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SOIL NITROGEN FORMS IN RELATION TO CROP RESPONSE

by

Mohamed Abdouh Yacoubi

A Dissertation Submitted to the Faculty of the

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In the Graduate College

THE UNIVERSITY OF ARIZONA

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THE UNIVERSITY OF ARIZONA

GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by MOHAMED ABDOUH YACOUBI, entitled SOIL NITROGEN FORMS IN RELATION TO CROP RESPONSE be accepted as fulfilling the dissertation requirement of the degree of DOCTOR OF PHILOSOPHY

J C Tucker	Dec 3, 1974
Dissertation Director	Date

After inspection of the final copy of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

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*This approval and acceptance is contingent on the candidate's adequate performance and defense of this dissertation at the final oral examination. The inclusion of this sheet bound into the library copy of the dissertation is evidence of satisfactory performance at the final examination.

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ABSTRACT

Twelve soils from three different areas in Arizona were collected, air-dried, and analyzed quantitatively for ammonium, nitrate, organic, and mineralizable nitrogen (N). The pH, electrical conductivity, and selected physical properties were measured on each soil.

Forty-eight 4-liter cans were lined with plastic, weighed, filled with soil and placed in a walk-in growth chamber in a randomized complete block design. Potassium phosphate fertilizer was applied to every pot at the rate of 80 kg/ha, and one-half of the pots received N fertilizer at a rate of 200 kg/ha as ammonium nitrate. Triticum aestivum L. cultivar Cajeme 71, a salt tolerant Mexican wheat, was seeded and all pots were irrigated. The environment included soil moisture above the 25 percent level of the total available water at all times by addition of distilled water, 12 hours daylight at 23 to 26 C and 12 hours night at 13 to 17 C.

After eight weeks of growth the plants were harvested, dried, ground and stored in plastic vials. Total N uptake was computed from total N analysis of sub-samples from each vial.

An identical second cycle was initiated after soil samples had been taken from every pot. A seeding in all pots was then made and the pots irrigated. The wheat was allowed to grow for eight weeks as outlined for the first crop.

The correlations between yield and N uptake were highly significant for both crops. The N concentration which was not correlated with yield in either cycle was highly correlated with N uptake.

Although none of the N test values gave satisfactory prediction of either yield or fertilizer need, nitrate N extracted with 1 M KCl was found to give the best correlation with yield and N uptake by the first crop. In the second cycle data of all N forms, the nitrate plus ammonium N resulted in the highest correlation with both yield and N uptake.

When the previous crop was a legume, the effect was to reduce the response to or need for additional N to the first crop, but the second crop did not show any differences related to crop history among any soils. Among the controls, the yields were much lower where cotton was the previous crop for two to four years as compared with the average for all soils. Also the first crop yield relationships with both nitrate plus ammonium and mineralizable N were linear and positive in the cases where no legume had been grown for two to four years, but linear and negative for soils having had alfalfa for a like period.

The correlations between initial N and soil N levels after the first crop as well as between initial N levels and second crop yields, and between the first and the second crop yields were also investigated.

INTRODUCTION

The need of plants for nutrients in general and nitrogen (N) in particular, has been known since the beginning of the eighteenth century (Dunham 1957). The necessity for efficient use of N, however, did not receive as much attention until recently. This attention was prompted by the increasing awareness of profit maximization achieved by applying optimum amounts of N to the soil, by pollution hazards caused by excessive N application and, lately, by supply limitations brought about by the current energy crisis.

Nitrogen being one of the essential mineral nutrients for plant growth, and the most abundant in plants thus has obvious importance. In addition to all its other functions in plants, N enters into the structure of the protoplasm of the cells. In view of this protoplasmic requirement, N is an important component of soil fertility. This importance resulted in prompting numerous investigations during the second half of this century. Nitrogen's normal low abundance in cultivated desert soils and its easy removal by natural processes make necessary the addition of a continuous supply to the soil for fertility maintenance. Low deficient N levels reduce yield drastically and lower crop quality; however, excessive amounts may be equally detrimental. The tremendous increase in N fertilizer use, especially since 1950, has significant economic and social importance. The principal concern of farmers is how much, when and how to apply fertilizer to optimize yield and/or maximize profits. Adequate means to achieve this goal in different cases are as yet unavailable, and an improvement of fertilizer use efficiency is needed.

To improve N use efficiency, one must insure that the soil always contains a sufficient amount to supply the minimum required to produce the yield objective. To achieve this, the exact amount of the various forms of N in the soil important to plant growth must be known so the quantity to be supplied in the form of fertilizer can be calculated. A suitable N test, i.e., one which will give the best correlation with crop response, is needed.

Soil nitrate N traditionally has been measured to determine fertilizer requirement. In numerous cases, however, this test failed to be adequate (Russell 1914, Harmsen and Lindenberg 1949, Rappe 1950, Black 1965). Hence a careful study of different forms of N in the soil and their correlation with crop yield and plant N uptake might provide insight to the usefulness of the NO_3^- soil test, or need for its modification.

The purpose of this study is to evaluate the usefulness of different soil N tests (analyzing for different N forms) in predicting yield and fertilizer need, when the soil crop history is taken into consideration, by comparing correlations between the N forms and yield, nitrogen uptake, and nitrogen concentration in the plants.

LITERATURE REVIEW

After the development of fertilizer, its use spread increasingly to all areas of the world resulting in higher yields and superior quality of numerous crops. Parker (1946) reported that world wide use of N fertilizer increased from 720,000 tons of N in 1913 to 2.8 million tons in 1937. A report by the Food and Agriculture Organization (FAO) mentioned that world N fertilizer consumption was 33.7 million tons in 1971-1972, representing 47 percent of the total nutrient consumption, two percent more than 1969-1970 season (FAO 1970, 1973a, 1973b). The Tennessee Valley Authority (TVA) predicted the N fertilizer use in 1975 as 44 million tons (cited by Olson et al. 1971).

Lower price, higher production and the common belief that large amounts of N were good for crops, resulted in excessive use leading to pollution by nitrates and contamination of drainage and underground water (TVA 1969). Oertli and Bradford (1973) found that the drainage water from corn fields contained the largest amounts of nitrates (2.7 meq/l) among carrot, asparagus, citrus and vineyard plots.

In developing countries, such as Algeria, N fertilizer use increased from 29,000 to 78,000 metric tons from 1970-1971 to the 1971-1972 season. In Morocco the increase from the 1965-1966 to the 1971-1972 season was 26,000 tons, a 115 percent increase (FAO 1973a, Tisdale and Nelson 1966).

Forms of Nitrogen in the Soil

Inorganic Nitrogen

Nitrogen occurs in either organic or inorganic forms in the soil; however, the plowed layers of most soils contains only .02 to .4 percent of N by weight (Black 1968). According to Waksman and Iyer (1932), the nitrate and ammonium forms amounted to less than two percent of the total N. Black (1968) reported that N in the gaseous elemental form was present in the soil atmosphere or dissolved in the soil solution, as well as absorbed on the dry surface of soil particles. Buckman and Brady (1969) traced the origin of this form of nitrogen mainly to the atmospheric air or less likely to the volitilization and denitrification of certain nitrogenous compounds such as nitrites. Nitrogen gas can be used both by symbiotic or non-symbiotic microorganisms, but in general it is not directly available to higher plants (Black 1968, Buckman and Brady 1969).

The combined inorganic forms of nitrogen in the soil occur as nitrous and nitric oxides, nitrates, nitrites, and ammonium. Nitrous and nitric oxides are gases occurring in trace amounts and are considered insignificant in relation to plant growth (Black 1968). Nitrate, nitrite and ammonium nitrogen are present in ionic forms in the soil and are readily absorbed and utilized by plants (Hoagland 1944).

Organic nitrogen forms constitute about 98 percent of the total nitrogen in most soils. This makes the organic nitrogenous compounds in the soil very important for fertility considerations (Bremner 1951).

Ammonium Nitrogen. Ammonium is formed as the first product of organic matter mineralization in soils; in most agricultural soils, however, this ammonium formation may be obscured (Waksman 1952, Black 1968). This is due to the fact that free ammonium was not found to accumulate in arable soils because of the higher rate of oxidation of ammonium to nitrite and then to nitrate (Harmsen and Van Schreven 1955).

In grassland, although the free ammonium nitrogen content is generally negligible throughout the season the ammonium concentration never falls below a certain limit (Theron 1951, Jackson 1958). More precisely, Richardson (1938) found the ammonium content in the grassland to range between 3 and 9 ppm under ordinary field conditions during a three year study conducted on well drained mineral soils. Later, however, Rappe (1950) reported higher levels for soils very rich in humus. Black (1968) pointed out that, especially at high pH, ammonium nitrogen becomes possible only when a surplus of carbohydrates is not available to the microorganisms.

The ammonification process which is controlled by many factors, such as pH and energy, affects the quantity and forms (readily available, fixed, etc.) of ammonium nitrogen in a given soil. Fraps and Sterges (1947) pointed out that ammonification and nitrification processes are not necessarily interrelated. The fact that ammonification proved to be active at temperatures as low as 0 to 5 C (Jenny 1928), probably explains why ammonification is much more common than nitrification in Tundra soils, in spite of the slow rate of the process (Harmsen and Van Schreven 1955).

Although the process of mineralization, as a whole is aerobic, Amer and Bartholomew (1951) found that ammonification was not necessarily an aerobic process; hence, the formation of ammonium is not hampered in soils containing very high moisture percentage. In support of this fact, many workers reported that ammonification was almost normal in water-logged, anearobic rice paddies (Bamji 1938, Bhuiyan 1949). Similarly, Smith and Cook (1947) found that in pots where large amounts of nitrogenous compounds were incorporated in the compacted soil, the nitrogen mineralization proceeded only up to the ammonium stage due to the anaerobic condition.

Cornfield (1953) studied the effect of acidity on mineralization. He found that a substantial lowering in pH of a nearly neutral clay soil (pH 6.65) resulted in a significant reduction in mineralization. Ammonium accumulated in acidified samples (pH 4.00) because ammonification decreased only slightly, whereas in some cases, nitification was completely suppressed. Fraps and Sterges (1947) also found that ammonification in Texas soils was not as sensitive to low pH as nitification. Other workers attributed the faster nitrification rate of anhydrous ammonia over ammonium sulfate fertilizer in acid soils to the probable rise in pH value caused by the ammonium (Eno and Blue 1954). Similarly, Volk (1959) reported that increasing soil pH of Florida soils decreased their ammonium-adsorption potential and resulted in greater ammonium volatilization from applied urea.

Chalaust (1948) found that a moderate salt concentration did not affect the ammonification of blood meal in the sandy soils of the Camargue (France) where he was working.

It is known that all degrees of availability of ammonium, from the free ion to the non-extractable forms, are found in most soils (Jenny and Overstreet 1939, Cornfield 1953, Harmsen and Van Schreven 1955). It was reported that ammonium nitrogen is strongly retained by adsorption especially in the fine textured soils (Jones 1942). That is, it can be trapped in the voids found in the crystal lattice of soil clay minerals. Allison, Doetch and Roller (1953) found that subsoils have, in general, a five to ten times stronger power to fix ammonium than the surface soils. They also suggested that illite was the most important ammonium fixing mineral in soils, although the much less occurring vermiculite has a higher fixing capacity when moist. Montmorillonite has a lower fixing capacity than illite, and pure kaolinite does not fix ammonium. In all cases, however, the rate of fixation decreases when the samples are heated to 100 C. Rodrigues (1954) pointed out that an appreciable amount of fixed ammonium N, extractable with hydrofluoric acid, may be present in relatively stable inorganic forms associated with certain clay minerals.

More recently, a different type of ammonium fixation was observed by Tamini, Kanehiro and Sherman (1963) when they obtained evidence from X-ray diffraction for the formation of a crystalline ammonium, iron, aluminum phosphate (taranakite) in soils treated simultaneously with soluble phosphate and ammonium. On a similar scale, Adams and Stevenson (1964) reported the inclusion of ammonium in primary silicate minerals such as micas and feldspars, where it appears to occupy sites normally occupied by potassium.

Ammonium N also occurs in a relatively stable organic form in the soil. Mattson and Kautler-Anderson (1943) showed that lignin was able to fix ammonium in a non-exchangeable form in the soils under field conditions by forming a resistant complex from which NH_4^+ could not be released by strong acids or alkalies.

When formation of nitrate is too slow, some plants such as trees, shrubs, and grass are forced to absorb N in the ammonium form (Harmsen and Van Schreven 1955, Voight 1958). On the other hand, Richards and Shrikhande (1935) reported that microorganisms "preferred" the use of ammonium over nitrate N.

Although not leachable, when held on the exchange complex, it can be easily oxidized under favorable conditions. Readily exchangeable ammonium availability depends upon the presence of a complementary ion in the soil solution. Albrecht and McCalla (1937) showed that the ammonium ion adsorbed on the clay particles was readily used by nitrifying microorganisms. They indicated, however, that adsorbed Ca^{++} may play an important role in accelerating the nitrification process.

<u>Nitrite Nitrogen</u>. Harmsen and Van Schreven (1955) reported that accumulation of nitrite N has never been found to an appreciable level in most cropped soils. They inferred that the oxidation of ammonium to nitrite must be slower than the formation of nitrate from nitrite N. In exceptional cases where accumulation of nitrites was observed, the soil pH was found to be rather high. Similarly, Fraps and Sterges (1947) reported that nitrite accumulated in soils to which magnesium carbonate or lime had been applied. This fact was later confirmed by Chapman and

Liebig (1952) who found that the accumulation of nitrites occurred under alkaline conditions, especially following heavy fertilization with nitrogenous substances or ammonium compounds. They also observed that accumulation of nitrites was favorably enhanced when urea was used as a source of N. They further reported that nitrite remained sometimes for as long as two or three months in the soil; however, they did not detect any presence of nitrites in denitrification of nitrate. Soulides and Clark (1958) found that in all cases, the occurrence of nitrite N could be correlated with the presence of a high ammonium content in the soil along with a neutral or alkaline condition. Tyler, Broadbent and Hill (1959) observed an accumulation of nitrite N during incubation at temperatures as low as 2.8 to 7.2 C. This agrees with the fact that nitrate formation is more sensitive to low temperature than nitrite formation. Aeration and moisture content are also very important factors in the buildup of nitrites in the soil.

Bingham, Chapman and Pugh (1954) reported that although nitrite is readily absorbed by higher plants, it had some toxic effects. They also found that below a critical toxic level, the presence of nitrites in soils was of no importance for crop production.

Nitrate Nitrogen. Hoagland (1944) established that most higher plants absorb N in the nitrate form under ordinary conditions. It is not surprising then, to find that most of the early investigators studied the nitrate N content of the soil and its variation as a function of such important factors as climate, season, crops, moisture, temperature, soil structure, humus content, and soil treatment such as tillage, mulching, and fertilization (Greaves, Stewart and Hirst 1917; Crowther and Mirchindanu 1931; Albrecht 1937; Russell 1961). That is also why the nitrate content of the soil has been used as a basis for soil fertility evaluation and fertilizer recommendations (Harmsen and Van Schreven 1955).

According to Russell (1914), the amount of nitrate formed over a period of time constitutes a good measure of thelevel to which organic matter decomposition has proceeded. This is based partly on the fact that the nitrate is actually the end-form in the chain of the decomposition and nitrification processes.

King and Whitson (1901) studying corn and potato fields in Wisconsin found that in the first foot of soil, nitrates were present in relatively small amounts in early spring, increased somewhat rapidly until July first, decreased until August first due to vigorous crop growth, then remained more or less constant with a slight tendency to rise until September. Russell (1914) stated that nitrates showed the greatest fluctuation and the highest susceptibility to textural influences over all other soil constituents, including even soil moisture. Batham and Nigam (1930) reported similar results. They also observed that the nitrates are removed to a large extent during wet winters, while they are found in the largest amounts in spring when the preceding winter and summer have been dry. Prescott and Piper (1930) reported nitrate accumulation to be highest in late spring in the soils of Australia. More generally, Shields (1953) found that relative humidity of 40 to 70 percent and temperatures of 34 to 38 C were optimum conditions for nitrate accumulation.

It has long been known that nitrates were among the most mobile forms of N compounds in the soil (spatial fluctuation). This mobility was attributed to the fact that the nitrate was a negatively charged ion and therefore was not adsorbed on the exchange complex. Similarly, many investigators established that the nitrates are free to move with soil water (Krantz, Ohlrogge and Scarseth 1943; Shopkhoyev 1958). Puchner who, as early as 1895, found that the soluble salts "rose and sunk" with the soil moisture, established that once the nitrates are present in the soil, their movement depends to some extent on the chemical and physical properties of the soil except for the water applied and the ion diffusion phenomenon. Lyon et al. (1930) found that due to leaching nitrates migrate from upper to lower horizons. Similarly, Shopkhoyev (1958) detected nitrates at a depth of ten feet in the central part of the European Soviet Union.

During periods of prolonged drought, when the net movement of moisture is upward, the fact that nitrates move upward with the soil solution as a result of capillarity was observed by many workers (Krantz et al. 1943). In semi-arid and irrigated areas of the world, where significant leaching of nitrates does not usually occur, there are relatively high concentrations of nitrate N in the surface soil. Early observations of these accumulations were reported by Hilgard (1906), Stewart and Peterson (1916), and Prescott (1919).

Texture affects significantly the movement of the nitrates in the soil (Larsen and Kohnke 1946, Webster and Gasser 1959); however, according to Jones (1942), nitrates, when present, can be leached from a clay soil as readily as from a sandy soil, except that the rate of diffusion will be slower in the finer textured soil.

The type of plant also affects the pattern of nitrate movement in the soil profile. Nitrate movement is not identical under a corn culture system and alfalfa or clover (King and Whitson 1901, Stewart and Greaves 1911). Therefore, plant root system and N use by the crop influences N movement.

In irrigated lands, the fluctuation of nitrate N is even larger. Jewitt (1945) came to the conclusion that hardly any regularity can be expected in the mineral N variation in these soils. Greaves et al. (1917) observed that nitrate N in the surface layer decreased while the quantity formed increased with increasing applied irrigation water.

Under grass cover it has been noted that the nitrate content is usually lower than in arable lands. Some workers observed that nitrate N in grass lands remains very low during the whole year, and that favorable conditions for available N immobilization by microorganisms prevail (Bizzel 1922, Prescott and Piper 1930, Gerretsen 1950).

Organic Nitrogen

Although most of the nitrogen in the soil occurs in organic form, only one to two percent is made available during the growing season (Waksman and Iyer 1932). In a review, Bremner (1951) mentions that under laboratory conditions, 30 percent of the soil N is resistant to acid or alkaline hydrolysis.

In arid and semi-arid areas, the arable soils are generally characterized by a great deficiency in organic matter and N. Oberholzer

(1936) pointed out also, that as far as organic matter content is concerned, the main difference between the soils of arid and humid regions, is that lignins are relatively more rapidly attacked in arid soils.

The N organic fraction was found to consist of approximately one-fourth non-hydrolyzable material, one-third amino acids, one-tenth amide and ammonium N and one-fifth soluble material (Kojima 1947). Since, several workers have performed the analyses in more detail and identified further the various compounds comprising the organic N in the soil. Recently Vlassak, Vestraeten and Livens (1969) found that when plants were taken into consideration, 20 percent of the total soil N was accounted for by ammonium N, about 30 percent as organic N, and 50 percent as acid-insoluble N organic-complexes in the hydrolysates obtained from the eight different soil profiles studied. Amino sugars and chitin were found to account for five to ten percent, and in some cases from six to fourteen percent for total soil N.

Studying the protein fraction in a highly organic muck soil, Kojima (1947) estimated at 37 percent the N fraction that was liberated by acid hydrolysis as α-amino N. Later, Bremner (1952) found this value to vary from 24 to 37 percent, and that about one-third of the soil N is in a protein form. If it is assumed that all the ammonium N that appears in a soluble form as a result of acid hydrolysis, which is used to liberate amino acids and amino sugars from the soil organic matter, comes from protein residues, it can be concluded that as much as 50 percent of soil N is in protein form. The amino acid composition of protein materials of different soils was found to be roughly similar. The same author (Bremner 1952) found that nucleic acids do occur in soils as part of the fluvic fraction of soil organic matter, but generally do not contain more than five to ten percent of the soil N. At present, many questions remain unanswered about the precise composition of the fluvic acid fraction in the soil (Watson and Parsons 1974). The occurrence of free amino acids in the soil was reported by many workers, but in every case the amounts detected were considered very small (Dadd, Fowden and Pearsall 1953; Bremner 1965).

Brigham (1917) showed that plants can absorb and assimilate some types of amino acids and aliphatic amines. He also found that the amount absorbed was a function of the plant species and the nature of the organic matter. Ghosh and Burris (1950) reported responses of tomatoes and clover to organic nitrogen compounds that were similar. On the other hand, they found that tobacco had less tolerance for amino acids and many of them even inhibited its growth. Using N^{15} techniques, they showed that, in general, the plant first uses its reserve of N in the seed, then ammonium and finally amino acids. At 1000 ppm, however, all amino acids, with the exception of alanine and glutamic acid, were found to inhibit root growth (White 1937, Audus and Quastel 1947).

Nitrogen also occurs in a certain set of organic complex-patterns that are unavailable to plants and not extractable by ordinary chemical procedures. Several theories concerning the nature and availability of the N in these complexes have been advanced. In 1932, Waksman and Iyer proposed the ligno-protein theory. A decade later, Ensminger and Gieseking (1942) explained the unavailability of this type of N as being due to both adsorption and stabilization or organic N compounds by the clay minerals. Mattson and Kautler-Anderson (1943) proposed the theory that in the process of humus synthesis the interaction of ammonium and oxidized lignin would produce a resistant N complex.

The unavailability of organic N as well as the stability of organic matter may be more apparent than real as Broadbent and Norman (1946) suggested. They attributed this unavailability to the absence of energy material needed to sustain a vigorous microbial population.

Nitrogen Transformation

It has long been known that plants and microorganisms compete very strongly for the available N in the soil. This competition can, in frequent cases, limit plant growth and reduce yield (Kelley 1915, Sievers and Holtz 1926). More recently, Harmsen and Van Schreven (1955) stressed, in a review, the limited value that the use of the momentary amount of soil mineral N has in the estimation of N requirement for crops. Many soil scientists have attempted to develop a method to measure nitrification rates of various soils in relation to response of crops to fertilizers since the turn of this century (Brown 1916, Burgess 1918, Fraps 1920). From these studies, the need for better methods to estimate the soil and cropping system to supply N became evident. Recent concern about N conservation created more interest in this subject.

The dependence of the rate of organic matter decay on numerous factors such as climate, vegetation and soil physical conditions complicates the problem (Jenny 1941). It has been found that the presence of certain specific clay minerals reduced markedly the hydrolysis of proteins by proteolytic enzymes. This hydrolysis which is indicative of the N availability, depends upon the pH of the medium and the clay mineral cation exchange capacity (Ensminger and Gieseking 1942). Later, Bower (1949) and Allison, Sherman and Pinck (1949), independently, found similar results on the hydrolysis of nucleic acids by nuclease enzymes.

Ammonium fixation is also related to N transformation. Allison, Doetch and Roller (1953) found that nitrate formation was a rather accurate measurement of the difficultly exchangeable NH_4^+ availability. The same studies showed that much less than ten percent of the fixed ammonium ions were available to nitrification. In soils where the fixation was by montmorillonite, the availability was slightly higher, but still below 15 percent. Similarly, Bower (1949) found the proportion of the difficultly-exchangeable ammonium nitified to be 13 to 23 percent after 14 days of barley plant growth.

The extent of higher plant-microorganism competition for N is influenced by the carbon to nitrogen (C:N) ratio in the soil. The importance of this ratio has long been recognized and its role in nitrate accumulation in the soil and crop production has been stressed in the extensive literature on this subject.

The C:N ratio was found to determine the amount of mineralized N during incubation (Cornfield 1952). It was also shown to remain within well-defined limits in the surface of the soil. This stability was so reliable that it has been used as a basis for organic matter calculations (Sievers and Holtz 1926). The two workers also suggested that the ratio approaches that of the microbial tissue. The reason for this stability, however, cannot be seen readily (Stevenson 1959). Cultivation may lower the C:N ratio in the surface layer, probably, by enhancing the fixation of ammonium N in the crystal lattice of the clay minerals (Leighty and Sharey 1930; Stevenson, Dhariwal and Choudhri 1958; Stevenson and Dhariwal 1959). The C:N ratio was found to generally decrease with increasing depth.

Crowther and Mirchandanu (1931) found that N was made more rapidly available from materials that had 13:1 than that with 26:1 C:N ratio. This indicates that the conditions which encourage organic matter decomposition result in narrowing the C:N ratio and are beneficial for crops. It was found that in soils with C:N ratios above 35:1 there is N stress in plants caused by excessive microbial activity, between 35:1 and 25:1 the amount of ammonium released will be about equal to the need of the heterotropes, and under 25:1 the N released from organic matter will be higher than the rate of inorganic N used by heterotropes thus N will be available for plant use (Iritani and Arnold 1960).

It is appropriate to conclude that cultural practices which maintain soil N, will aid in the maintenance of the maximum soil organic matter level possible under the prevailing environmental conditions.

Soil Nitrogen Tests versus Crop Response

An accurate satisfactory test for soil N has not been developed. The amount of N available for a crop is very hard to determine due to the fact that N is subject to microbial transformations to a far greater extent than any other plant nutrient. Only a small part of the total nitrogen is active. In some non-cultivated soils as much as 50 percent of the total available N is "monopolized" by microorganisms (Gainey, Sewell and Myers 1937; Gerretsen 1950).

Bray (1949), specifying "the requirements for a successful soil test," reported that there were three criteria, namely, the total (or a proportionate part) of the available form or forms should be measured, the extraction should be of reasonable accuracy and speed,and the amounts extracted should be correlated with the growth and response of each crop. The latter requirement has not been satisfied largely because of variability in the amounts of the available forms during the season and variations in rate of release from unavailable forms.

It is difficult to assess the part that can be utilized by plants when evaluating the ammonium N in the soil. This is due in part to the fact that plant roots are capable of absorbing the ammonium from the crystal lattice of the clay minerals. Since only a slight proportion of the fixed ammonium is available to plants, extracting the soil N with electrolytes such as KCl or NaCl would remove the ammonium ions that give only a value which more or less corresponds with the availability to the plants (Harmsen and Van Schreven 1955).

The amount of nitrate N in the soil fluctuates with any of the many variable factors mentioned earlier. Due to this fluctuation, Harmsen and Lindenberg (1949) and later Rappe (1950), recognized that the determination of soil nitrates does not give accurate information about the need for N fertilization. On the other hand, Omar et al.

(1969) found that the one percent K_2SO_4 extractable N can be used successfully as a reliable index for predicting available N status in Egyptian soils. They also showed that the modified Mitscherlich-Baule equation in the form $Y = 100(1-10^{-0.01b-0.0084x})$ could be used meaningfully to determine N fertilizer needs. Gardner and Tucker (1967) reported that soil nitrate can be used "as a diagnostic tool" to predict the needs of cotton for N at the early stage of growth. Unless the yield possibility can be predicted accurately, they noted, this soil nitrate test value cannot be used to predict either N requirement or maximum yield. They also showed that sampling location in cotton beds was very important for a meaningful soil N test.

Harmsen and Van Schreven (1955) mentioned in a review that Koenig and Hassembaumer were reported to have observed a rather good correlation between the mineral N and the N requirements of the crop. In the same review, they mentioned that Goy and Koenig observed similar relations in 1928 and 1929, respectively, and that in 1932, Nemek and Koppova found the amount of soluble N to be related to the response of the crops. Similarly, Carpenter, Haas and Miles (1952) found a highly significant correlation between grain yield and the N content of the soil for the 0 to 6 and 6 to 12 inch depths. They pointed out, however, that the relationships were not as close as those between yield and plant N uptake. Similarly, even when the calculations were based on individual analyses, Allison and Sterling (1949) obtained highly significant correlation coefficients (0.7 to 0.8) in all cases. Data were, however, obtained with different crops but only one soil type.

There has been relatively little done on the study of crop response to N fertilizer in relation to the soil organic N, although the latter is the reservoir of native N utilized by plants (Stojanovic and Alexander 1958). Millar (1955) pointed out that organic N in the soil is not a reliable indication of the N availability to plants during the growing season. He suggested that one of the reasons is that the rate of organic matter decomposition is affected by numerous environmental factors. Some attempts have been made to predict, on the basis of organic matter, the amount of N that will be available to plants during a given season. Woodruff (1949) suggested that the organic matter content of the soil would provide a satisfactory basis for estimating the N fertilizer required. He based this on his findings in Missouri, that the average delivery of N from the soil was two percent for corn, one percent for small grains, and 0.75 percent for a crop of non-leguminous meadow. He also assumed the amount of N required by each crop to be known.

Tests for predicting available N throughout the growing season have been receiving more attention than other methods in the last two decades. A recent procedure has been reviewed and outlined by Stanford and Hanway (1955). From the incubation data, a "potentially mineralizable N" value is computed for the soil. The artificial conditions of this test obviously are not representative of the field conditions; therefore, data thus obtained need to be correlated with field conditions and the N requirement of the crop if results are to be meaningful (Beaton, Warren and Hubbard 1960).

Several investigators worked, using laboratory incubation methods, to establish relationships between the ability of soils to produce N and crop production (Kellerman 1911; Brown 1916; Lipman, Burgess and Klein 1916; Burgess 1918; Fraps 1920; Gainey et al. 1937; Allison and Sterling 1949; Harmsen and Van Schreven 1955; Harpstead and Brage. 1958; Beaton et al. 1960). In general, these relationships were found to be fairly close, and more so when experiments were more carefully controlled. When only one soil type was used, White et al. (1949) obtained a correlation significant at the one percent level for these test values. Yet, it is important to be aware of the limitations the incubation method induces by the interaction among the factors affecting the incubation techniques. It is more difficult to interpret the results obtained from this method and advise the farmer than to run the test itself. The time involved makes this method very expensive to use for a low cash crop or for an average farmer.

Richardson (1938) showed that it is difficult to apply the incubation method to grassland and forest soils. Beaton et al. (1960) could not find a good correlation between the cumulative total N formed and the yield obtained from eight grassland soils in British Columbia. They also showed that soil textural differences can influence the formation of nitrate N during incubation, in that finer textures may provide favorable moisture conditions for the nitrate formation. Harmsen and Van Schreven (1955) found that soil fertility, soil depth, slope and exposure might obscure the relationship between the cumulative nitrate and yield.

Various workers found that the field conditions before sampling, the storage period of the samples before incubation, and the moisture content of the soil at the time of sampling are, among others, important factors which have to be considered when incubation tests are interpreted.

Recently, Stanford, Carter and Smith (1974) tried to reduce the incubation period and found that a minimum of two weeks following a pre-incubation period of one to two weeks did give potentially mineralizable N predictions that were as accurate as the ones obtained from longer periods (6 to 30 weeks) for all the 39 widely different soils they studied.

MATERIALS AND METHODS

Plant Growth Conditions

The plant growth phase of this investigation was conducted in a Percival growth chamber. Lighting in the growth chamber was provided by 12 one-hundred-watt tungsten bulbs and 26 cool white 229 centimeter long fluorescent tubes. The spectral energy value for this combination was 10.5×10^4 ergs cm^{-2} sec (2500 foot-candles) at the top of the plants under experiment 65 cm from the light source.

All lights were on from 7:00 a.m. to 7:00 p.m. The air temperature and relative humidity were continuously recorded on a hygrothermograph. The air temperature ranged from 23 to 26 C during light hours and 13 to 17 C in the dark periods. The temperature change required about two hours when the lights came on and about one hour when the lights went off, simulating a natural environment. The air was circulated and mixed at all times by means of five fans mounted on the walls of the growth chamber. Relative humidity fluctuated between 30 and 40 percent during the light hours and 40 to 50 percent during the dark periods.

Experimental Procedure

Twelve different soils of known crop histories were studied. Four were collected from each of the following locations: the Avra Valley area (north of Tucson), the Salt River Valley area (east of

Phoenix), and the Yuma area (University of Arizona Experimental Farm). The soils were air-dried and ground to pass a 4 mm screen. A representative sample was taken from each soil for physical and chemical analyses. A list of soils with preliminary data is presented in Table 1.

Forty-eight four-liter cans were cleaned thoroughly, dried, lined with plastic bags, numbered and weighed. Every four cans (pots) were two-thirds filled with the same soil (about 2200 g of soil per can).

The pots were placed in the growth chamber described above and arranged in 12 rows in order of increasing numbers, four pots per column. All pots received 0.4 g of potassium phosphate (KH_2PO_4) fertilizer mixed thoroughly with soil equivalent to a rate of 80 kg of phosphate per hectare.

A 200 kg of N per hectare fertilizer treatment was applied at random to two of the four pots within each column. The N was applied as 1.09 g of ammonium nitrate (33% N) per pot. The design was thus a randomized complete block with two treatments and two replications.

On March 5th Triticum aestivum L. Cajeme 71, a salt tolerant Mexican wheat cultivar, was seeded in all pots which were then irrigated with distilled water. The pots were subsequently irrigated whenever about 75 percent of the available water had been depleted.

The wheat was allowed to grow for eight weeks under the environmental conditions described previously. On April 29, the wheat plants were harvested by cutting the stems at the soil surface using an industrial steel blade. Some of the plants were in early flowering stage while some were still in early heading or even at jointing stages. The

Table 1. Description and source of soils studied.

Soil	Location	Date Collected	Crop History*	Soil Type	pH	EC(mmhos/cm)
1	Cotton Res. Center(Phx)	1/17/74	c,a,a,a,a	Mohave clay loam	7.59	0.65
2	idem.	idem.	c,c,a,a	idem.	7.75	1.03
3	idem.	idem.	c,sg,sg	idem.	7.83	1.40
4	idem.	idem.	c,c,c,c,c,c	idem.	7.72	1.40
5	Agri.Res. Sta.(Yuma)	1/24/74	f,a,a,a	Pimer silt	7.86	1.43
6	idem.	idem.	a,a,a,a,a	Gadsden silty clay	7.85	4.60
7	idem.	idem.	w,sg,sg, cantalope	Pimer silty loam	7.70	6.00
8	idem.	idem.	w,f,barley, b,b	Indio silty loam	7.68	4.25
9	Avra Val. (Wong Farm Tcs)	idem.	a,a,a	Tubac sandy clay loam	7.50	1.20
10	idem.	idem.	a,a,a	Tubac clay	7.68	1.10
11	idem.	idem.	1,1,1,1,1	Gila loam	7.47	2.05
12	idem.	idem.	f,sorghum, 1,1	Mohave clay loam	7.72	2.40

* The first crop indicated was on the field during 1973; succeeding crops were for previous years: a = alfalfa, b = bermuda grass, c = cotton, f = fallow, sg = small grain, 1 = lettuce.

green matter was placed in paper bags and dried for 72 hours in a 68 C oven. The bags were then weighed, the dried material was ground to pass a 20 mesh screen, and the samples were stored in vials.

A representative sample of about 200 mg was taken from every vial for total N determination. The N determined by the procedure to be described later was expressed on a percentage basis, then multiplied by the total oven-dry weight of dry material harvested from every pot to determine the total N uptake by the wheat plants from the soil in each pot.

After harvest, the soil in each pot was mixed and a representative sample was taken for chemical analysis. The size of the sample was calculated so that the equivalent of 2000 g oven dried soil remained in each pot. The pots were again replanted and managed exactly as for the first crop.

Chemical Analysis

Soil Analyses

Nitrate and ammonium nitrogen were extracted by 1 M potassium chloride (KCl) solution from the soil and analyzed using the micro-Kjeldahl method (Black 1965). A 50 g soil sample was extracted by shaking for one hour in 100 ml of KCl. The soil suspension was filtered through a Buchner funnel. The filtrate was then diluted to 200 ml in a volumetric flask, and a 25 ml aliquot was transferred to the micro-Kjeldahl distillation flask. The pH was raised by use of magnesium oxide and the nitrate N was reduced to NH_4^+ and condensed in a beaker containing 5 ml of boric acid indicator. After 25 ml have been collected in the flask, Devarda's alloy was added to the distillation flask and the distillation continued to collect ammonium N in a new 5 ml of boric acid indicator.

The soil remaining in the Buchner funnel was dried in a freeze dryer for three days and a 1 g sample was used for organic N determination. The sample was transferred to a micro-Kjeldahl flask and digested for five hours after the addition of 1.5 g of a catalyst (K_2SO_4 + $CuSO_4$ + Se in a 100:10:1 ratio) followed by 5 ml of concentrated sulfuric acid (Bremner 1965). After cooling, the hydrolysate was diluted with 25 ml of deionized water. The total N organic N in this case, was determined by micro-Kjeldahl method using sodium hydroxide (40%) to raise the pH of the flask content and a .010 M of $KH(IO_3)_2$ for titration.

The potentially mineralizable N was determined by the method described by Stanford and Hanway (1955) modified by Stanford and Smith (1972) then simplified by Stanford, Carter and Smith (1974). A further modification was introduced to use samples of 25 g and 125 ml of calcium chloride followed by 40 ml of nutrient solution without N for leaching.

Plant Material Analyses

Samples weighing 200 to 300 mg were transferred to micro-Kjeldahl digestion flasks. A 1.5 g of potassium sulfate catalyst, described above, was added to each flask followed by 5 ml of concentrated (95%) sulfuric acid. The flasks were then placed on a low heat for 30 minutes. The heat was then raised to the maximum of the electric (12 units) heater and maintained for about five hours. The flasks were rotated and shaken every half hour to insure uniform digestion of the sample.

After cooling, but prior to the solidification of the salts, about 20 ml of de-ionized water was added followed by approximately 0.3 g of Devarda's alloy. The flask was then placed on a micro-Kjeldahl distillation apparatus, at which time the solution was made alkaline by addition of 20 to 25 ml of 40 percent sodium hydroxide solution. The N, in ammoniacal form, was collected in a 50 ml Erlemyer flask containing 5 ml of boric acid indicator solution. The N was then determined by titrating the distillate (about 30 ml) with 0.010 M of potassium biodate solution (McKenzie and Wallace 1954, Kowalenko and Lowe 1973).

Statistical Analyses

Standard statistical tests and procedures were performed on the collected data. The relationships between the total N uptake by the plant, the plant N concentration, the total dry matter and the various forms of N in the soil were studied. All relationships among the soil N forms of initial and second soil samples were examined as well as soil N forms in relation to yield, N concentration, and N uptake.

In the modified Mitscherlich-Baule equation the coefficients "c" and "c_1" were computed for various forms of N. A SNK test was run to determine whether these coefficients were significantly different or from the same population and if they could be considered as one constant value for all soils and all crop histories (Steel and Torrie 1960).

The potentially mineralizable nitrogen was computed following the method outlined by Stanford et al. (1974). The "k" in the formula

$N_o = N_t(1-10^{-kt/2.303})$ was estimated at 0.059 from the first crop data and 0.054 for the second crop data, based on the mean (0.054) and the distribution of the experimental data.

The crop histories were classified into two categories, namely, two to four years alfalfa and two to four years non-legumes. Then by use of graphical methods, characteristic relationships were studied. Responses to added N fertilizer were numerically compared.

RESULTS AND DISCUSSION

All data reported are averages of four analytical values (chemical analyses were in duplicate on the two experimental replications), unless otherwise specified.

From the data obtained (Tables 2, 3, 4 and 5) and the analysis of variance, it is clear that higher yields as well as higher total uptake by plants were obtained from pots that received fertilizer on all soils (F tests were highly significant). Significant differences were observed among most soils both for yield and degree of response to N fertilizer.

Nitrate Nitrogen

The initial and residual nitrate N in the 12 soils studied are reported in Tables 2 and 3, respectively. Yield and N uptake by plants for the corresponding conditions are given in Tables 4 and 5.

The relationship between nitrate-nitrogen test values and the other nitrogen forms was investigated. For the initial test values, highly significant correlations were observed between nitrate and the other forms of N determined: ammonium, organic and potentially mineralizable (Table 6). However, the variation in values of nitrate was associated with less than 30 percent of the variations in values for ammonium, organic or pot mineral. Initial nitrate N was exponentially related to yield (Figure 1). In spite of the heterogeneity

Table 2. Soil analyses for N fractions and mineralization in the initial samples.

Soil	Source	Soil Classification*	NO_3-N	NH_4-N	ORG-N	TOTAL-N	MIN-N
					ppm N		
1	C.R.C. (Phoenix)	Typic Haplargids (FL,M,T)	40.4	23.2	448	512	148
2	idem.	idem.	8.2	4.9	476	489	121
3	idem.	idem.	15.5	4.7	1252	1272	153
4	idem.	idem.	11.7	4.5	521	537	94
5	Un.Exp. Farm (Yuma)	Anthropic Torrifluvents (FS,M,H)	6.7	8.4	228	244	283
6	idem.	Vertic Torrifluvents (F,M,H)	5.4	6.7	868	880	81
7	idem.	Anthropic Torrifluvents (FS,M,H)	23.5	7.3	658	689	59
8	idem.	Typic Torrifluvents (GS,M(Ca),H)	6.8	13.4	746	766	83
9	Avra Valley (Tucson)	Typic Paleargids (F,M,T)	4.7	4.9	353	363	164
10	idem.	idem.	7.2	7.2	308	322	213
11	idem.	Typic Torrifluvents (CL,M(Ca),T)	15.0	19.7	455	490	145
12	idem.	Typic Haplargids	13.4	27.3	238	279	132

* F = fine, L = loamy, M = mixed, T = thermic, H = hyperthermic, C = coarse, S = silty, Ca = calcareous.

Table 3. Forms of nitrogen in the soil following the first cropping cycle.

Soil Number	Control				Treated			
	NO_3-N	NH_4-N	ORG-N	MIN-N	NO_3-N	NH_4-N	ORG-N	MIN-N
	ppm N							
1	1.1	2.5	462	54.9	109.0	5.4	635	80
2	2.6	2.8	618	23.9	279.5	5.6	802	64
3	2.6	2.6	482	43.3	371.6	3.8	797	103
4	2.0	2.8	615	42.4	219.1	3.0	831	85
5	2.4	4.7	483	47.7	114.2	3.3	872	146
6	2.2	3.1	548	42.0	127.1	4.1	816	134
7	94.8	2.4	280	45.6	369.4	3.9	891	82
8	92.9	3.3	398	37.6	405.6	6.7	782	69
9	9.0	3.9	290	65.8	368.4	19.1	569	134
10	4.1	2.9	359	61.0	175.0	10.6	825	125
11	39.7	3.0	331	43.4	185.3	4.8	686	79
12	8.3	2.9	398	40.1	249.9	4.8	758	73

Table 4. Nitrogen uptake by wheat plants and their yield in the first eight-week cycle of growth.*

Soil Number	Control			Treated		
	Uptake		Yield	Uptake		Yield
	mg/g	mg/pot	g	mg/g	mg/pot	g
1	9.72	31.5	3.24	22.5	89.0	3.96
2	13.7	32.1	2.34	21.4	72.0	3.37
3	15.3	58.6	3.83	24.2	93.6	3.86
4	15.7	27.4	1.74	24.7	81.6	3.31
5	13.6	53.0	3.90	25.2	132.0	5.24
6	9.71	34.6	3.57	24.2	119.2	4.93
7	20.3	50.0	2.46	22.5	84.2	3.74
8	18.9	83.6	4.42	21.9	110.3	5.03
9	18.8	68.8	3.67	26.8	86.9	3.25
10	14.7	29.4	3.31	24.9	95.1	3.82
11	10.8	29.4	2.73	24.5	89.0	3.63
12	14.1	40.8	2.89	21.2	73.5	3.46

* Note: All weights and concentrations are expressed on an oven-dry basis.

Table 5. Nitrogen uptake by the wheat plants and their yield in the second eight-week growth period.*

Soil Number	Control			Treated		
	Uptake		Yield	Uptake		Yield
	mg/g	mg/pot	g	mg/g	mg/pot	g
1	5.34	25.74	1.68	24.88	92.84	3.73
2	11.03	9.08	0.89	25.51	65.87	2.58
3	11.44	17.13	1.50	30.22	120.65	3.99
4	11.59	13.24	1.14	27.34	100.23	3.67
5	14.15	32.19	2.28	34.32	173.52	5.06
6	14.72	13.54	0.92	32.56	175.71	5.40
7	18.95	63.00	3.32	30.86	95.49	3.09
8	15.58	56.55	3.63	32.39	165.69	5.11
9	21.11	42.70	2.02	29.86	88.86	2.98
10	11.90	20.25	1.70	25.27	107.55	4.26
11	11.91	27.69	2.32	23.99	74.92	3.12
12	13.29	19.93	1.50	28.64	101.8	3.53

* Note: All weights and concentrations are expressed on an oven-dry basis.

Table 6. Correlation coefficients among various forms of initial soil nitrogen and yield, and N-uptake of the first cycle plants.

	NO_3	NH_4	NO_3+NH_4	ORG-N	Total	MIN-N	Yield	N-u/g	N-u/pot
NO_3	--								
NH_4	.484**	--							
NO_3+NH_4	.893**	.826**	--						
ORG-N	.520**	.343	.143	--					
Total	.739**	.300	.090	.999**	--				
MIN-N	.397**	.100	.096	.353	.372	--			
Yield	.864**	.129	.120	.231	.226	.095	--		
N-u/g+	.357	.247	.314	-.544**	.061	-.422*	.120	--	
N-u/pot	.849**	.187	.323	-.660**	-.461*	.209	.634**	.702**	--

* Significant at the 1% level.
** Significant at the 5% level.
\+ N-u/g = N-uptake per g of dry matter.
n = 24

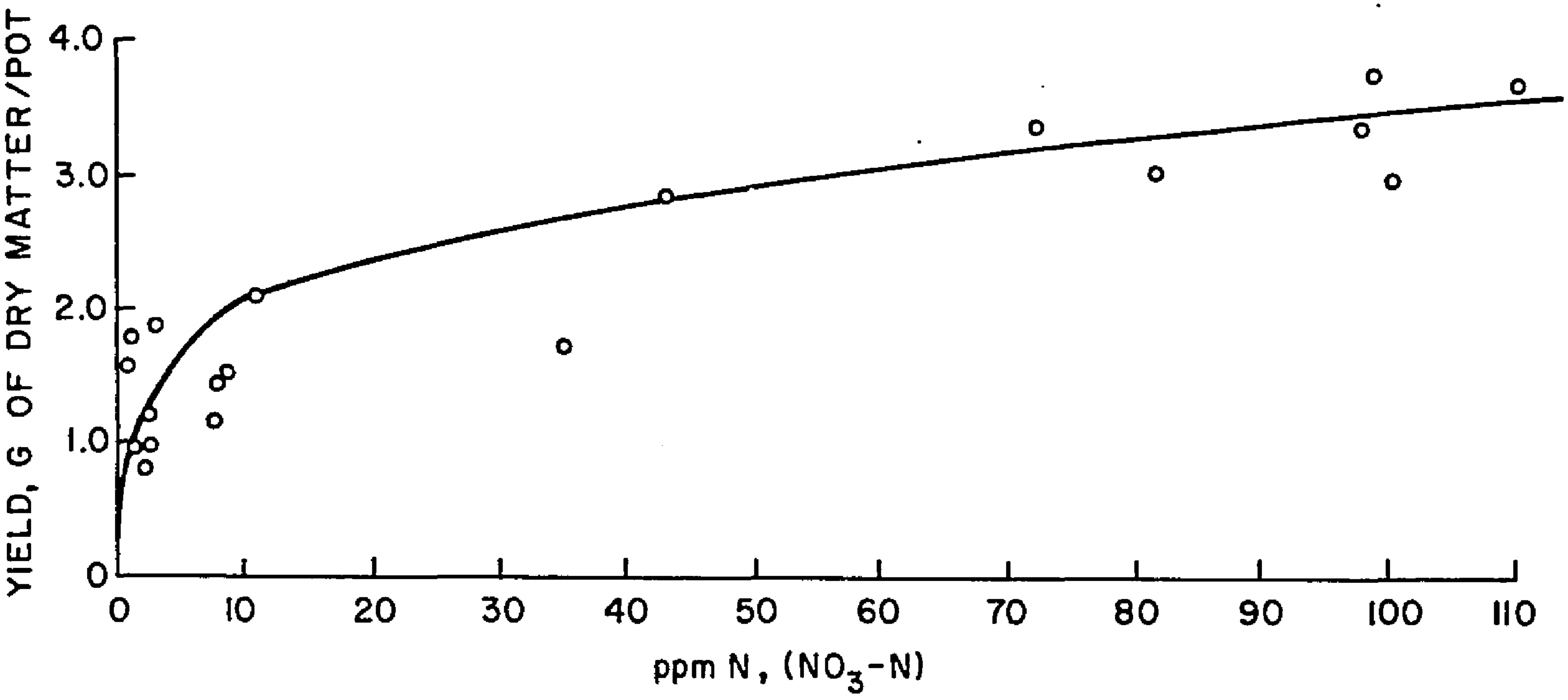

Figure 1. Yield versus initial soil nitrate nitrogen.

of the soils, there was a highly significant correlation between nitrate nitrogen and yield as well as with total nitrogen uptake; the correlation with nitrogen concentration, however, was not significant.

In the first cropping cycle, soil nitrate-N accounted for 74 percent of the variation in the yield and 72 percent in the N uptake variation. In the second cycle (Table 7) where most of the other correlations were also highly significant, the amount of variations accounted for by nitrate-N declined to 31 percent in yield and 44 percent in N uptake variation. This is probably due to the release of N from organic and difficultly available sources during this first and second cycle. This may also account for the higher correlation coefficients obtained with the other forms of N.

Ammonium Nitrogen

The correlation of ammonium N with yield and uptake for both cycles was low and non-significant; however, a low, but significant value was obtained for the relationship between some ammonium N and plant N concentrations for the second crop. The correlation values among N forms and plant parameters suggest that the ammonium N test values do not appear to be suitable for predicting either yield or N uptake for soils having no legume for 2-4 years. Graphically the scatter follows closely the calculated regression line of yield on ammonium-N (Figure 2). The ammonium-N test values should not be used as such as a basis for fertilizer recommendation even when cropping history is known. This agrees with the findings of Harmsen and Van Schreven (1955) cited earlier.

Table 7. Pearson correlation coefficients among various forms of nitrogen in soil after first cycle and yield and N-uptake by plants in second cycle.

	NO_3	NH_4	NO_3+NH_4	ORG-N	Total	MIN-N	Yield	N-u/g	N-u/pot
NO_3	--								
NH_4	.516**	--							
NO_3+NH_4	.9998**	.101	--						
ORG-N	.663**	.208	.511*	--					
Total	.879**	.376*	.246	.940**	--				
MIN-N	.526**	.540**	.154	.553**	.596**	--			
Yield	.550**	.141	.868**	.498**	.567**	.650**	--		
N-u/g+	.785**	.411*	.363	.696**	.802**	.804**	.383	--	
N-u/pot	.663**	.271	.855**	.648**	.715**	.794**	.921**	.687**	--

* Significant at the 1% level.
** Significant at the 5% level.
\+ N-u/g = N-uptake per g of dry matter.
n = 24

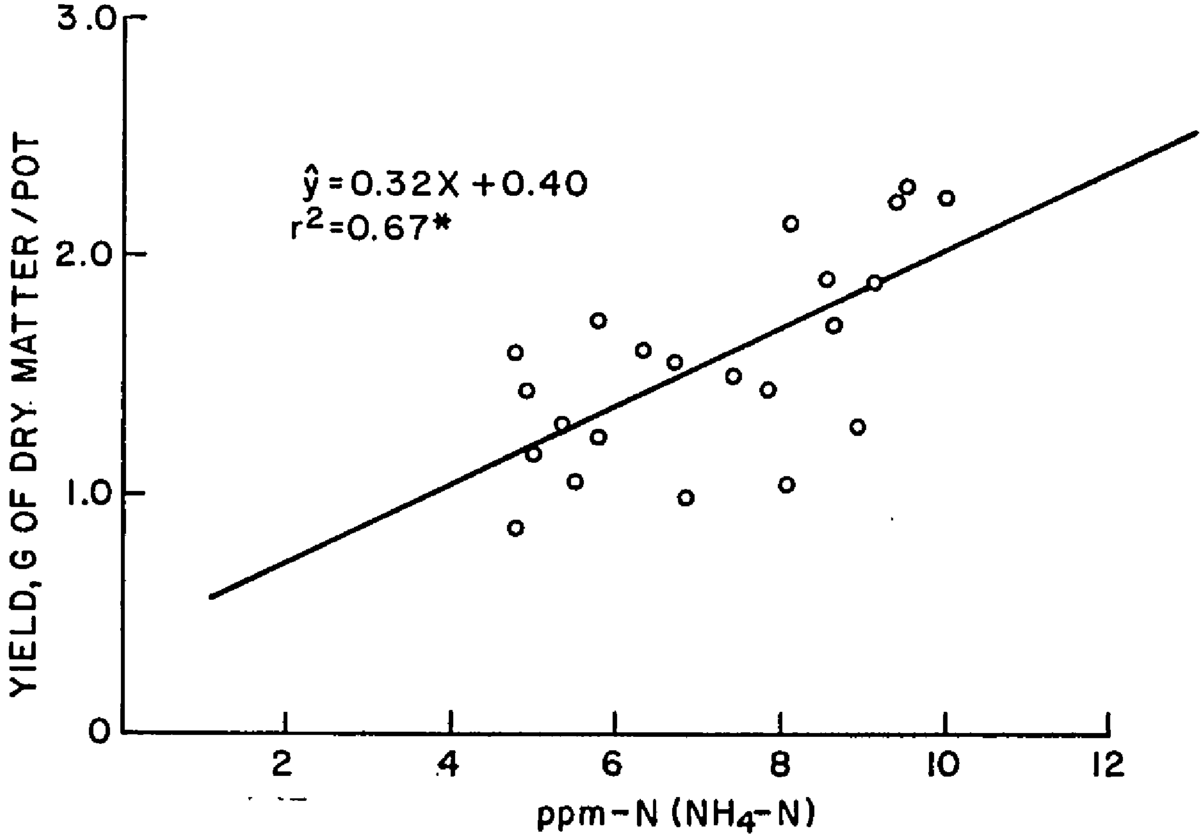

Figure 2. Second crop yield versus ammonium nitrogen in soils of similar crop histories (2-4 years no legume).

Nitrate Plus Ammonium Nitrogen

The initial (nitrate + ammonium) N was poorly correlated with yield, concentration, total N uptake, and all other forms of N except nitrate and ammonium N. After the first crop, these test values of N were highly correlated with nitrate and ammonium N, yield, and total N uptake, and were significantly correlated with the organic N. The correlation of these test values with potentially mineralizable N and total N were not significant. Linear relationships between this ($NO_3^- + NH_4^+$) N test values and yield were observed for soils of similar crop histories (Figures 3 and 4).

Organic Nitrogen

Organic N constitutes the "stored" N that becomes available at a very slow rate depending on microbial activity. It is thus fairly stable and subject to very limited loss through leaching. For all the 12 soils, when taken as a whole, there was no significant correlation between the organic N and the yield of the first crop; however, a significant negative correlation was observed with total N uptake as well as with N concentration. This negative relationship probably resulted from partial immobilization of N induced by wide C:N ratios in soils previously in small grains or cotton where a large amount of residue accumulated. More meaningful correlations are likely on similar soils with similar crop and fertilizer history.

In the second crop cycle, following apparent partial organic matter decomposition, the correlation between organic N test values and the three plant parameters studied were positively and highly

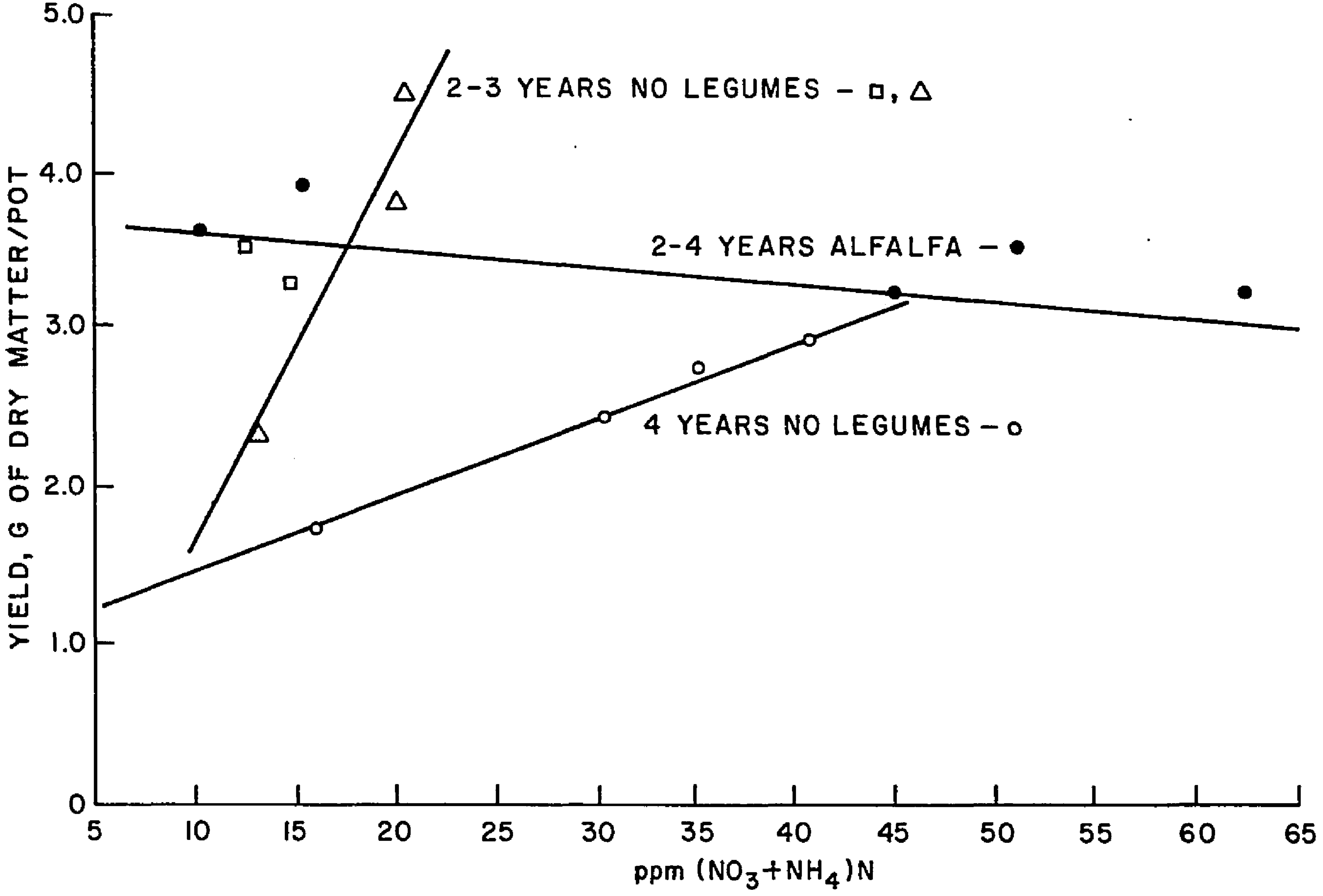

Figure 3. Yield versus $(NO_3^- + NH_4^+)$-N for soils of similar crop histories.

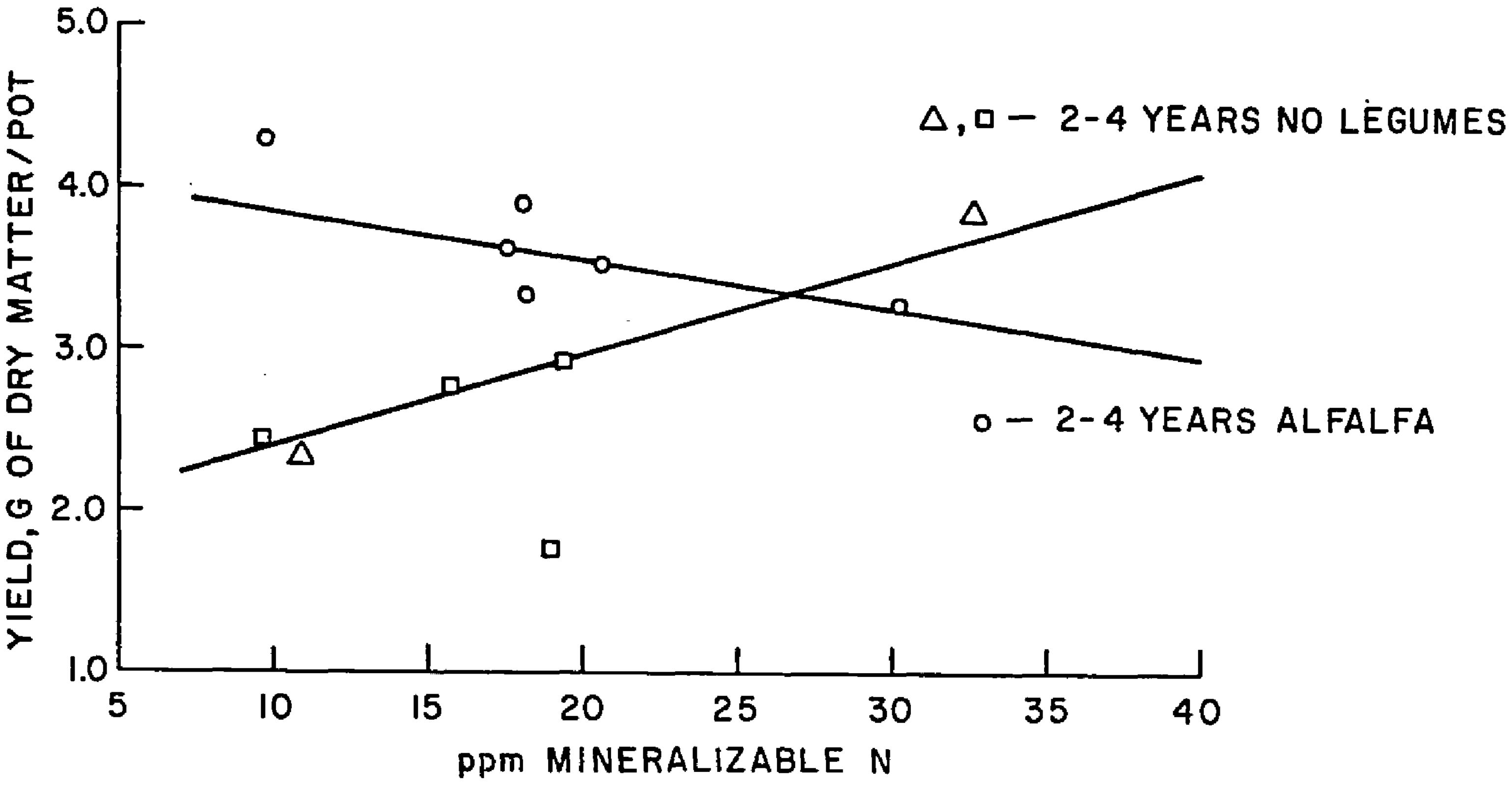

Figure 4. Yield versus mineralizable-N for soils of similar crop histories.

correlated (at the one percent level). The part of variation accounted for by this form of nitrogen was still less than 50 percent.

Total Nitrogen

Total N consists mainly of organic N. Hence total N should relate to plant uptake in much the same manner as organic N. The initial total nitrogen was, thus, poorly correlated to the yield and plant N concentration, and showed a negative correlation with total N uptake for the first experiment.

In the second cycle, the correlation coefficients were positive and highly significant. The amount of variation accounted for by total N was as high as 64 percent for concentration but only 34 percent for yield. Thus, neither total nor organic N would offer the precision desired for prediction purposes.

Mineralizable Nitrogen

For the first crop, the potentially mineralizable nitrogen was significantly correlated only to nitrate nitrogen test value and plant nitrogen concentration. The correlation with nitrate-N was low and negative with plant-N concentration. There was a poor correlation with yield, total nitrogen uptake and the other forms of nitrogen.

For the second cycle, the yield, nitrogen concentrations and total nitrogen uptake were positively correlated with the potentially mineralizable nitrogen, and the correlationswere highly significant. The amount of variation accounted for by this form of nitrogen was the highest of all test values; this reflects the same tendency obtained for the organic nitrogen. The coefficient of correlation with yield was lower than that between yield and total N uptake. There were also highly significant correlations between this and other forms of nitrogen, although a lower degree of association of variations was observed.

Crop History

The crop history of soils resulted in significant differences both in matter of response to fertilizer and in relating yield to soil forms of nitrogen.

In soils, where alfalfa was the previous crop for two to four years, the response to applied nitrogen was, on the average, lower than in the cases where no legume had been grown (Table 8). In soils where cotton or sorghum was the previous crop for more than one season, the yield was lower than with other crop histories in all the cases where no nitrogen fertilizer was added. The yield was linearly and positively related to the nitrate and ammonium nitrogen when legumes had not been grown for the past two to four years. The relationship was approximately linear but apparently negative for soils where the previous crop was two to four years alfalfa (Figure 3).

The yield from pots where the soil had grown alfalfa for the last two to four years was linearly but negatively related to the potentially mineralizable nitrogen as determined in the first part of this study. For soils where no legume was grown for the past two to four years, this relation was linear and positive. Mineralizable N test values after the harvest of the second cycle resulted in a scattered

Table 8. Crop history versus yield and nitrogen uptake for the first crop.

Crop History	Soil Number	Yield			Nitrogen Uptake		
		Control g	Treated g	Increase %	Control g	Treated g	Increase %
2-4 years alfalfa	1	3.24	3.96	22.2	31.4	89.0	183.4
	6	3.57	4.93	38.1	34.6	119	215
	5	3.9	5.24	34.4	53.0	132	149
	9	3.67	3.25	-11.4	68.8	86.9	26.3
	10	3.31	3.82	15.4	29.4	95.1	224
Mean		3.34	4.26	19.7	43.4	104.4	180
2-4 years no legume	2	2.34	3.37	44.2	32.1	72.0	124
	3	3.83	3.86	0.8	58.6	93.6	59.7
	8	4.40	5.03	36.4	83.6	110.3	29.5
	4	1.74	3.31	90.2	27.4	81.6	198
	7	2.46	3.74	52.0	50.0	84.2	68.4
	11	2.73	3.63	33.0	29.4	89.0	203
	12	2.89	3.46	19.0	40.8	73.5	105
Mean		2.55	3.82	39.3	46.3	86.3	112

set of points along a linear curve when plotted against the yield of the second crop. The variation was too large to be meaningfully interpreted. For nitrate, ammonium, organic and total nitrogen, taken individually, although the relationships were loosely linear, the scatter was too great to justify a definitive evaluation.

The case of 2-3 years with no legume versus $(NO_3^- + NH_4^+)N$ is particularly interesting (Figure 3). This high slope is probably due to an increase in N mineralization for which no simple causal reason seems to be available.

In soils where no additional N was added, the yield from these soils where cotton was the previous crop for 2-4 years was lower than the average yield of these control pots. This is due, probably, to the higher depletion of N from the soils where cotton was a previous crop than from any other soils in this study. The plants in these pots had also the highest response to the N fertilizer applied.

Interrelationship Between Crop and Nitrogen in Cycles 1 and 2

The relationship between the initial forms of nitrogen and yield, concentration and total nitrogen uptake as well as various forms of nitrogen test values determined after the first crop were investigated.

The initial potentially mineralizable nitrogen was highly correlated to the soil ammonium nitrogen following the first crop and accounted for 31 percent of its variation. It was also significantly correlated with the sum of nitrate and ammonium N, but accounted for only 21 percent of its variation. The high variation in nitrates due to their mobility probably explains the change in correlation values. None of the other correlations were significant, except the correlation between N concentration in plants and total N uptake in the first crop which were highly correlated to the second cycle crop. The total N uptake in the first crop was highly correlated to the N concentration and total N uptake of the second crop. The N concentration in the first and second crop were significantly correlated (Table 9). The yield as well as the total N uptake of the first crop were significantly correlated to the residual ammonium soil N, while the N concentration in the first crop was highly correlated with the residual soil nitrate and nitrate plus ammonium N. The total N uptake of the first crop was also significantly correlated to the residual soil organic N.

The yield was very highly correlated with total N uptake but not correlated to concentration in the plant. The variation in total N uptake was associated with 42 percent of the variation in the first crop and 85 percent in the second cycle crop. This was the highest correlation between yield and any other factor studied (Tables 6 and 7). Total N uptake was in turn correlated at the one percent level to N concentration in plants. The association of the variation of these parameter were lower than 50 percent for both crops.

The Mitscherlich Equation

As mentioned previously, Omar et al. (1969) applied successfully the modified Mitscherlich-Baule equation to predict yield from initial

Table 9. Correlation coefficients between initial soil nitrogen, soil nitrogen following the first crop cycle and yield, N-concentration and total N-uptake both for first and second cycles.

After the 1st Crop	Initial						1st Crop		
	NO_3	NH_4	NO_3+NH_4	ORG-N	TOTAL	MIN-N	YIELD	N-CONC.	N-UPTAKE
NO_3	.088	.070	.092	.188	.195	-.468*	.283	.563**	.380
NH_4	-.501	-.153	-.401	-.337	-.360	.564**	.481*	.124	.412*
NO_3+NH_4	.078	.067	.084	-.182	.188	-.457*	.293	.567**	.389
ORG-N	-.115	-.250	-.203	.195	.186	-.042	-.165	-.387	-.431*
TOTAL	-.104	-.206	-.200	.280	.271	-.198	-.089	-.249	-.358
MIN-N	.121	-.012	.071	-.267	-.265	-.373	.115	.108	.305
<u>2nd Crop</u>									
YIELD	.102	.110	.122	-.024	.031	-.083	.370	.550**	.548**
N-UPTAKE	.064	-.057	.012	-.082	-.082	-.165	.256	.418*	.429*
N-CONC.	.111	.023	.083	.000	.004	-.115	.376	.642**	.582**

* Significant at the 1% level.
** Significant at the 5% level.

nitrogen as well as needed fertilizer for projected yield in the U.A.R. soils. This equation has been previously applied successfully to immobile nutrients such as potassium and phosphorus (Bray 1954). An attempt was made here to determine the value of "c" factors in the Mitscherlich equation for the 12 soils used in this study. A SNK test (Steel and Torrie 1960) was made to determine if they were significantly different. If not, then "c" is a constant and the equation could be used to predict yield and fertilizer need.

In the equation:

$$\log(A-y) = \log A - cb - c_1x$$

A = yield possibility
y = actual yield
b = soil nutrient test value
x = fertilizer added

where A was taken as the highest yield for every soil in grams per pot and y as the yield in grams per pot with different forms of nitrogen test values used in b. The value of "x" was taken as 0 for controls, as 116 ppm for nitrate nitrogen and as 34 ppm for ammonium nitrogen for pots receiving N-fertilizer (Mitscherlich 1909, Bray 1954).

When b was taken as the test value of nitrate N, organic N or mineralizable N for the checks, the "c"s varied from 0.0070 to 0.0688, from 0.00056 to 0.00177 and from 0.0088 to 0.0776, respectively. The SNK test showed that the samples were from different populations and no attempt was made to calculate c_1.

When ammonium nitrogen test values were used for "b" in the same equation, the "c"s were distributed as follows:

.024 .055 .064 .065 .072 .078 .098 .132 .134

The smallest and largest values are from different populations, but the values from .055-.098 are in one population and their mean is .073; the mean for all 12 soils is .079. By using .073 we could predict yield for nine out of 12 or 75 percent of the cases. The graphical solution gave a c = .076 which is between both averages (Figure 5).

Using these "c"s, the c_1 values were computed (Table 10) but were found to be widely spread with a mean of .021. In all cases, however, the coefficients were very close for a given soil.

Due to the large variation in the coefficients, it is the feeling of the author that this method cannot be used as yet for predicting accurately either yield or fertilizer requirement. More work needs to be done to find a better way to estimate "c" and "c_1", once they have been shown to be actual constants, or compute them for every individual soil type if they prove to be constant, only for soils of similar types and crop history.

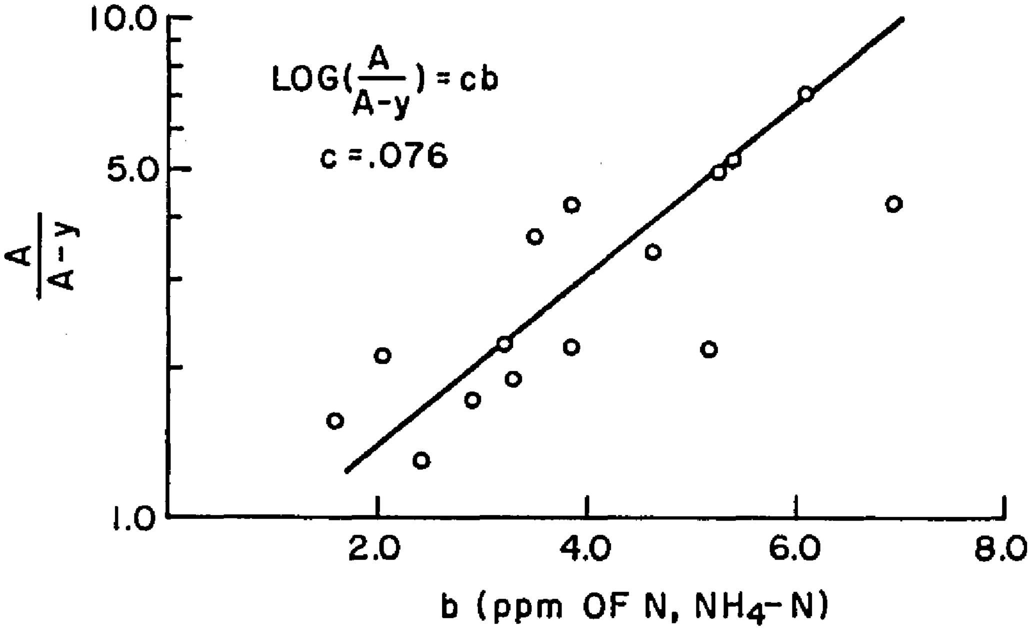

Figure 5. Ratio of A (yield possibility) to (A-y) versus soil ammonium nitrogen.

Table 10. The coefficients "c" and "c_1" in the Mitscherich equation when "b" is taken as ppm of ammonium-N.*

Soil Number	c	c_1
1	.098bc	.026d
2	.065b	.032e
3	.064b	.009b
4	.055ab	.026d
5	.072b	.006a
6	.024a	.081f
7	.098bc	.010b
8	.078b	.009b
9	.132c	.001a
10	.064b	.014c
11	.134c	.027d
12	.064b	.012cb
Mean	.079	.021

* $\log(A-y) = \log A - cb - c_1x$. In the same column, coefficients followed by the same letter are not significantly different at the 1% level by SNK test.

SUMMARY AND CONCLUSION

The purpose of this study was to evaluate the importance of various forms of soil N to crop utilization in order to better predict N fertilizer requirements and improve fertilizer use efficiency.

Twelve soils were used and represented different textures and cropping histories. Two crop cycles (eight weeks each) of <u>Triticum aeativum</u> L.,Cajeme 71 cultivar, were grown under controlled environmental conditions.

The yield was highly correlated with total N uptake of crops in both cycles. The N concentration which was not correlated to yield was highly correlated to N uptake in both cycle data.

Initial soil nitrate-N had the highest correlation with yield and N uptake but was independent of the organic and potentially mineralizable for the first crop. In the second cycle, nitrate N was highly correlated with all other forms of N as well as with yield, N uptake and concentration of the wheat plants. The amount of variation in the yield associated with the nitrate variation was lower than with the first crop. This was probably due to an increasing importance of N from organic sources after the readily available N had been depleted to varying degrees by the first crop. This conclusion was confirmed, to an extent, by the potentially mineralizable N which was better correlated in second cycle data. Time also has allowed organic matter decomposition which probably resulted in a narrower C:N ratio.

The ammonium N was not correlated significantly with either yield or N uptake; however, when used in conjunction with the modified Mitscherlich-Baule equation, it was possible to predict yield with reasonable precision under the controlled conditions of the study when the yield possibility (A) was known.

The sum of initial ammonium and nitrate N was not correlated to either yield, N concentration or N uptake when all the soils were combined for the first cycle data. This sum was linearly and positively related to yield for soils in which legumes had not grown for the past two to four years. Following legumes, a linear but negative relationship between this sum and yield was found. The sum of nitrate and ammonium in the soil after the first crop was highly correlated with both yield and N uptake of the second crop. Since the ammonium fraction alone was not significantly correlated, this relationship was essentially due to the nitrate fraction.

The organic and total N resulted in similar relationships except for the correlation with the N concentration in the first cycle crop. There were no significant correlations between either of these two forms and either yield or N uptake of the first crop. Highly significant correlations were observed in the second cycle data.

The correlations of the potentially mineralizable N with yield and N concentration and uptake of the first crop were not significant. In the second cycle, the mineralizable N resulted in higher correlation coefficients than other N forms with all the plant parameters.

Crop history had significant effect on the relationship between yield and N forms of the first crop but no detectable effect on the second crop. When no legume had grown for the past two to four years linear and positive relationships between yield and ammonium plus nitrate and mineralizable N were observed graphically. Following a legume (alfalfa), a linear but negative relationship was obtained between the same parameters. Among the control pots, the yield on those soils where cotton was the previous crop for two or more years was lower than the average of these control pots.

In conclusion, for most soils, to get an immediate fertilizer recommendation, the surface soil nitrate N appears to offer the greatest promise. This agrees with the findings of Gardner and Tucker (1967), and the results of Omar et al. (1969). It contradicts, in many ways, the findings of Harmsen and Lindenberg (1949) and many others cited in the Harmsen and Van Schreven (1955) review. For a whole cropping season, a more accurate way to predict fertilizer need is to measure the sum of the soil ammonium and nitrate N. This confirms the findings of Peterson, Attoe and Ogden (1960) and of Harmsen and Van Schreven(1955), but does not agree in some ways with the results reported by Black (1968, p. 469).

Information under field conditions is needed to determine the various levels of yield at different soil N levels for each of the various crops grown in an area. Together with information on yield possibility for early crops, these soil N data could then be used to predict the yield level without added fertilizer, and thus the probability of an N response, as well as an estimate of the N fertilizer requirement.

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