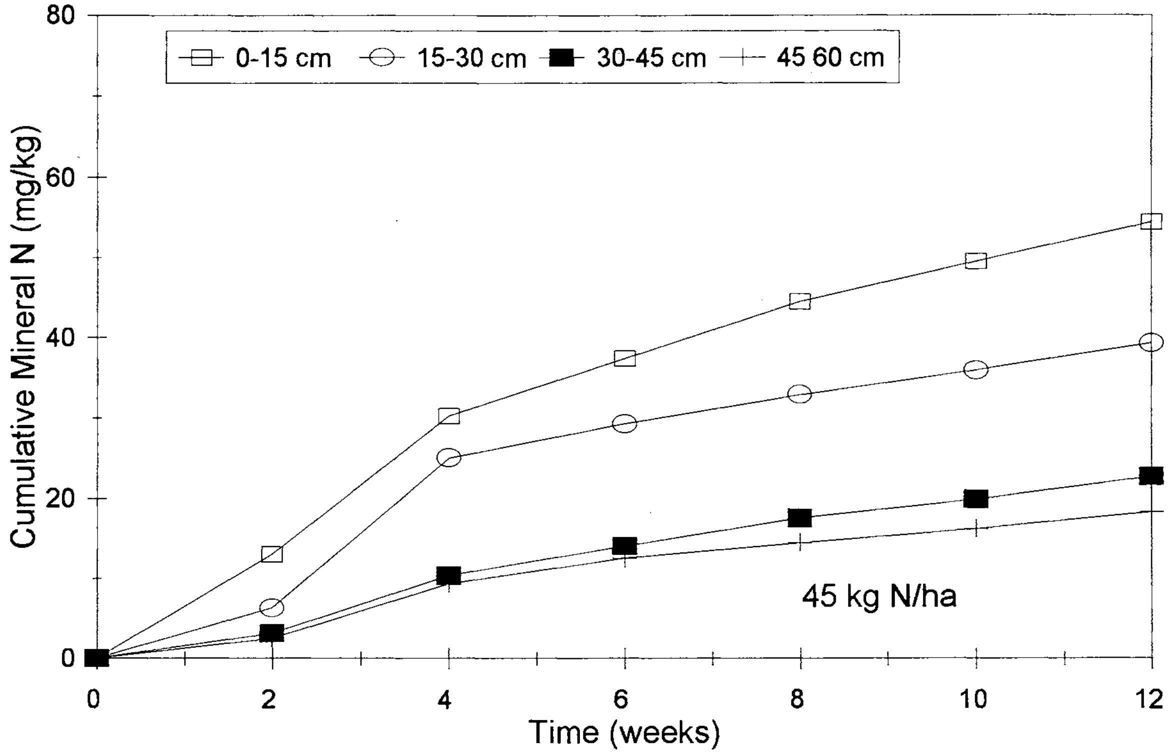
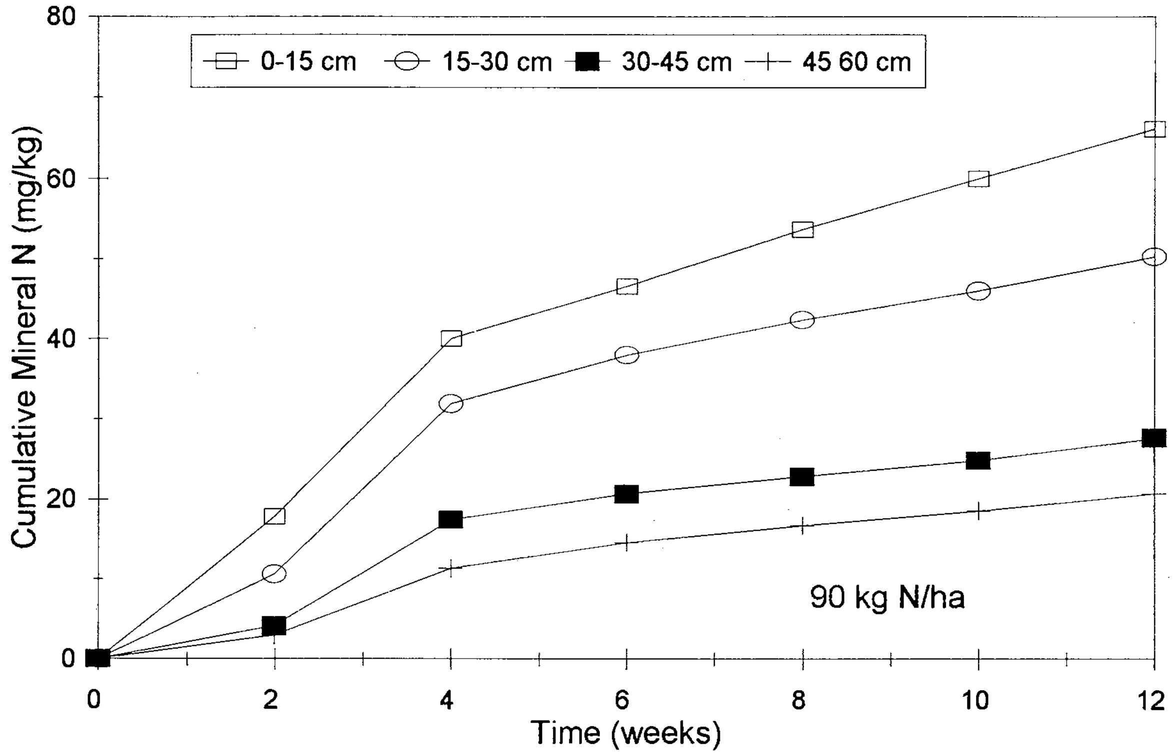


Fig. 1. Continued



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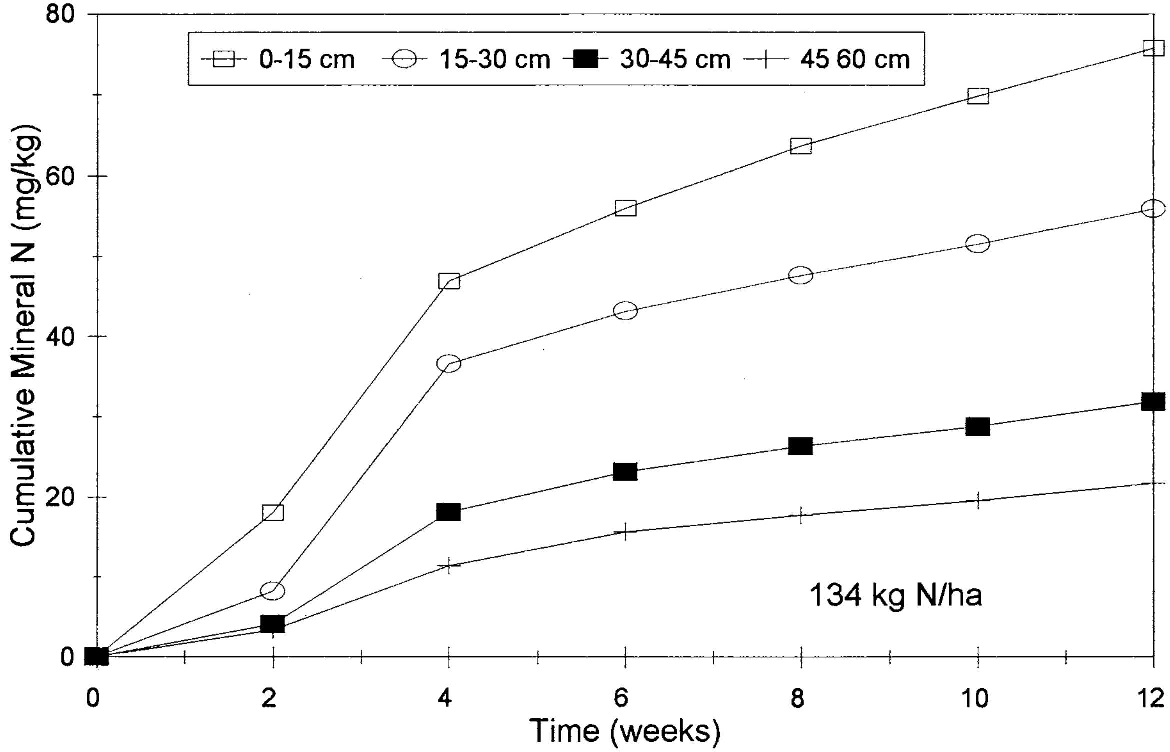

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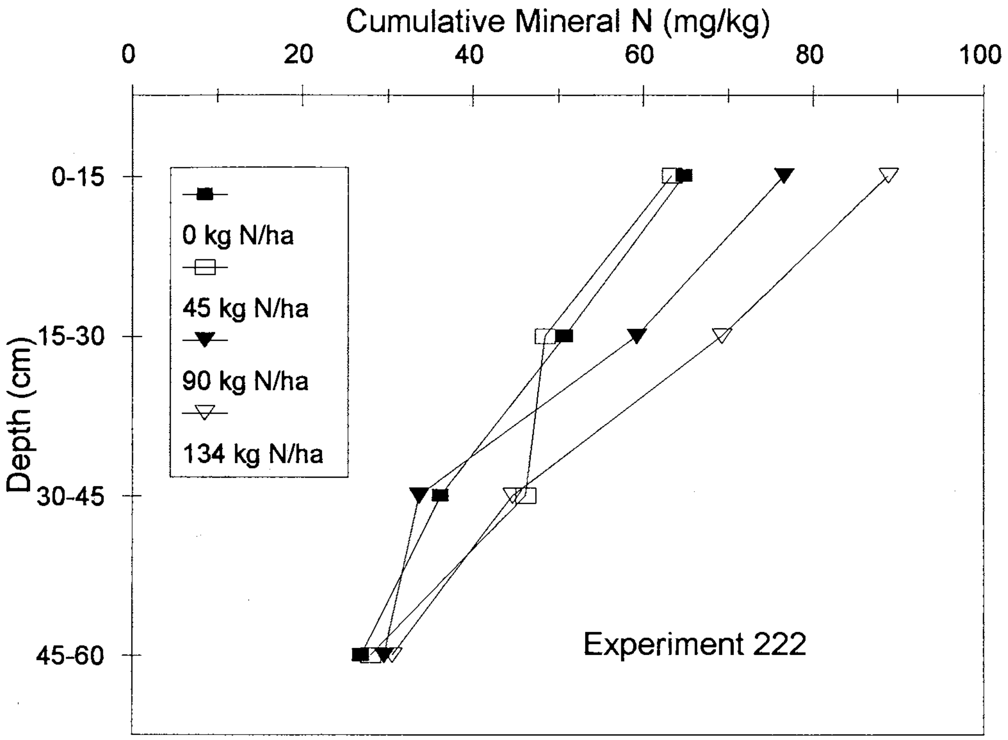

Fig. 2. Effect of Depth on N Mineralization Potential at Different Locations

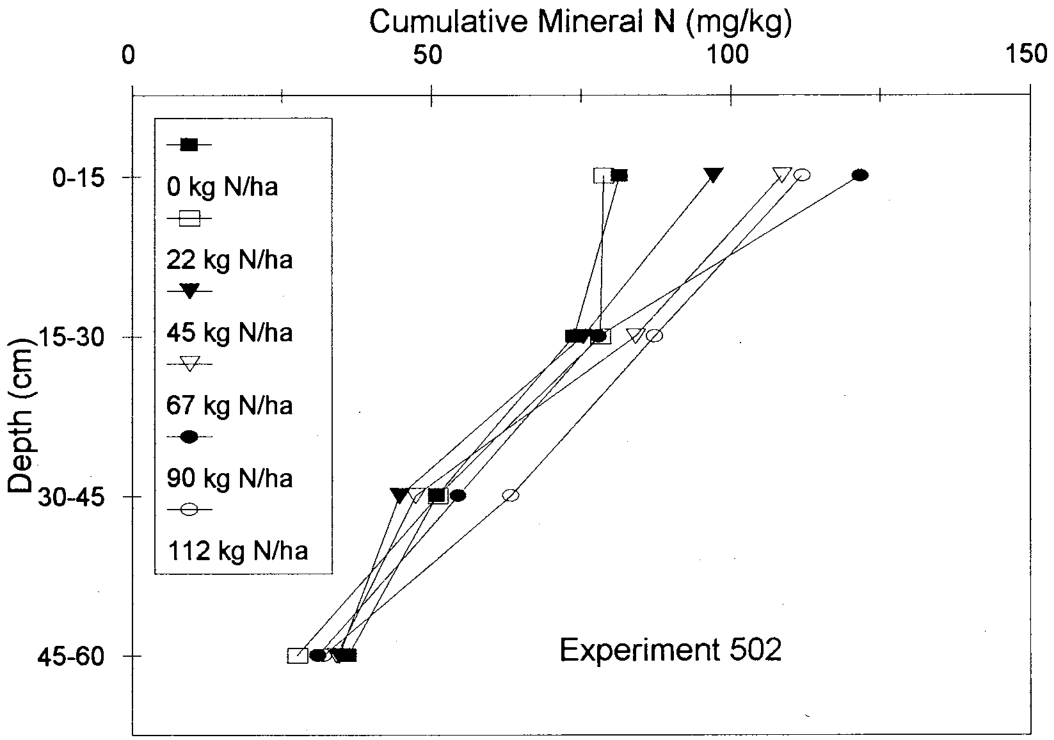

Fig. 2. Continued

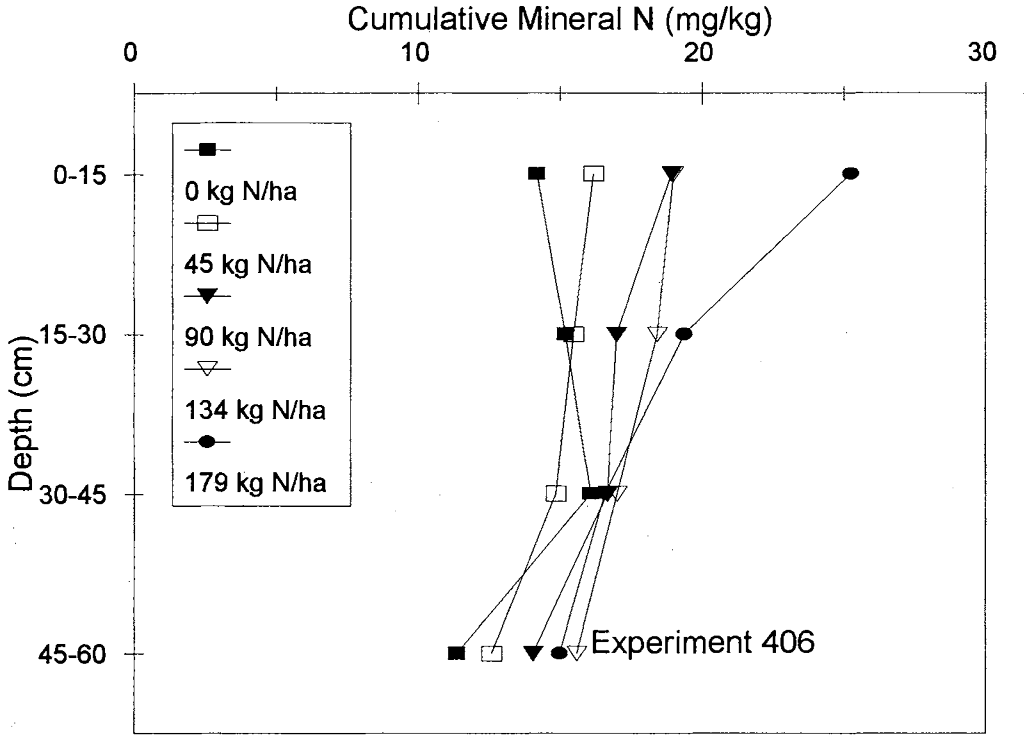

Fig. 2. Continued

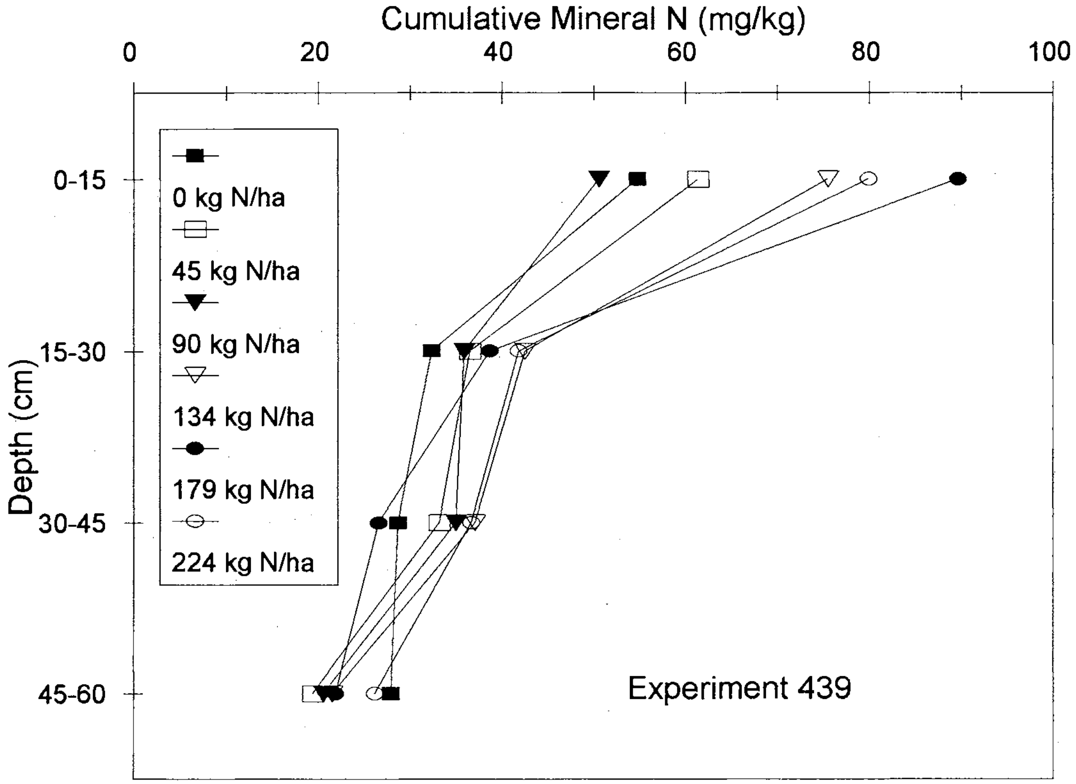

Fig. 2. Continued

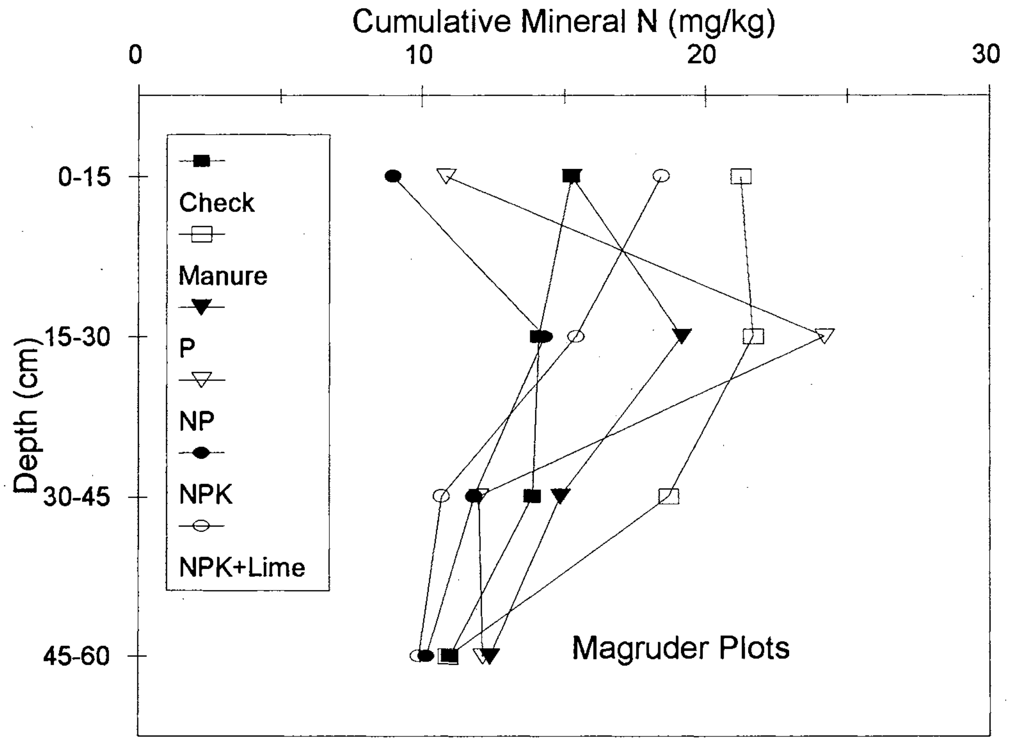

Fig. 2. Continued

CHAPTER V

NITROGEN MINERALIZATION POTENTIAL OF SOILS

I. CORRELATION OF N AVAILABILITY INDICES WITH N UPTAKE BY PLANTS

NITROGEN MINERALIZATION POTENTIAL OF SOILS
I. CORRELATION OF N AVAILABILITY INDICES WITH N UPTAKE BY PLANTS

Abstract

Growing plants derive their nitrogen from the mineralization of soil organic matter, from atmospheric N brought into chemical combination through the activities of certain organisms, or from applied fertilizer. In this study bioassay plant N uptake and N mineralization kinetics using incubation techniques in various soil types were used in order to estimate the soil N mineralization potential (N_0) and the decomposition rate constant (k). Also, to evaluate the effect of fertilizer N on N_0 and the corresponding k and to relate the rate parameters obtained to plant N uptake and initial soil mineral N.

Soil samples to depth of 20 to 30 cm were collected from two different agricultural zones of the semi-arid regions of Morocco. Nitrogen fertilizer was applied at rates of 0, 20, 40, 80, and 120 kg N ha^{-1}. The soil samples were then put into plastic pots and planted to bread wheat (Triticum aestivum). Mineral N in soil was determined at different wheat growth stages and total N uptake was determined at anthesis. Both linear and quadratic relationships were tested to evaluate the relationships between different N parameters.

Soil samples were incubated for a period of 20 weeks under optimum conditions of moisture and temperature and N_0 and k were estimated from an

exponential model using a non-linear least squares iterative statistical model.

Values of N_0 ranged from 109 to 257 mg N kg^{-1} in the Chaouia region and from 66 to 343 mg N kg^{-1} in the Abda region. The N_0 values were highly correlated to both plant N uptake and initial soil mineral N. The per week rate of mineralization (N_0k) improved both the correlation coefficient and the root mean square error (RMSE) of the regression equations.

The effect of fertilizer N was not shown at lower N rate (20 kg N ha^{-1}) but was significant at higher rates. The percent increase in soil N_0 due to fertilizer N over check plots was 20% in the Chaouia region and 43% in the Abda region. The k values were affected by N fertilizer in the same manner as N_0.

Mineral N initially present in soil and N_0k were the best estimates of N mineralized in soil.

Introduction

A government policy of Morocco has been to increase agricultural output in order to satisfy the needs of rapidly expanding population and to reduce the exodus to cities. Recent surveys of cereals production (Ouattar and Ameziane, 1989; Shroyer at al., 1990) show deficits with respect to satisfying domestic demand. As most of the arable land is under cultivation (Crawford and Purvis, 1986), the only feasible option to overcome the problem is to increase grain yields per hectare.

Limited rainfall in semi-arid areas is the overwhelming constraint to crop production, however, nutrient deficiency, especially N and to lesser extent P, is also seen as a limiting factor in many cases (Soltanpour et al., 1989; Abdel Monem et al., 1990a). Various fertility experiments in Morocco's dryland have demonstrated significant responses to additions of fertilizer N (Abdel Monem et al., 1990b; Ryan et al., 1991). The intensification of agriculture in semiarid zones of Morocco, however, demands the use of fertilizer N, or at least that N supplied by the soil be used as efficiently as possible.

As the cost factor of synthetic fertilizer N is becoming more important, it is imperative that conditions where its use will increase yield be identified. For example, in semiarid areas, the amount of N required for optimum yield increases as rainfall increases (Jackson et al., 1983). Fertilizer input in dryland farming in Morocco is less than adequate (Primov et al., 1987). In fact, due to various socio-economic factors, many farmers use little or no fertilizer at all.

The soil test calibration project initiated to establish a rational and economic basis for fertilizer use in dryland farming of Morocco has shown that the need for fertilizer is dependent on a number of factors such as soil type, previous crop, and the level of soil NO_3-N before planting. Soil types differ in their fertility and moisture holding capacity, and therefore their productivity. Thus shallow soils of dryland zones of Morocco may need less fertilizer input than deep soils. Legumes as previous crops may reduce the need for addition of N for the subsequent crop. The impact of a legume crop, however, is dependent on the crop management and the ability of the species to fix atmospheric N. The level of soil NO_3-N for the subsequent crop is also dictated by the capacity of the soil to mineralize organic matter.

Nitrogen uptake depends upon the crop's demand for N, the ability of soils to supply nitrogen and the rate of transport of N to the roots (Campbell et al., 1981). Information on the capacity of Morocco's dryland soil to mineralize organic matter is very limited. Chiang et al. (1983) have studied the mineralization of soil organic matter of three soil types, a vertisol, and two typical red Mediterranean soils and reported that the N available to the growing crop is mainly governed by the light rainfall occurring in the late autumn and early winter. El Gharous et al. (1990) have determined the N mineralization potential of 14 soil types of the dryland zone of Morocco. However, neither of these two studies considered the relationship of N_0 to crop N uptake or crop response to fertilizer N in order to establish a basis for N recommendation. The objectives of this study were to estimate N supplying power of different soil types, to evaluate the effect of chemical fertilizer N on the soil N supplying power, and to evaluate a nitrogen availability index for these soils.

Materials and Methods

Site Characteristics

Cereal production in Morocco is dictated by the amount of rainfall and its distribution pattern. About 50% of Morocco's arable land receives less than 450 mm per year and it is generally cultivated under cereals/fallow rotation (Shroyer et al., 1990). The arid and semiarid regions of Morocco are characterized by moderate winters and dry hot summers. Although the mean annual temperature is 17°C, it ranges from 11°C in the coldest month, January, to 27°C in August, the hottest month. Precipitation occurs between October and April. The yearly rainfall range from 200 to 400 mm in the southern half and above 400 mm in the northern part, but the distribution and occurrence vary widely from year to year.

The cereals grown in the arid and semi-arid zones of Morocco represent 45% of the nation's cereal crop. It represents 27% of wheat, 56% of barley, and 83% of corn. The two main agricultural zones of the arid and semi-arid regions are Abda and

Chaouia.

Abda region is situated at approximately 32 degrees north of latitude. It is located about 20 km inland from the Atlantic coast. Its area is approximately 229,000 km^2, of which 211,000 km^2 are classified as arable land. Most of the plain is characterized by a deep, black vertisol which distinguishes the region from its surroundings and which renders it an important agricultural center. Local farmers recognize four other major soil types in addition to the black vertisol.

Chaouia region is located north-east of Abda region and is primarily in Settat province. It is further subdivided into the lower and upper Chaouia by an escarpment which runs from near Oulad Said in the west, northeast to Mgarto, near Ben Ahmed. The lower Chaouia and central subregion of upper Chaouia are characterized for the most part by deep vertisols. Cereals and food legumes are predominant, with very little fallow on vertisols. Corn occupies a very important place in the rotations in the western and central part of this subregion, but drops out rather abruptly to the east. The remainder of the Chaouia region presents a considerable heterogeneity in soil types and depth, with a tendency towards poorer and more shallow soils to the southeast (Stitou, 1984).

Field Sampling

Thirteen soil types were selected for this study, seven soil types were from the Chaouia region (Stitou, 1984) and six soil types from the Abda region (El Oumri, 1984). Within each region fields with cereals as previous crop were sampled from the plough layer. The classification and certain chemical and physical characteristics of the 13 soils are given in Tables 1 and 2. The soil samples were air dried and thoroughly mixed with N fertilizer. Nitrogen fertilizer rates were 0, 20, 40, 80 and 120 kg ha^{-1}.

Amount of soil collected were used for both incubation and plant bioassay studies.

Incubation Study

The procedure was based on the leaching method proposed by Stanford and Smith (1972). Triplicate samples of 30 g of air dried soil from each treatment were uniformly mixed with an equal amount of pre-acid washed sand, moistened with distilled water and gently mixed. The mixtures were transferred to a 250 ml Corning disposable sterile filter/storage system and the soil was covered with a thin (0.25 cm) glass wool pad to avoid dispersing the soil when solutions were poured into the tubes.

Mineral N initially present was removed by leaching with 100 ml 10 mM $CaCl_2$ in 10 to 20 ml increments, followed by 25 ml of N-free nutrient solution (2.0 mM $CaSO_4$; 2.0 mM $MgSO_4$; 5.0 mM $Ca(H_2PO_4)_2.H_2O$; and 2.5 mM K_2SO_4). Excess water was removed under vacuum (0.02 MPa). The tubes were then incubated at 35 ± 1°C. After two weeks, mineral N was recovered by leaching with 100 ml of 10 mM $CaCl_2$ and 25 ml of N-free nutrient solution, followed by applying suction as described above. The sample-sand mixture were returned to the incubator for periods of 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 weeks cumulative, with intermittent leaching of mineral N. Optimum soil water content was maintained at approximately 0.02 MPa throughout the incubation period.

Greenhouse Study

A greenhouse experiment was conducted on the samples as a vegetative test for N availability. The experimental design was a completely randomized bloc design with five levels of N fertilizer, thirteen soil types and three replications. Ten kilograms of soil from each soil type was mixed thoroughly with appropriate amount of fertilizer N to give 0, 20, 40, 80 and 120 kg N ha^{-1} and then transferred to plastic pots.

Phosphorus and K fertilizers were added according to soil test levels to ensure that N was the only nutrient limiting growth. Wheat (Triticum aestivum L.) was sown at high density and then thinned to 15 seedlings. In addition, three replicates from each soil type with no fertilizer N added were left bare in order to estimate the N supplied by the soil. During the experiment daytime temperatures ranged from 23 to 28°C, and the night temperatures ranged from 6 to 11°C due to lack of heating facilities in the greenhouse.

The soil samples were collected at stage C (two leaves), stage F (tillering), stages M and N (heading) and after harvest at stage S and T and were analyzed for ammonium and nitrate plus nitrite.

Laboratory Analyses

Soil Sample Analyses

Soil samples were analyzed for total N using the Kjeldahl method (Bremner, 1965), and organic carbon using the Walkley and Black method (Allison, 1965). The pH values were obtained with a glass electrode using a soil-water suspension 1:2 (w/v) ratio. Ammonium and NO_3-N plus NO_2-N in the soil at different growth stages and in soil extracts during the incubation period were determined using an automated flow injection system (Lachat, 1988, 1991).

Plant Sample Analyses

Plant samples were dried at 65°C for 48 hours. After dry weights were taken, entire samples were grounded to pass through a 2 mm screen. Total plant N was determined by steam distillation following a sulfuric acid digestion (Bremner, 1965).

N Balances

The actual amount of N mineralized in the cropped soils were estimated with the following equation:

N mineralized= inorganic N end - inorganic N start + N uptake.

The actual amount of N mineralized in the bare soils were estimated by subtracting inorganic N start from inorganic N end.

Statistical Analyses

The N mineralization potential and the decomposition rate constant were determined from the first-order exponential model to describe net N mineralization proposed by Stanford and Smith (1972).

$$N = N_0(1 - e^{-kt})$$

where N is mineralized nitrogen in time t, N_0 is the N mineralization potential and k is the decomposition rate constant. A nonlinear least-squares iterative regression program was used to evaluate N_0 and k (Wilkinson, 1990).

Results and Discussion

N Mineralization Potential

Nitrogen mineralization potential (N_0) were calculated for different soils of the Chaouia and Abda regions at 35°C using a single exponential model proposed by Stanford and Smith (1972). The cumulative N mineralized-time curves were of similar shape to those obtained by El Gharous et al. (1990).

Values of N_0 of different soils were observed to increase and those of k to decrease with increasing incubation time. The increase in N_0 was more than 40% from week 14 to week 20. In this regard, Cabrera and Kissel (1988) also reported, in a study on the effect of length of incubation on the parameters of the double exponential model, an increase of 13 and 50% in the first and second parameter of the model respectively from week 20 to week 36.

Nitrogen uptake and dry matter yield were correlated to N_0 estimated at different weeks starting week 12 and it was found that the correlation coefficients were best at weeks 12 and 14. However, when N uptake or dry matter yield were correlated with the product of N_0 and k, the correlation coefficients were about the same at all weeks (Table 3). In this study we will be using N_0 and k estimated at week 14 to make comparisons with the data of El Gharous et al. (1990).

Nitrogen mineralization potential of the soil types studied ranged from 109 to 257 mg kg^{-1} in the Chaouia region and from 66 to 343 mg kg^{-1} in the Abda region (Table 4). The N_0 values obtained were, in general, within the range reported by El Gharous et al. (1990), which included 14 different soils from the Chaouia region. Though the range of N_0 in Abda was wider, the overall values of N_0 obtained were lower than those obtained in Chaouia region. The k values, on the other hand, were higher at Abda region. The high k values reflect the instability of organic matter accumulation under these soils. In fact, organic matter content of these soils was, in general, lower than that of the soils at the chaouia region (Table 2). Farmers at Abda region practice mainly one crop rotation (wheat/fallow). During the fallow season, farmers till the soil at least three times and that during spring (in March), during summer (in July) and prior to planting (in October). These soils with rather constant crop rotation and repeated soil tillage have probably increased the soil microbial activities and hence the amount of the active fraction of organic N in soils. The product of N_0 and the decomposition rate constant k which gives an estimate of the amount of N mineralized per week was, however, about the same in both regions (Table 4).

The effect of N fertilizer on N_0 and k was significant. The statistical analyses also showed a significant soil type x N interaction which restricted the interpretation of both variables. Considering each soil independently, N fertilizer increased N_0 significantly up to 80 or 120 kg N ha^{-1}. The rate of 20 kg N ha^{-1} did not affect N_0, in fact, there was an apparent decrease in some soils. The increase in N_0 over a check plots (no fertilizer N added) was about 20% in the Chaouia region and 43% in the Abda region (Fig. 1). The k values were increased by the application of N fertilizer in the same way as N_0. Nevertheless, the product N_0 and k increased linearly with N rate at both regions (Fig. 2). The variation in N fertilizer effect among soils suggest that the positive priming effect on the decomposition of organic material is not governed solely by fertilizer N but by a combination of several mechanisms (Jansson and Persson 1982). Though N fertilizer increased the soil N supplying power under optimum conditions of soil moisture and temperature, it decreased significantly the quantity of the actual N mineralized (Fig. 3).

N Mineralized in soil

The amount of mineral N measured in bare soil ranged from 75 to 144 mg kg^{-1} of soil in the Chaouia region and from 80 to 158 mg kg^{-1} of soil in Abda region, and that in cropped soils ranged from 114 to 142 mg kg^{-1} of soil in the Chaouia region and from 43 to 151 mg kg^{-1} of soil in Abda region (Table 5). The average net N mineralization in cropped soils was about 127 and 106 mg kg^{-1} in Chaouia and Abda region respectively. Measured mineral N in bared and cropped soil usually exceeded calculated amount of N mineralized using the exponential model over a period of the growing season (16 weeks). The average over-estimation for cropped soils was 11% and 25%, and that of bare soils was 6% and 45% in Chaouia and Abda regions respectively. The increase in the overestimation from cropped to bare soil observed in Abda region is thought to be due to the nature of soil organic matter. In fact, the active fraction of the soil total N (N_0/Nt) was higher in Abda (11.7 to 33.2%) compared to that in Chaouia region (6.1 to 12.9%). We believe that the overestimation in cropped soils would have been higher than reported here if we had considered N losses (Stevenson, 1982).

N Availability Index

High efficiency of fertilizer N use by a crop should be expected if N applied or N available in the soil matches the crop needs. This, however, requires adequate N availability indices. In this study, correlations between crop N uptake, N_0, N_0k and initial soil mineral N (NH_4-N, NO_3-N and NO_2-N) were tested (Table 6).

Wheat N uptake was found to be linearly related to initial soil N, N_0 and N_0k. Correlation coefficients and root mean square errors (RMSE) are shown in Table 6. The quadratic relationships were also tried. These relationships have, in general, improved the correlation coefficients but the RMSE were larger than those of the linear relationships. The high RMSE indicate that the quadratic models had a larger variance than the linear models.

The highly significant correlation between the bioassay plant N uptake and both N_0 and mineral N initially present in soil indicates that both parameters provide an adequate index for plant available N under semi-arid conditions.

Initial soil mineral N in the surface layers, which is mostly dealt with in practice, was found to be an adequate index for soil N mineralization potential (N_0)

(Fig. 4). Correlation coefficients and RMSE of this relationship were significantly improved with the use of the product of N_0 and k (Fig. 5). This product was also reported to be an interesting parameter (Mary and Rémy, 1979) because it represents the initial rate of mineralization and gives a reliable approximation of the quantity of N mineralized per week. Based on these results and for practical routine use, mineral N present in soil at start was the best soil test index under our conditions.

This study also suggest that soils of the semi-arid regions of Morocco in some N mineralization characteristics are alike under greenhouse conditions. However, the prediction of N availability index under field conditions should be pursued.

Summary and Conclusions

The mineralization potential of soils from Abda region was lower than that of soils from Chaouia region. Nitrogen fertilizer application increased the potential of soils to decompose soil organic materials in both regions and in all soil types regardless of their initial mineral N but decreased the actual N mineralized in soil.

Both crop N uptake and N mineralization potential were highly correlated to initial soil mineral N. The product of N mineralization potential and the decomposition rate constant seemed to be an interesting parameter for soil N availability index than N_0.

Initial soil mineral N was also found to be a reliable estimate of soil N availability index in semi-arid soils of Morocco.

References

Allison, L.E. 1965. Organic carbon. In C.A. Black et al. (ed) Methods of soil analysis. Part 2. Agronomy 9:1367-1378.

Abdel Monem, M., J. Ryan, and M. El Gharous. 1990a. Preliminary assessment of soil fertility in the mapped area of Chaouia. Al Awamia 72:85-107.

Abdel Monem, M., A. Azzaoui, M. El Gharous, J. Ryan, and P.N. Soltanpour. 1990b. Demonstrating fertilizer response and hessian fly resistance with wheat in Morocco. J. Agron. Educ. 19:77-80.

Bremner, J.M. 1965. Total nitrogen. In C.A. Black et al. (ed) Methods of soil analysis. Part 2. Agronomy 9:1149-1176.

Cabrera, M.L. and D.E. Kissel. 1988. Evaluation of a method to predict nitrogen mineralized from soil organic matter under field conditions. Soil Sci. Soc. Am. J. 52:1027-1031.

Campbell, C.A., R.J.K. Myers, and K.L. Weier. 1981. Nitrogen mineralization potential, decomposition rates and their relationship to temperature for five Queensland soils. Aust. J. Soil Res. 19:323-332.

Chiang, C., B. Soudi, and A. Moreno. 1983. Soil nitrogen mineralization and nitrification under Moroccan conditions. In Nutrient balance and the need for fertilizers in semiarid and arid regions. Proc. Colloq. Int. Potash Inst., 17:77-87.

Crawford, P.R. and M.J. Purvis. 1986. The agricultural sector of Morocco: a description. United States Agency for International Development, Rabat, Morocco.

El Gharous, M., R.L. Westerman, and P.N. Soltanpour. 1990. Nitrogen mineralization potential of arid and semiarid soils of Morocco. Soil Sci. Soc. Am. J. 54:438-443.

El Oumri, M. 1984. Etude pédologique au 1/100,000 édité au 1/50,000 de la zone Abda. Projet Intégré de Développement Agricole de Safi. Convention No. 14-82-SAF. INRA, Service d'Ecologie. Rabat, Maroc.

Jackson, T.L., A.D. Halvorson, and B.B. Tucker. 1983. Soil fertility in dryland agriculture. In H.E. Oregne and W.O. Willis (ed.). Dryland Agriculture. p. 229-332. Agron. 21. Am. Soc. Agron. Madison WI.

Jansson, S.L., and J. Persson. 1982. Mineralization and immobilization of soil nitrogen. In F.J. Stevenson (ed) Nitrogen in Agricultural Soils. Am. Soc. of Agron., Madison, WI. Agron. 22:229-248.

Lachat. 1988. Ammonia (Phenolate) in 2M KCl soil extracts. QuikChem Method No. 12-107-06-1B. Lachat Instrument, 6645 West Mill Road, Milwaukee, WI 53218 USA.

Lachat. 1991. Nitrate and Nitrite in 2M KCl soil extracts. QuikChem Method No. 12-107-04-1A. Lachat Instrument, 6645 West Mill Road, Milwaukee, WI 53218 USA.

Mary, B., and J.C. Rémy. 1979. Essai d'appréciation de la capacité de mineralisation de l'azote des sols de grande culture. I. Signification des cinétiques de mineralisation de la matière organique humifiée. Ann. Agron. 30 (6):513-527.

Ouattar, S. and T.E. Ameziane. 1989. Les céréales au Maroc: de la recherche à l'amélioration des techniques de production. Les Editions Toubkal, Casablanca, Morocco.

Primov, G. I.Said and A. Herzenni. 1987. Crop production in Abda Region. Aridoculture Center, Settat, Morocco.

Ryan, J., M. Abdel Monem, M. Mergoum, and M. El Gharous. 1991. Comparative triticale and barley responses to nitrogen at locations with varying rainfall in Morocco's dryland zone. Rachis 10: (2) 3-7.

Shroyer, J.P., J. Ryan, M. Abdel Monem, and M. ElMourid. 1990. Production of fall planted cereals in Morocco and technology for its improvement. J. Agron. Educ. 19:32-40.

Soil Taxonomy. 1975. A basic of soil classification for making and interpreting soil surveys. Soil Conservation Service USDA. Agricultural Handbook no. 436.

Soltanpour, P.N., M. El Gharous, A. Azzaoui, and M. Abdelmonem. 1989. A soil test based N recommendation model for dryland wheat. Commun. in Soil Sci. Plant Anal. 20:1053-1068.

Stanford, G., and S.J. Smith. 1972. Nitrogen mineralization potential of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Stevenson, F.J. 1982. Origin and distribution of N in soil. In F.J. Stevenson (ed)

Nitrogen in Agricultural Soils. Am. Soc. of Agron., Madison, WI. Agron. 22:1-39.

Stitou, M. 1984. Etude pédologique au 1/100,000 de la region Settat Ben Ahmed. Marché no. 46/82/DPA/42. Dep. des Sciences du Sol, Inst. Agronomique et Véterinaire Hassan II, Rabat, Morocco.

Wilkinson, L.S. 1990. The system for statistics. SYSTAT Inc., Evanston, Il.

Table 1. Physical Characteristics of Soils Studied.

Soil no.	Soil Great Group (Soil taxonomy, 1975)	Clay	Silt	Sand
	Chaouia Region			
		---%	---	---
U10	Typic Chromoxererts	54.2	10.6	34.6
U15	Typic Rendolls	58.9	14.8	26.6
U18	Xerochrepts	46.7	23.4	27.1
U19	Xerochrepts	44.9	8.5	39.4
U24	Argiustolls	59.5	8.3	38.3
U33	Aridic Subgroup of Ustolls	60.9	10.5	33.7
U39	Xerochrepts and Ustochrepts	41.9	7.6	49.6
	Abda Region			
U19	Typic Rendolls	59.6	9.4	30.4
U28	Typic Rendolls	65.1	9.4	29.4
U31	Eutrochrepts	52.9	6.4	39.1
U32	Palloxererts	34.5	31.7	33.4
U35	Chromoxererts	42.8	34.0	23.6
U40	Argiustolls	31.7	23.0	45.0

Table 2. Chemical Properties of Soils Studied.

Soil no.	Surface soil properties				
	pH	Organic C	Total N	K	Ca
		Chaouia Region			
		g kg^{-1}			
U10	7.9	11.66	1.3	0.22	3.08
U15	7.7	18.55	2.3	0.24	3.61
U18	8.0	17.74	1.3	0.13	3.14
U19	8.0	18.55	1.9	0.09	2.48
U24	7.7	9.14	1.3	0.14	1.43
U33	8.1	9.32	1.6	0.12	1.38
U39	7.5	18.01	1.0	0.19	1.98
		Abda Region			
U19	8.0	17.04	0.8	0.18	4.05
U28	8.2	9.50	1.6	0.15	1.95
U31	8.1	8.06	0.6	0.15	3.85
U32	8.1	9.05	0.9	0.28	3.82
U35	7.6	6.28	0.4	0.20	2.87
U40	7.9	3.59	0.2	0.13	0.65

Table 3. Correlation Coefficients Between N Uptake, Dry Matter Yields, N_0 and N_0k at Different Period of Incubation.[a]

Weeks	N Uptake		Dry Matter Yield	
	N_0	N_0k	N_0	N_0k
12	0.356 (0.004)	0.387 (0.002)	0.426 (0.000)	0.599 (0.000)
14	0.340 (0.006)	0.383 (0.002)	0.368 (0.003)	0.599 (0.000)
16	0.218 (0.083)	0.374 (0.002)	0.177 (0.161)	0.594 (0.000)
18	0.255 (0.042)	0.373 (0.002)	0.255 (0.042)	0.592 (0.000)
20	0.271 (0.030)	0.374 (0.002)	0.284 (0.023)	0.592 (0.000)

[a] Values in parenthesis are probability values at 0.05 level

Table 4. Check Plots Nitrogen Mineralization Potential (N_0) for Different Soils Studied.

Soil No.	N_0 (mg kg^{-1})	k (week^{-1})	N_0k (mg kg^{-1}week^{-1})
		Chaouia Region	
U10	139.5	0.150	20.93
U15	257.2	0.067	17.23
U18	126.5	0.098	12.40
U19	116.2	0.134	15.57
U24	109.7	0.197	21.61
U33	188.9	0.036	6.80
U39	129.2	0.152	19.64
		Abda Region	
U19	133.7	0.107	14.31
U28	343.6	0.022	7.56
U31	79.1	0.215	17.01
U32	105.1	0.094	9.88
U35	83.8	0.210	17.60
U40	66.4	0.169	11.22

Table 5. Measured and Calculated N Mineralized in Soils with no Addition of Fertilizer N at Chaouia and Abda Regions.

Soil No.	Soil Type	Measured		Calculated[a]
		Cropped	Bare	
		Chaouia Region		
		mg kg^{-1}		
U10	Typic Chromoxererts	133.64	83.47	126.81
U15	Typic Rendolls	123.29	135.50	168.70
U18	Xerochrepts	115.56	140.28	100.25
U19	Xerochrepts	122.43	143.85	102.60
U24	Argiustolls	125.87	75.62	104.99
U33	Aridic Subgroup of Ustolls	142.75	127.97	82.20
U39	Xerochrepts and Ustochrepts	127.03	141.98	117.91
Average		**127.23**	**121.24**	**114.78**
		Abda Region		
U19	Typic Rendolls	129.35	126.20	109.44
U28	Typic Rendolls	138.98	158.06	101.95
U31	Eutrochrepts	152.60	135.61	76.54
U32	Palloxererts	102.23	126.12	81.64
U35	Chromoxererts	41.60	115.36	80.86
U40	Argiustolls	71.98	80.46	61.94
Average		**106.12**	**123.64**	**85.40**

[a] $N=N_0*(1-e^{-kt})$ where t=16 and N_0 and k are parameters determined for each soil

Table 6. Correlation Coefficients Between Different N Availability Parameters in Semi-Arid Soils.

Models[a]	**Probability**		**RMSE**
	Model	**Intercept**	
Uptake=25.25+0.093N_0	0.000	0.000	12.09
Uptake=0.235N_0	0.000	-	15.07
Uptake=29.76+0.311(N_0k)	0.000	0.000	10.74
Uptake=0.885(N_0k)	0.000	-	21.32
Uptake=-3.51+0.44N_0-0.001N_0^2	0.000	0.519	11.20
Uptake=0.403N_0-0.001N_0^2	0.000	-	11.18
Uptake=27.46+0.45N_0k-0.001$(N_0k)^2$	0.000	0.000	10.71
Uptake=1.654N_0k-0.011$(N_0k)^2$	0.000	-	15.22
Uptake=22.46+0.462Ninit	0.000	0.000	10.43
Uptake=0.951Ninit	0.000	-	14.22
N_0=88.41+1.565Ninit	0.000	0.000	40.58
N_0=3.463Ninit	0.000	-	55.19
N_0k=-4.549+0.978Ninit	0.000	0.136	18.25
N_0k=0.879Ninit	0.000	-	18.31

[a] N_0=N mineralization potential, k=decomposition rate, N_0k=product of N_0 and k, Ninit=Mineral N initially present in soil, RMSE=Root Mean Square Error

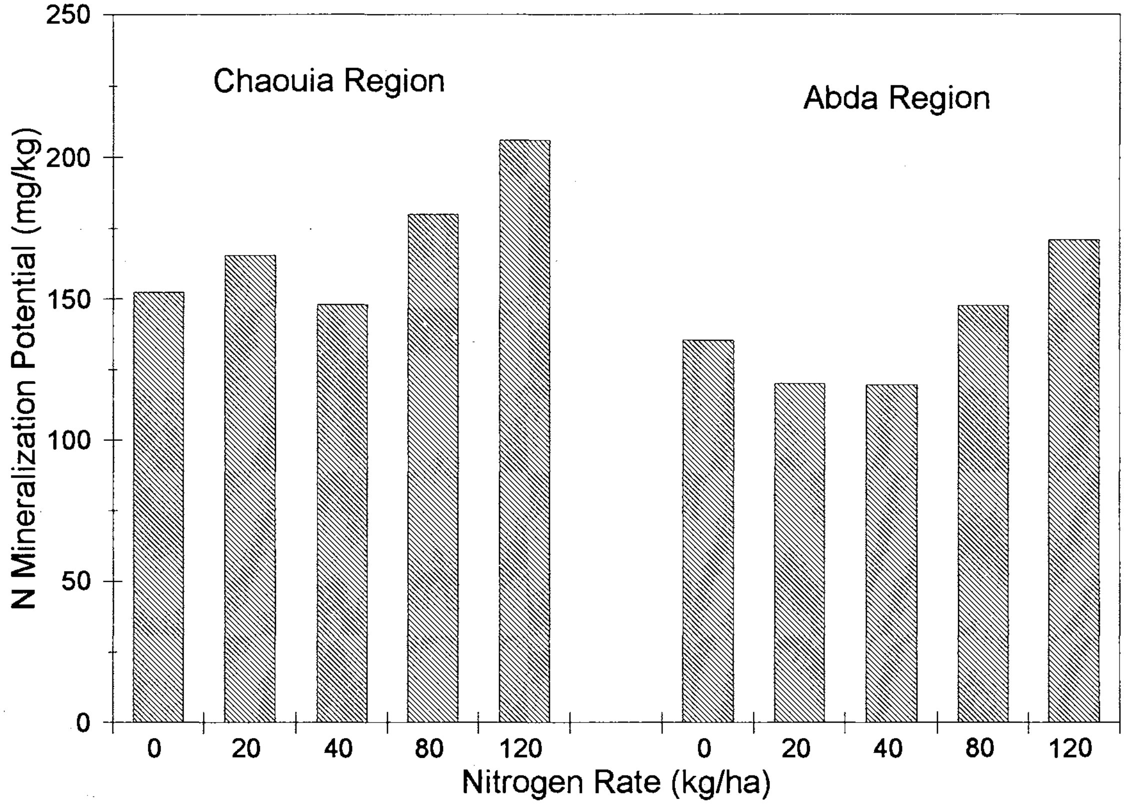

Fig. 1. Effect of N Fertilizer on N Mineralization Potential at Abda and Chaouia Regions

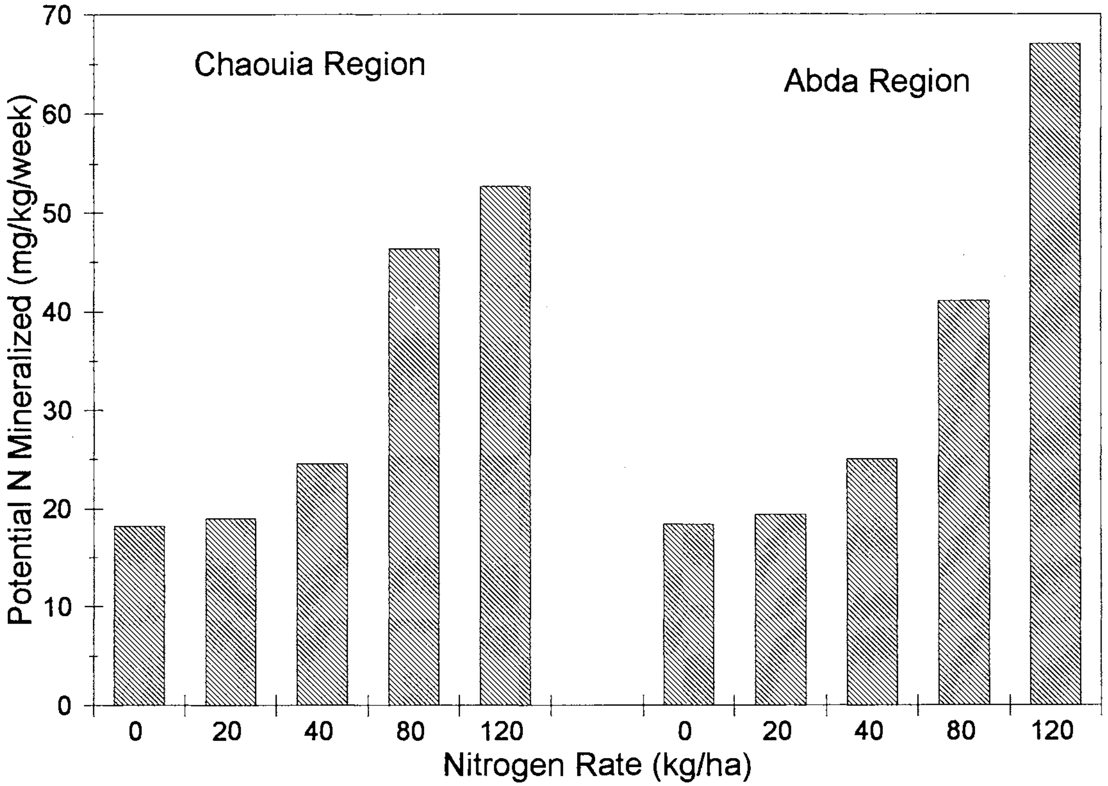

Fig. 2. Effect of N Fertilizer on Potential N Mineralized per week (N0k) at Abda and Chaouia Regions

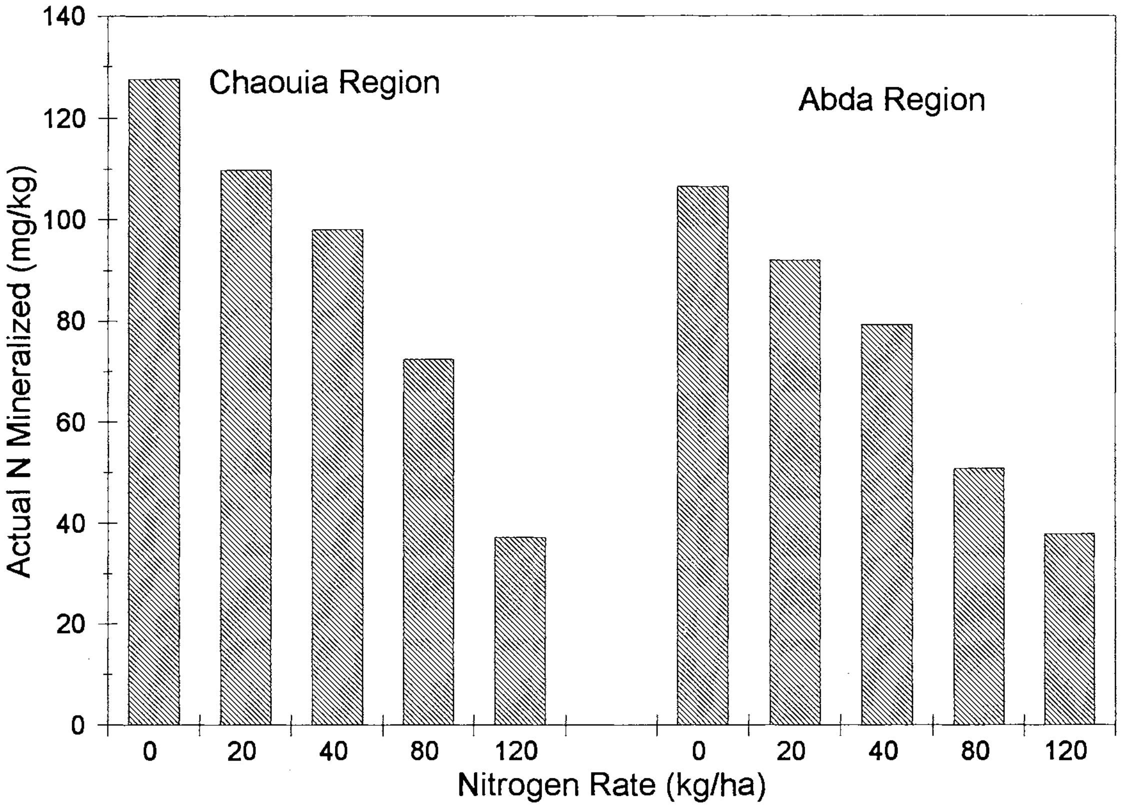

Fig. 3. Effect of Fertilizer N on Actual N Mineralized at Abda and Chaouia Regions

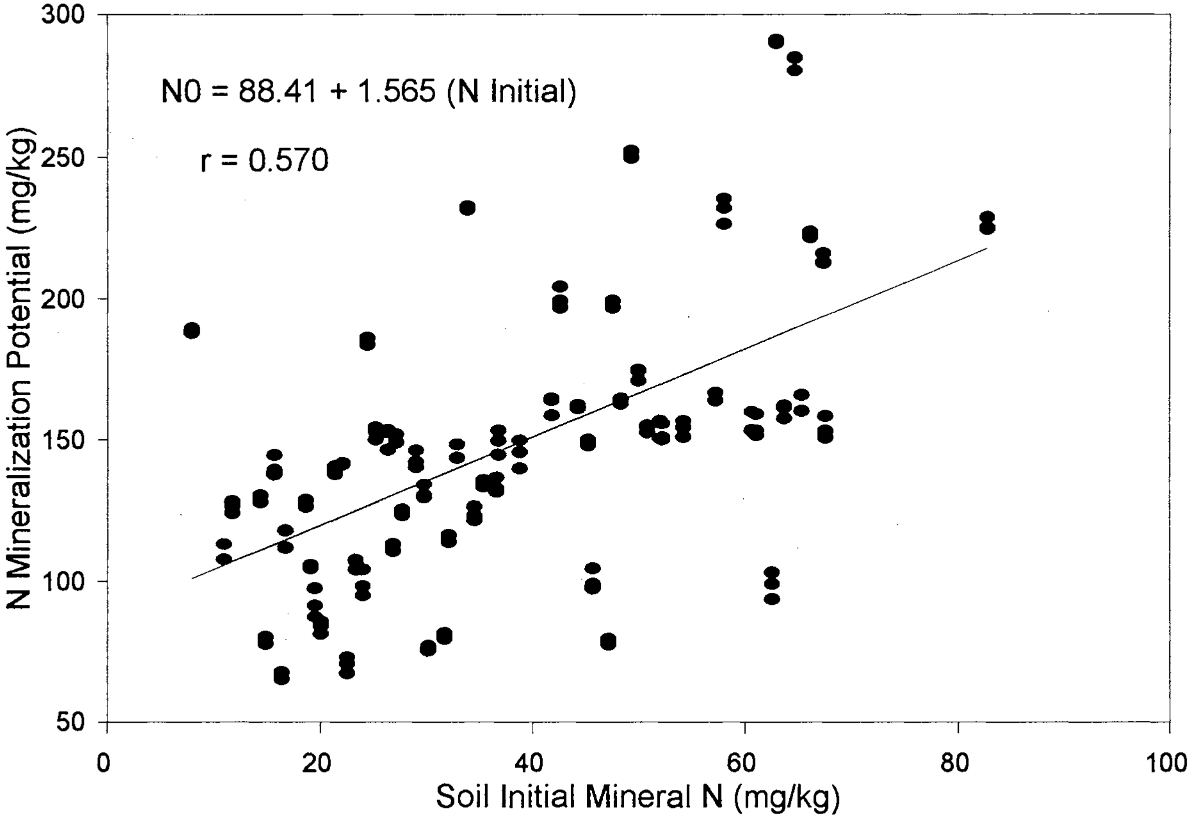

Fig. 4. Nitrogen Mineralization Potential and Soil Initial N Relationship.

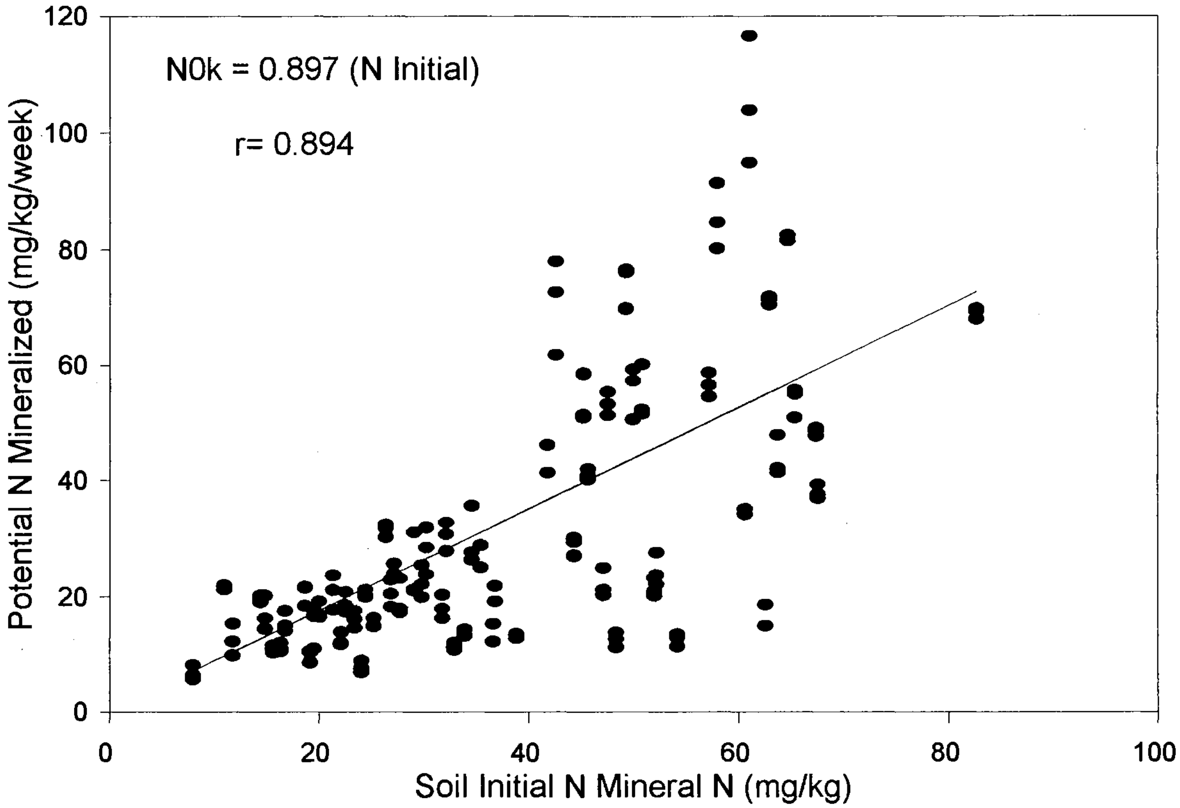

Fig. 5. Potential N Mineralized per Week and Soil Initial N Relationship.

CHAPTER VI

GENERAL CONCLUSIONS

GENERAL CONCLUSIONS

Nitrogen Mineralization potential (N_0) is a measure used to characterize soils according to their ability to supply mineral N from their content of organic N. Nitrogen mineralization potential were determined for different soil types of Oklahoma and Morocco under different environments and different soil management systems.

Nitrogen mineralization potential is strongly affected by soil type. Soils of Morocco were found to have a higher potential compared to those of Oklahoma.

It is obvious, from this study, that continuous cropping or a uniform crop rotation decrease the ability of soils to supply mineral N.

The N supplying power of soils under both Oklahoma and Morocco conditions was increased significantly by the application of fertilizer N. However, there was a significant N fertilizer x soil types interaction. The positive effect of fertilizer N on soil's N_0 was not obvious at depth below 45 cm, though in some soils it was observed at 60 cm deep.

The amount of N mineralized in the surface soil accounted for more than 50% of the total N mineralized in the soil profile (0 - 60 cm).

Nitrogen mineralization potential was found to be strongly related to both wheat N uptake and dry matter yield in Morocco and to grain yield and grain N uptake in Oklahoma. The relationships obtained for Oklahoma soils were not as good as those obtained for Moroccan soils. This is believed to be due to the fact that grain yield and grain N uptake used in the relationships were an average over a number of years and not for the year of the soil sampling.

These relationships were significantly improved by the use of the product of N_0 and the decomposition rate constant. The significant relationships obtained in this study emphasize once more the importance of the amount of N coming from soils during the growing season and suggest that N_0 or N_0k could be used as an index to predict the amount of N a soil can supply.

The application of fertilizer N, though increased the soil's potential to mineralize organic matter under optimum conditions of temperature and soil moisture, it decreased the actual amount of N mineralized in soils during the growing season.

VITA 2

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Doctor of Philosophy

Thesis: LONG-TERM N FERTILIZATION EFFECTS ON N MINERALIZATION POTENTIAL IN SOILS UNDER DIFFERENT CROPPING SYSTEMS AND DIFFERENTENVIRONMENTS

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