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ASSESSMENT OF THE NITROGEN MINERALIZATION POTENTIAL OF A BRAZILIAN OXISOL

A Thesis

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment for the Degree of

Master of Science

by

Kate Barger Showers

August 1977

ABSTRACT

Topsoil and subsoil samples were collected from the check (0 nitrogen added) plots of a nitrogen fertilizer experiment with maize located on an Oxisol in the Central Plateau of Brazil on land which had been recently brought into cultivation. The samples were evaluated for their potential to supply nitrogen to a crop by a standard incubation technique and by a chemical procedure which had shown some promise as a predictive tool for other tropical soils. The results were compared with nitrogen uptake data available for a maize crop grown on these soils. A long term incubation study was also conducted in order to characterize the nitrogen release pattern of these soils.

All samples were extracted with 1 N KCl. The chemical test procedure, which measured a fraction of the extractable organic and inorganic NH_4^+, involved the digestion of extracts with concentrated H_2SO_4 and analysis for NH_4^+ by steam distillation. Extracts from incubated and non-incubated soil were also analyzed for mineral nitrogen by steam distillation. Difficulties were encountered in the analysis of these dark red Oxisols by the macro-Kjeldahl procedure.

The number of samples was insufficient for a satisfactory interpretation of the correlations between the chemical soil test and crop nitrogen uptake data. The only strong relationship in the soil test data was that between Δmineralizable nitrogen and digest nitrogen. This would lend some support to the hypothesis that the digest nitrogen does measure some portion of the soil nitrogen which is potentially available to plants. The incubation studies showed a difference between topsoils

and subsoils in their patterns of release of NH_4^+ and NO_3^-; the topsoils showed rapid increases in the amounts of NO_3^- and rapid decreases in NH_4^+, while the subsoils showed an initial accumulation of NH_4^+ and decrease in NO_3^-. The values of Δmineralizable nitrogen from this study were similar to those reported in the literature from incubation studies of soils with similar chemical properties from temperate and tropical regions. It cannot be concluded that these Oxisols from the Central Plateau of Brazil have the same potential for nitrogen production as temperate region soils, for the cropping histories of the various temperate and tropical soils were different.

BIOGRAPHICAL SKETCH

Kate Barger Showers was born on February 22, 1949. She graduated from Ridgewood High School, Ridgewood, New Jersey in 1966 and entered Kalamazoo College, Kalamazoo Michigan. In 1968 she worked on the Cheyenne River Indian Reservation, LaPlant, South Dakota and in 1968-1969 was a foreign student at Njala University College, University of Sierra Leone, Sierra Leone, West Africa. In 1970 the author received a Bachelor of Arts degree from the Department of Anthropology and Sociology, Kalamazoo College. After working for two years, the author enrolled in the Department of Soil Science, Michigan State University, East Lansing, Michigan. She received a Bachelor of Science degree in 1974. In August 1974 the author began her M.S./Ph.D. program in the Agronomy Department, Cornell University.

The energy represented by

this work is dedicated to

Dr. Kay M. Sperry

Dr. Edith K. Ligeti

Mary Jackson

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INTRODUCTION

Nitrogen is a major element required by all plants for growth, and although it is present in the biosphere in large quantities, much of the N is in forms which are unavailable to plants. Today N can be supplied to plants from two major sources: the natural processes of N fixation, rainwater introduction and mineralization, and the technological processes of N fixation in the manufacture of nitrogenous fertilizers. The capacity of the natural systems to supply N to crops is more limited than the capacity of people to manufacture nitrogenous fertilizers. Therefore, with the advent of relatively inexpensive and abundant fertilizer supplies, research interest shifted from the utilization of natural supplies of N to the manipulation of technologically produced fertilizers in plant production. Recent concern about environmental degradation due to inappropriate uses of fertilizers, the increasingly high cost of fertilizer production, and the realization that many farmers in the world do not now and will not soon have access to commercial fertilizers has lead to a renewed interest in the sources of N in the biosphere. Precise recommendations for fertilizer rates and management schemes which maximize the resources of the land for those farmers without access to N fertilizers cannot be developed without an understanding of the processes of N circulation in the soil system.

Nitrogen exists in the soil system in many forms, both organic and inorganic. The organic forms are subject to transformation to inorganic forms in a microbial process called mineralization, and inorganic forms may be transformed to organic forms by the process of immobilization.

Organic N enters the soil system through the additions of plant and animal residues and through the fixation of N by symbiotic and non-symbiotic organisms in the soil. Microorganisms are responsible for recycling the N by degrading organic matter and converting it to NH_4^+, NO_2^-, and NO_3^-. The process, being a biological one, is influenced by the physical, chemical, and environmental conditions of the soil. Physical factors which affect water supply and aeration, chemical factors such as pH and the presence or absence of essential nutrients or toxins, and environmental factors such as climate and the presence of an energy source affect the growth and composition of the microbial community. The nature of the microbial community will determine the type of activities carried out, and thus the forms of N in the soil system. Factors such as desiccation affect the nitrifying bacteria more than the ammonifiers, resulting in an accumulation of NH_4^+ in drought or dry seasons, while an excess of water will favor the growth of anaerobic organisms which reduce NO_3^- to NO_2 and N_2 gasses. Under conditions of moderate pH, moisture, oxygen supply, and energy source, organic forms of N are converted to NH_4^+ which is oxidized rapidly to NO_3^-. Under most conditions, most of the N in the soil is in organic combination, and the N which is inorganic is either in NH_4^+ or NO_3^- form.

Ammonium may be fixed in the clay minerals in the soil or held on the cation exchange sites. Under many conditions, however, most NH_4^+ is nitrified to NO_3^-. Nitrate may be held on the anion exchange sites of the soil system, but most is thought to be in the soil solution. As it is in the soil solution, NO_3^- is available for plant uptake and loss by leaching as the solution percolates through the soil. Nitrate can also be utilized by microorganisms, either through the conversion to organic

forms in microbial tissue or as an oxygen source, resulting in the conversion to a gaseous form which is lost from the soil system.

The nitrogen system within the soil is a dynamic one, with changes in forms occurring continuously. The development of procedures for studying the N supply of a given soil must involve consideration of all of the N fractions and the interaction between environmental factors, the N system and the microorganisms. The development of techniques to quantify such a complex system is necessarily difficult. Today a great deal is still unknown about the nature of the forms of nitrogen in the soil and their interaction with the physical system of the soil components and the microbial community. Problems of technique are also related to the ephemeral nature of the various forms of N: they change even as one attempts to measure them. The decision concerning which fraction of N to measure when estimating the soil supply of available N must be largely based upon empirical measurements, because so little is known about the nature of the N in organic combination.

The most direct measure of plant available N supplied by the soil is the analysis of the N content of a plant grown without N fertilizer (Beckwith, 1963). If other factors are not limiting, then the plant would theoretically take up all of the N which is available during the growing season. In practice, it is difficult to grow a plant in an environment in which no other factor is limiting. Greenhouses provide the opportunity to control some variables, but they do not offer a totally controllable environment. It is impossible to control variability in the field. Less direct methods of estimating the ability of a soil to supply N involve chemical and biological tests in the laboratory. The reasoning behind this approach is to find a procedure which

consistently produces a result which can be correlated with the N uptake by plants grown in controlled environments and in the field, when no other factors are limiting. A procedure which demonstrated close correlations over a range of soil conditions could possibly be used to predict the amount of N that might reasonably be expected to be released by the soil in a growing season. This would aid in making fertilizer and management recommendations. The soil test procedures proposed to date have had mixed and limited success in N prediction. The procedure which is most generally accepted as reliable involves the incubation of soil samples for varying periods of time, and the measurement of N mineralized during the time of incubation. As this biological procedure is both time and space consuming, efforts have been made to develop more rapid chemical methods.

In this thesis, soil samples of an Oxisol from the central plateau of Brazil were evaluated by a standard incubation technique and by a chemical procedure which had shown some promise as a predictive tool on other tropical soils. The results were compared with nitrogen uptake data available for a corn crop grown on the soil. A long term incubation study was also conducted in order to try to characterize the N release of these soils.

LITERATURE REVIEW

The objectives of soil testing have been stated by many authors (Melsted, 1967; Tisdale, 1967; Hanway, 1973; Welch and Wiese, 1973) in various ways, but in general the objectives are to provide a method for rapidly and easily determining the nutrient status of a soil and to provide a basis for making recommendations for fertilizer and soil management practices in terms of plant yield response to fertilizers applied. An ideal test would describe the nutrient status of the soil and the exact yield response to fertilizers, thus providing a basis for an economic interpretation of the fertilizer recommendation. These objectives cannot be met with precision, for crops are part of a biological system of which nutrient status is only one of many intervening variables.

The development of a soil test, in the broad sense defined above, has two aspects: first, the development of a procedure which provides numerical values that are related to some measure of plant growth and second, the establishment of a predictive relationship between the test values and crop response to added increments of nutrients. In the literature different words are used for these rather distinct aspects of the soil test process, which has lead to some lack of clarity. Welch and Wiese (1973) call for the use of the term correlation "to express the relationship between the amount of nutrient extracted by laboratory tests and uptake by plants in the greenhouse or field" and the reservation of the term calibrate for "the relationship between laboratory soil test values and yield response from incremental rates of the nutrient applied in the field." A soil test which is highly correlated may not be well

calibrated, so that criticism of the calibration may instead be leveled at the actual laboratory test method. However, it is important for researchers to be sure that highly correlated tests can also be well calibrated. A farmer, after all, is interested in yield response.

The development of a soil test for N has been particularly difficult due to the behavior of N in the soil. A desirable test procedure is one which is simple, precise, and applicable over a wide range of soil conditions (Stanford and Smith, 1972). Because the N system in the soil is biologically controlled, the factors which affect the microbial process are those which affect the N supply. Furthermore, because there are so many forms of N in the soil, it has been difficult to determine which fraction should be measured. A laboratory soil test for N, then, must either describe some aspect of the process of N mineralization, or else measure some fraction of the N in the soil and assume that it is proportional to that N which becomes available to the crop during a growing season. The former approach is a biological one, the latter a chemical approach. There are advantages and disadvantages to both approaches; neither one has yet produced a simple, quick method which is applicable over a broad range of conditions.

The advantages and disadvantages of the biological approach stem from the same fact: the techniques involve direct work with the biological system which is responsible for the mineralization of N in the soil. The advantage is that if the environment can be controlled to reduce the sources of variation, a direct measure of the maximum amount of N which can be mineralized from a given soil system is obtained. The disadvantages are that the optimal conditions of the lab or greenhouse make extrapolation to the field difficult, and variation in field experiments

due to uncontrolled factors make data collection and interpretation difficult, if not impossible.

Biological approaches to the measurement of available N involve the determination of the rate of mineralization (Harmsen and VanSchrevan, 1955). This can be attempted through the use of various laboratory procedures including studies of microbial cultures and incubation of soil samples, and by greenhouse and field plot experimentation. In microbial culture tests, microorganisms are grown in a nitrogen-free medium and a soil sample. Since N is essential for microbial growth, and the soil is the only source of N, the activity of the microorganisms is taken to be a measure of the availability of the soil N (Cornforth, 1966). The measurement of CO_2 evolution by a microbial population has also been used as a measure of N mineralization based on the assumption that the rate of CO_2 evolution is dependent upon the amount of N available for microbial activity (Cornforth, 1966). This is true only if N is the limiting factor to microbial growth (Cornforth, 1966).

Incubation methods are based on the fact that the N which is released in the soil during the cropping season is released by the same organisms which release N upon the incubation of soils under laboratory conditions (Bremner, 1965; Cornforth, 1966). This technique is considered to be a direct measurement as it involves the actual organisms which are responsible for N release. The technique has been widely used, and is considered to be the most satisfactory procedure available (Harmsen and VanSchrevan, 1955; Bremner, 1965). The procedures most widely used are based upon the aerobic incubation techniques developed by Stanford and Hanway (1955), Stanford and Smith (1972) and the anaerobic incubation techniques introduced by Waring and Bremner (1964). Incubation techniques

vary tremendously; each variation in technique is an attempt to create laboratory conditions which are closer to the ideal for microbial growth. What is desired is the elimination of factors influencing mineralization other than the supply of available forms of organic N, to provide a measure of the potential of the soil to supply mineral N, thus permitting a ranking of soils based upon N availability. Since factors such as date of sampling and treatment of samples prior to incubation can affect the mineralization measured (Harmsen and VanSchrevan, 1955; Eagle and Mathews, 1958; Cornforth, 1971), it is necessary for the techniques to be standardized if there is to be any possibility of comparison (Bremner, 1965). One of the problems with incubation studies is that they are both time and space consuming. Various other aspects of incubation technique have been discussed and criticized in such review articles as Harmsen and VanSchrevan (1955), Bremner (1965), Black (1968), Dahnke and Vasey (1973). The chief objections to the incubation techniques are summarized by Harmsen and VanSchrevan:

> ...it must be formulated that reliable results, sufficiently correlated with the N requirement of field crops, can be expected only when the incubation technique is restricted to one soil type, one climate zone, and one farming system and when all samples are collected within one season, preferably during the early spring. For each set of conditions the interpretation of results must be developed separately.... Besides these limitations of the incubation method the results and their interpretation certainly will vary from one year to another, owing to uncontrollable and often unpredictable variations of the weather conditions. So the method should never be overestimated, and consequently the determination of the N requirement of soil presumably never will reach the same accuracy as the determination of P and K requirements.

Researchers in both temperate and tropical regions have related incubation results to N uptake by a crop and to crop yield. In research

with tropical soils, good correlations were reported between mineralizeable N and tobacco quality in New Zealand (Ross, 1960), between mineralizable N and both N uptake and yield of dry matter by 6 week old tomato plants grown on a variety of East African soils in the greenhouse (Robinson, 1968). Good correlations were also reported between mineralizable N and N uptake by crops of maize and sorghum grown in 10 Puerto Rican soils in the greenhouse (Lathwell, 1972). Fair correlations were reported between mineralizable N and the N content of maize plants at tasseling which were grown in farmers' fields in Western Tanzania.

The alternative to laboratory experimentation with the components of the biological supply system isolated from the growing plant is to include a plant in the system being studied. Greenhouse experiments are a type of incubation experiment, with the plant added to the system. Here the environment can be largely controlled, the volume of soil explored by the roots is limited, so that the measured N uptake can be expressed in terms of a given amount of soil, and any interactions between plant roots and microorganisms (supply of growth factors, etc.) are included in the experiment. Good correlations should be expected between this system and a laboratory incubation technique, and in fact such correlations have been widely reported (Gasser, 1961; Gasser and Jephcott, 1964; Robinson, 1968; Cornforth and Walmsley, 1971; Lathwell, 1972).

The variation introduced by adding a plant to the system provides an intermediate step between the controlled conditions of the laboratory and the variability of the field. The fact of the addition of a plant to the soil system should not mislead the researcher to believe that there is reason to extrapolate from greenhouse results to the field. Since greenhouse conditions are more or less controlled, the pot system

bears only slight resemblance to the soil system in the field. Field experimentation as an initial tool is unwieldy due to the large requirements of land, labor, time, expense, and the unpredictability of the environmental conditions. The object of a field experiment should be to characterize and quantify the entire set of conditions in the field (Hanway, 1973). A test procedure which is well correlated with nutrient uptake in a controlled environment must be tested for predictive value under field conditions. Once the correlation is established with the field data, field research for purposes of calibration can be conducted.

According to Melsted (1967), "it is a basic principle of soil testing that simple, rapid chemical analytical procedures can be designed to accurately measure or be a measure of the level of available nutrients". The advantages of chemical soil tests compared with biological tests are that commercial tests are generally more rapid and more convenient (Keeney and Bremner, 1964; Bremner, 1965), simpler, more reproducible, and more suitable for routine soil testing (Cornforth, 1966). It was assumed that chemical tests were less subject to influence by previous treatment, such as date of sampling and type of storage, but according to Bremner (1965) there is little evidence to support this assumption.

The disadvantages of chemical methods are numerous. The major body of criticism of the chemical approach stems from the facts that chemical methods are completely empirical in nature and can make no allowance for the fact that the supply of mineralizable N is dependent upon the microbial community which is affected by factors such as crop residues with a high C:N ratio (Keeney and Bremner, 1964; Bremner, 1965; Cornforth, 1966). It is unlikely that a chemical reagent will be found that can simulate the activities of soil microorganisms or that can

release selectively the fraction of the soil N which is made available for plant growth by organisms (Bremner, 1965). Furthermore, chemical methods which depend upon surface soil samples cannot be expected to integrate the various soil-plant interactions which affect the release and uptake of N and growth of the plant (Bremner, 1965). Changes in nutrient concentration which occur in soil solutions also are not reflected in chemical soil tests (Beckwith, 1963). Since soils are not homogeneous, there probably are areas in the soil where the rate of release of N is greater than in others; this variability cannot be adequately expressed in chemical procedures (Beckwith, 1963). Finally, most of the research has been performed on temperate region soils; the complications introduced by tropical conditions of extreme weathering, and the variations due to different soil moisture and temperature regimes are largely unstudied. Despite the many problems associated with chemical test methods, however, fairly good relationships between chemical estimates of N availability and crop data have been reported; these relationships are usually found for soils belonging to similar groups or series (Cornforth, 1966).

Of the many extraction techniques described in the literature, only a few of the major methods used in recent years will be described to illustrate the type of work done and the problems encountered. Truog first proposed (Richard, Attoe, Moskal, Truog, 1960; Keeney and Bremner, 1966) a method for extracting the readily oxidized organic N with alkaline permanganate, based on the procedure already established for evaluation of the N status of organic measures (Subbiah and Asija, 1956; Richard et al., 1960). Modifications of the procedure by Subbiah and Asija (1956), accompanied by some high correlation values for wheat and rice on Indian soils, stimulated interest in this procedure. Subsequent

research has produced mixed results. Richard et al. (1960) found highly significant correlations between the test results and the N uptake response of maize grown on Wisconsin soils in the greenhouse; the correlation coefficients accounted for 72 percent of the variation. Olson et al. (1960) tested the method against the N response of oats grown in the greenhouse and with yields of wheat and oats in the field in Nebraska and found no significance in either relationship. Tamhane and Subbiah (1962), reporting a compilation of previously unreported data from undescribed experiments showed highly significant correlations between the alkaline permanganate test and yield response to N by wheat and paddy rice in greenhouse experiments and in the field on various Indian soils. The reported correlations accounted for as much as 77 percent of the variation. Keeney and Bremner (1966) modified Subbiah and Asija's method slightly and compared results with N uptake by the 2nd and 3rd cuttings of ryegrass on Iowa soil and found significance at the 5 percent level, but correlations which accounted for only 18 percent of the variation. Jenkinson (1968) working in Great Britain using Keeney and Bremner's modification of Subbiah and Asija's modification of the alkaline permanganate method found low correlation with N uptake by all cuts of ryegrass, accounting for only 18 percent of the variation. Cornforth and Walwsley (1971) working with 154 soils from 6 islands in the West Indies reported slightly significant correlations between Truog's method and N uptake by 35 day old maize plants. The correlations, however, only accounted for 14 percent of the variation. When taken on an island by island basis, there were some islands for which the test could account for 58 percent of the variation. Walmsley, Twyford and Cornforth (1971) reported no correlation between the soil

test and yield of bananas grown in the field on the Windward Islands. Herlihy (1972) used a modification of the method by Kresge and Merkle (1957), and Peterson, Attoe, Ogden (1960) in a study of the variation in N availability under two different crop rotations in Ireland. The correlations between the values of the alkaline permanganate test and those of the nitrogen mineralization experiments were significant but low after the first year of the experiment. The test was therefore not used in subsequent years.

In 1960 Cornfield proposed the measurement of easily hydolyzed N released by alkaline hydrolysis of soil in a diffusion cell. Cornfield (1960) reported a high correlation between the values derived from this technique and those of N mineralization experiments using soils from England, but cautioned that individual variations were very high, making the test only approximate in the prediction of the N supply of a specific soil. Keeney and Bremner (1966) found very low and insignificant correlations between the method and N uptake by the 2nd and 3rd cuts of ryegrass in pot experiments with Iowa soils. Cornforth and Walmsley (1971) measured N uptake by 35 day old maize plants in West Indian soils in a greenhouse and found that total N and Cornfield's method were the only two chemical procedures used that not only had significance at the 10 percent level of probability but also accounted for more than 50 percent of the variation. When the soils were broken down into various groupings by properties, Cornfield's method was found to be particularly good when the CEC was 30 me./100 gm. soil, and when the percent base saturation was between 80 and 99 percent. Walmsley, Twyford and Cornforth (1971) found no significant correlation between the yield of bananas in the field and the test values determined by Cornfield's technique. Keeney

and Bremner (1966) found the values of N obtained by this method to change between moist and air dried samples.

Keeney and Bremner (1966) proposed a method of extraction which was based upon that of Livens (1959) involving the extraction of N with boiling water and K_2SO_4, and subsequent digestion of the extract with sulfuric acid. Keeney and Bremner claimed improved ease of filtration and the reduction of the size of the soil sample which was required with this modification of the procedure. The proposed method was found to be significantly correlated at the .1 percent level of probability, and accounted for 62 percent of the variation of N uptake by the second and third cuts of ryegrass grown on soils representative of the major soil types of Iowa. Jenkinson (1968), using British soils, reported significant correlations between both N extracted by boiling water and N mineralized by aerobic incubations, and different cuts of ryegrass grown in pots in the greenhouse. Only 42 percent of the variation was accounted for, however. Values obtained by this method were shown to be unaffected by whether the soil was moist or air dry. Stanford (1968) proposed a modification of the boiling water technique, substituting 0.10 M $CaCl_2$ for water, arguing that the salt concentration is near that of the soils, that the pH tends to hold constant even with successive leachings, and that the soil does not become dispersed. Ryan, Sims, and Peaslee (1971) found significant relationships between the procedure and the third harvest of sorghum from pot experiments with 15 soils from Kentucky, but the correlations could only account for 37 percent of the variation. Lathwell et al. (1972) found significant correlations between extractions by this method and the uptake of N by maize and sorghum grown in pots in 10 different soils from Puerto Rico.

Stanford (1968) used different concentrations and different numbers of extractions with sodium pyrophosphate, and found that extractions with dilute Na-pyrophosphate were related to the readily mineralizable portion of the soil organic N. Lathwell et al. (1972) modified this procedure and found correlations which were significant at the 1 percent level and accounted for up to 81 percent of the variation with N uptake by maize and sorghum grown on Puerto Rican soils in pots. Various other methods have been used to extract one fraction or another of the soil organic N and to relate it to mineralizable N or plant uptake. Stanford and Demar (1969) found correlations between total distillable NH_4^+ extracted by boiling NaOH and aerobic mineralization. Cornforth and Walmsley (1971) had limited success correlating acid hydrolyzable N with uptake by young maize plants grown on West Indian soils in the greenhouse. Smith and Stanford (1971) found a high correlation between Conway distillable N and anaerobic incubations using 39 soils from different locations in the United States.

Jenkinson (1968) attempted to break from the notion of measuring some fraction of the available soil N supply and developed a test based upon earlier work of Hobson and Page (1932) and Paul and Schmidt (1960) using cold dilute $Ba(OH)_2$ in an attempt to measure the soil biomass. He argued that "by taking the size of the soil biomass as a measure of the mineralizing power of a soil, some allowance can be made for the N mineralized from slowly decomposing fractions and that from labile ones. If it is assumed, therefore, that a soil maintaining a large biomass mineralizes more N per unit time than one maintaining a small biomass, and that $Ba(OH)_2$ extractable organic matter is correlated closely with the amount of biomass in a soil, then $Ba(OH)_2$ extractable organic matter

should serve as a measure of the N mineralization power of the soil." Jenkinson measured both non-NO_3^--N extracted by $Ba(OH)_2$ and hexoses determined by the anthrone method, termed glucose equivalent or "glucose" extracted by $Ba(OH)_2$. The results of these tests were correlated with the N uptake data from ryegrass grown in the greenhouse and reported by Gasser (1961) and Gasser and Jephcott (1964) and with yield data from field experiments with barley reported by Gasser (1961). Correlations between non-NO_3-N extracted and mineralizable N were significant, but accounted for only 32 percent of the variation, and were not significantly correlated with N uptake by ryegrass in the greenhouse. Keeney and Bremner (1966) found that the amount of N extracted by this method was affected by the status of the soil moisture; air dry samples gave higher values than wet samples. $Ba(OH)_2$ extractable "glucose" was found to be highly significantly correlated with mineralizable N, accounting for 61 percent of the variation, and was highly significantly correlated with N uptake by ryegrass, although accounting for only 52 percent of the variation (Jenkinson, 1968). $Ba(OH)_2$ extractable "glucose" was highly significantly correlated with the yields of unfertilized barley fields, and the correlation coefficient accounted for 69 percent of the variation (Jenkinson, 1968). Robinson (1968) tested the $Ba(OH)_2$ extractable "glucose" method with N uptake by 6 week old tomato plants grown on various East African soils in the greenhouse and found no significant relationship. Cornforth and Walmsley (1971) working with 154 West Indian soils in the greenhouse, found a correlation with N uptake by maize plants which was significant at the .1 percent level, but could account for less than 50 percent of the variation when the soils were separated on the basis of percent base saturation. Those soils with a base saturation between 80-99 percent

had a good correlation between the extractable "glucose" and N uptake by maize. The $Ba(OH)_2$ extractable "glucose" method was modified by using N $NaHCO_3$ instead of 0.01N $Ba(OH)_2$ by Walmsley, Twyford and Cornforth (1971) for use with the analysis of yields of bananas. No useful correlation was found.

Various other methods have been proposed and tried, and all have met with the same variable fate as the methods discussed. Because each author either modified a technique or used one of a variety of parameters to evaluate the test methods, such as N value, N uptake, yield, percent yield response to fertilizer, it is difficult to compare the results of the various researchers with respect to the evaluation of one test procedure. Further, and most seriously, a number of papers reported incomplete information, questionable experimental designs, or poor techniques for data analysis, which makes interpretation of the data in the papers difficult, if not impossible.

Several of the papers do not detail the properties of the soils being tested. Saunder (1957) only described the texture of the soils, and Robinson (1968) gave ranges of soil properties, suggesting that interested readers communicate with him for details. Neither Subbiah and Asija (1962) nor Tamhane and Subbiah (1962) in their summary article gave the properties of the soil used in their original alkaline permangante experimental work. Olson et al. (1960), similarly, did not describe the soil being studied. Most researchers simply gave the pH, total N, and organic C. When the soil properties were mentioned, and in detail, mineralogical characteristics were not described. Cornforth and Walmsley (1971) using 154 soils from 6 Caribbean Islands, mentioned that the soils were formed on very different materials (coral limestone,

volcanic materials, igneous rock and mixed alluvia) but did not use this information in their interpretation of the test results. Walmsley, Twyford and Cornforth (1971) reported the failure of chemical tests to predict yields of bananas grown on volcanic soils. While it was noted that "surprisingly, response (to N) increased with average amounts of N in the three groups of soil and was independent of pH." It would have been helpful to have had a discussion of the influence of an analysis of the allophane content of the soils, and an interpretation of the results of the chemical tests in light of the relationship between allophane and organic matter content (Buol, Hole and McCracken, 1973; Sanchez, 1976). Very few of the papers gave the classification of the soils being studied, so that the reader has difficulty determining the general nature of the soils. Lathwell et al. (1972) were exceptional for including great group and soil order as well as series names.

Once the soil was sampled, the handling of the soil was quite varied by different researchers. Early workers did not consider the possibility of the effects of handling and pre-treatment on subsequent laboratory study. Gasser (1961) froze and then thawed his soils to improve the physical structure, and made no mention of the N flush which could result from such a procedure. Although Jenkinson (1968) studied the effects of length of storage on soil tests, he correlated his soil test results with yield data from the work of Gasser (1961) and Gasser and Jephcott (1964), who had used the freezing-thawing technique. Other researchers did not mention the nature of the handling at all (Subbiah and Asija, 1956; Richard, 1960; Tamhane and Subbiah, 1962). Although many authors did note the type of handling and storage, some did not consider the influence of a N flush resulting from wetting a dried soil

on the growth of plants in pots. Researchers using crops with multiple harvests did separate out the first crop or cut from the others (Keeney and Bremner, 1966; Gasser, 1960; Lathwell, 1972) in the correlation work in an attempt to recognize the N flush phenomenon. Robinson (1968) developed a pretreatment system of wetting and drying the soil which was supposed to give all soils a uniformity of pretreatment, and Ryan, Sims, and Peaslee (1971) placed moist soils in pots in the greenhouse for 6 weeks before planting grain sorghum. The variety of treatment of soils not only influences N uptake by plants but also the amount of N measured by the different chemical and biological methods. Keeney and Bremner (1966) evaluated several test methods for change in amount of N measured from fresh, air dried, and air dried plus stored samples and found that different procedures were affected in different ways. The variety of treatment of the soils, then, makes it difficult to compare conditions of the soil, and thus test results.

Once the soil is put in pots in the greenhouse, all sorts of variation in experimental design and procedure is introduced. One author did not detail greenhouse procedure at all (Olson et al., 1960), while others gave incomplete information (Subbiah and Asija, 1956; Tamhane and Subbiah, 1962; Keeney and Bremner, 1966). Plant density in the pots is variable, ranging from 1 plant to several plants per pot; the ratio of plant to soil volume is also variable. Robinson grew one tomato plant per pot, using the micro-pot method of Chenery (1953). Richard et al. grew 3 maize plants per pot of 3 kg soil, Cornforth and Walmsley (1971) grew 4 maize plants per pot containing 1 kg soil and Lathwell et al. (1972) grew 4 maize plants per pot containing 1600 g soil. Ryegrass density was similarly variable, with 1 gm of seed sown in each pot containing 3 kg

soil by Gasser (1961) and Gasser and Jephcott (1964) approximately 100 seeds sown in a pot containing layers consisting of 2 kg sand, 1 kg soil and 500 kg sand by Keeney and Bremner (1966). Ryan, Sims and Peaslee (1971) grew 5 sorghum plants in 1500 g soil placed between layers of quartz sand, while Lathwell et al. (1972) grew 6 plants in 1600 g soil. Not one article discussed the possibility of interplant competition for light, water, and other nutrients which might affect N uptake by the plants. In no paper was the growth habit or nutrient uptake pattern of the test crop described; it is, therefore, difficult to know how to compare data concerning the N uptake by ryegrass, and maize, sorghum, or tomatoes. The rationale behind the choice of the test crop plant was not discussed in any paper; one was not sure whether the plants were chosen because of known physiological response, the importance of the crop to the area being studied, or due to some factor of convenience. It was not clear, then, whether the researcher wished to extrapolate from greenhouse crop to similar crops in the field, or from a particular greenhouse crop to a variety of plant species.

The age of the crops at harvest for analysis was as varied as the plant density and variety of crops grown. Researchers have reported correlations between various soil tests and N uptake by maize plants that were 3 and 4 weeks old from seeding (Lathwell, 1972), 35 days from planting (Cornforth, 1971), 50 and 75 days from planting (Richard et al., 1960). Correlations have been reported for 3 cuts of ryegrass, all at different lengths of growing time. Thus Gasser (1961) reported the first cut 33 days after planting, the second 37 days after the first cut and the third 56 days after the second cut in one experiment and 28, 35, and 49 days in the second. Gasser and Jephcott (1964) reported cuts at 35,

31 and 39 days while Keeney and Bremner (1966) reported cuts at 32, 26 and 44 days. In all cases the first cut listed is days after seeding, and thus includes the time required for germination and emergence. Ryan, Sima and Peaslee (1971) harvested grain sorghum 3 times at 6 week intervals for N uptake studies while Lathwell et al. (1972) harvested and analyzed 4 week old plants. Robinson (1968) measured N uptake in tomato plants six weeks after sowing the seed. In no case did the researcher discuss the possible effects of the stage of development of the plant on either rate or amount of N uptake. Hanway (1963) discussed the growth stages of maize varieties adapted to Iowa conditions in relationship to the uptake of N, P and K and the accumulation of dry matter. In varieties studied by Hanway, at 30 days after emergence the maize plants had produced approximately 5 percent of their total dry matter and had taken up less than 10 percent of their total N, at 45 days after emergence they had accumulated approximately 15 percent of their dry matter and had taken up about 30 percent of the total N and by 70 days after emergence the plants had accumulated approximately 45 percent of their total dry matter and about 70 percent of their total N. Since there is evidence that the amount and rate of N uptake at a given time after emergence varies with different varieties grown in the same location (Rodriguez, 1977), it may not be possible to extrapolate from Hanway's data to all of the maize in the aforementioned experiments, and certainly there is no justification for the extrapolation to ryegrass, tomatoes, and sorghum. However, the data of Hanway and Rodriguez clearly shows that the rate and amount of N uptake by maize is small in the first month of corn growth, and changes as the plant ages. It is reasonable to suspect that plants other than maize show differences in rate and amount of nutrient uptake in the

course of their development.

Since the N uptake is different by plants at different stages of their development, it becomes difficult to compare results of data collected from several plants of the same species at different stages of their growth, and it is extremely hard to determine what meaning can be drawn from a comparison of two entirely different plant species at some stage of immaturity. With the nutrient requirements of a young plant being relatively low, little stress is being placed on the capacity of the soil to supply nutrients. All that can be measured is the rate at which the soil can supply N relative to the needs of a plant at a given stage of growth. It is entirely possible to have soils with the same rate of mineralization and very different amounts of mineralizable N; plants grown on the soils for a short time might not reflect the difference in potential, as the demand of the immature plants could be met by the rate of mineralization, and the supply would not be used up before the harvest of a crop. The situation becomes more complicated when more than one plant is grown in a pot, for the plant-plant interactions and competition for light, nutrients and water will confound the measurement of N release in the system. Finally, some of the soils in the various studies were air dried or frozen before being used in the pot experiments, and the resultant N flush could be adequate to supply the N needs of young plants grown for a short period of time. In this instance, the plants might not in their lifetime ever draw upon the mineralizable N which would normally be made available to a crop during the growing year. In the tropics, where wet/dry climates produce an initial N flush, much of the N released in the flush is leached out of the profile before plant roots are sufficiently developed to utilize it (Sanchez, 1976).

Field experiments should serve two purposes--to make sure that the text procedures developed with greenhouse studies perform under field conditions and to calibrate the chemical test values with yield response to fertilizer applications. In order to fulfill the first purpose, it would be logical to use the same crop in the field as was used in the greenhouse. Using a different crop in the field experiment would introduce a new source of possible variation and error. In many of the field experiments reported in the literature, which follow up greenhouse work a different crop from the one used in the greenhouse is planted. Thus, Gasser (1961) and Gasser and Jephcott (1964) used HI ryegrass in the greenhouse and barley and potatoes in the field; Robinson (1968) used 6 week old tomato plants in the greenhouse and maize at tasseling in the field; and Walmsley, Twyford and Cornforth (1971) reported the failure of a number of chemical tests to predict yield of bananas in the field by tests which had been evaluated for their relationship to N uptake by 35 day old maize plants in the greenhouse (Cornforth and Walmsley, 1971).

While it might be argued that a test is needed for a wide range of conditions and plants, in the process of developing a new test, it is important to control as many variables as possible in order to evaluate the sources of error and weakness. Once a test is determined to have some success with a field experiment, then subsequent trials can be conducted to establish the utility of the test over a range of crops and soil conditions.

The reporting of data and data analysis in the literature also has some areas of weakness. Many authors simply reported correlation coefficients without reproducing the data in a way that a reader could manipulate the data to verify the authors' conclusions (Olsen et al., 1960;

Jenkinson, 1968; Robinson, 1968; Cornforth and Walmsley, 1971; Ryan, Sims and Peaslee, 1971). Other authors reported correlations with the means of several crops (Gasser, 1961; Lathwell, 1972). There is nothing wrong with such a reporting system, except that when means are the population used for the correlation calculations, extrapolations from the data only apply to populations of means. Since the function of soil tests is to determine the requirements of a given soil, it might be best to be sure to clarify to which population the correlation coefficients apply.

Misuses of the correlation coefficient has lead to misinterpretations of data. In a regression calculation, if there are a cluster of points and an outlying point, the cluster of points acts as one point and the one outlying point is given a greater value in determining the slope than any single point in the cluster (Daniel and Wood, 1971). The same holds true for two clusters of points; the individuals within the clusters contribute less than the cluster as a unit. These types of situations lead to very high r values, approaching 1. Lack of consideration of this fact has lead several researchers to report high correlation coefficients which were actually artifacts (Subbiah and Asija, 1956; Gasser, 1961). Some authors seemed to misunderstand the linear nature of the simple regression function and fitted linear relationships to apparent curvilinear sets of points (Gasser, 1961). Gasser and Jephcott (1964), and Robinson (1968a, 1968b) simply presented regression lines with their equations drawn on a set of axes without any points. This is no better than a table of correlation coefficients. For the work of Gasser and Jephcott the omission of the data points is particularly suspect, as the experiments reported in this paper were a continuation of the data reported in 1961 where straight lines were drawn through curvilinear data

and outlying points and clusters were analyzed with linear regression.

Some of the papers showed a lack of consideration of the meaning of a correlation coefficient; the value of r is important, and so are statistical significance at .01, .1 and .5 levels of probability, but it is the value of r^2 which gives an estimate of how much variation has been accounted for by the particular test under consideration. Cornforth and Walmsley (1971) used the minimul level of r^2 for a given test procedure of .50 and argued that a test accounting for less than 50 percent of the variation was not particularly helpful. Many authors have not established minimum levels of r^2 which are acceptable. Many of the proposed methods with promise do not account for more than 60 percent of the variation.

Chemists working with chemical and biological procedures only, seemed to present the data most completely and clearly (Keeney and Bremner, 1966; Stanford and Smith, 1972). Unfortunately, the laboratory work is only one part of the process of soil test development. Given the great variability in experimental design, treatment of soil samples and plants, and complexity of data analysis, it is difficult for this author to determine just what the state of the art is in the area of developing a soil test procedure which is useful for prediction of fertilizer needs of crops grown to the harvestable state in the field.

THE EXPERIMENTAL SITE, EXPERIMENTAL DESIGN, AND DISCUSSION OF VEGETATION AND SOILS

The experimental site was located on the grounds of the Estacao Experimental de Brasilia in the north central part of the Federal District, near the municipality of Planaltina, approximately 40 kilometers from Brasilia. The location is between 15° 34' 30" and 15° 37' 30" south latitude and the meridians 47° 41' 30" and 47° 45' 30" west longitude. The climate corresponds to the type Aw in Kloppen's system of classification (Boletim Technico No. 8, 1966), with a wet season generally from October through April and a dry season from May to September (Feuer, 1956). The wet season is often interrupted by periodic dry spells, called veranicos, of varying duration. Veranicos of 10 days may occur one year in two, and veranicos of two weeks or more may occur one year in five (Wolf, 1975). These veranicos can be a serious problem to crops grown without irrigation.

The soil of the site is classified as Latosol Vermelho Escuro distrofico, textura argilosa, fase Cerradao (Dark Red Latosol, dystrophoc, clayey texture, Cerradao phase) by the Brazilian classification system (Boletim Technico No. 8, 1966). These soils would most likely be classed as Typic Haplustox, fine, isohyperthermic, kaolinitic in the U.S. Soil Taxonomy (Cline and Buol, 1973). For a profile description, see Table 1. The soils of the experimental site are friable, porus, permeable, and highly aggregated (Cline and Buol, 1973). The maximum amount of water which can be stored in these soils to a depth of 30 cm is about 50 mm (Wolf, 1975). Since evapotranspiration can be 7 mm or more per day,

Table 1. Soil Profile Description.

Perfil: 1
(Profile)

Municipio: Distrito Federal
(Municipality)

Local: Estacao Experimental de Brasilia
(Site)

Unidade de Mapeamento: Latosol Vermelho Escuro Distrofico textura argilosa fase cerrado.
(Mapping unit)

Classificacao:
(Classification)

Amostra de Lab. n.º (Sample number)	HORIZONTE (Horizon) Simbolo (symbol)	Profundidade cm (Depth, cm)	(Sample, air dry) AMOSTRA SECA AO AR (%) (Stones) Calhuas 20 mm	(Gravel) Cascalho 20-2 mm	pH agua (water)	KCl N (N KCl)	Equivalento de Umidade (moisture equivalent)
2258	A_p	0 - 10	0	x	4.9	4.2	22
59	A_3	- 35	0	x	4.8	4.3	23
60	B_1	- 70	0	x	4.9	4.2	23
61	B_{21}	-150	0	x	5.0	4.2	22
62	B_{22}	-260+	0	x	4.6	4.4	20

(Attacked by) ATAQUE POR H_2SO_4 %			(Density 1.47) D - 1,47						
SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	MnO	ki	kr	$\frac{Al_2O_3}{Fe_2O_3}$	P ppm
14.2	15.7	7.4	0.38	0.05		1.54	1.19	3.35	2
14.7	16.5	7.8	0.32	0.04		1.51	1.16	3.31	1
15.1	16.6	7.5	0.38	0.04		1.55	1.20	3.47	x
15.3	17.7	7.6	0.35	0.04		1.47	1.15	3.63	x
14.4	16.2	7.5	0.31	0.03		1.51	1.17	3.38	x

(continued)

Table 1. (continued)

COMPLEXO SORTIVO (Absorption complex) (em E/100 g) (MEQ)								V % (% Base saturation)	100.Al / Al+S
Ca^{++}	Mg^{++}	K^{+}	Na^{+}	S	Al^{+++}	H^{+}	T		
0.4		0.10	0.02	0.5	1.9	7.8	10.2	5	79
0.2		0.05	0.03	0.3	2.0	5.8	8.1	4	87
0.2		0.03	0.03	0.3	1.6	5.2	7.1	4	84
0.2		0.01	0.01	0.2	1.5	4.4	6.1	3	88
0.2		0.02	0.02	0.2	0.7	2.7	3.6	6	78

C%	N%	C/N	(Partial size distribution) COMPOSICAO GRANULOMETRICA (%) Dispersao com NaOH (Dispersed with NaOH)				(Clay) Argila natural %	(degree) Grau de floculacao (of flocculation)	(Silt) Silte / Argila (clay)
			Areia grossa 2-0,20 (course sand)	Areia fina 0,20-0,05 (fine sand)	Silte 0,05-0,002 (silt)	Argila 0,002mm (clay)			
1.76	0.21	8	16	17	23	44	13	70	0.52
1.16	0.08	15	13	17	22	48	22	54	0.46
0.91	0.05	18	14	19	21	46	22	52	0.46
0.73	0.05	15	14	19	21	46	22	52	0.46
0.32	0.03	11	16	20	22	42	0	100	0.52

SOURCE: Boletim Tecnico No. 8 (1966). Ministerio da Agricultura, Escritorio de Pesquisas e Experimentacao, Equipe de Pedologia e Fertilidade do Solo.

water stress is likely after one week without rain if the rooting depth is no more than 30 cm (Wolf, 1975). Field observations reported in the 1972 Annual Report state that corn showed wilting after 6 days without rain (Annual Progress Report, 1972-1973). In the area of the experiment, the duration of the veranicos is variable, but the regularity of their occurrence makes them an important factor in crop production.

The history of the experimental site prior to clearing for the N experiment is uncertain. It apparently was used by researchers affiliated with an animal science group (Bouldin, pers. com.). It is possible that the land had some lime applied to it 4 or more years previous to the advent of the nitrogen experiment. When the land was cleared for the experiment, the project technician noted "one spot perhaps 5-10 feet in diameter in which it appeared perhaps a wheelbarrow load or so of lime might have been dumped and never thoroughly distributed. In fact, we removed that lime material and the upper inch or so of soil and excluded it from the plot as best we could" (Naderman, pers. com.). The area had a number of termite mounds which could contribute to the heterogeneity of the site (Bouldin, 1977). Since the occurrence of termite mounds is widespread in the Federal District (Feuer, 1956), the presence of the mounds would serve to make the site more, rather than less, representative of the region.

The experimental design was a randomized block with 5 replications of 10 levels of N fertilizer application. The plots were 5 x 10 meters, with 6 rows per plot and a plant population equal to 50,000 plants/ha. A locally produced maize variety, Cargill 111, was grown in all years. The rates, sources, and times of application of N were changed over the course of the experiment in an attempt to get an appropriate set of

rates for developing a response curve. The first year there were no zero N check plots -- the check had 20 kg/ha N applied at planting. However, the check plot received no N fertilizer each year following 1972-73. The consistent rates of N applied in the experiment were 60, 80, 100, 140, and 200 or 220 kg/ha, applied in various combinations of split applications. Phosphorus, K and minor elements were applied, and the rate adjusted as more was learned of this particular soil system. The most critical change was in the application of P. It was shown in the P experiment that, contrary to expectations, P applied as a broadcast fertilizer gave greater yield response than the same amount of P applied in the band (Annual Progress Report, 1972-1973). In accordance with these findings, the P applications were changed from 200 kg P_2O_5 in the band and 200 kg broadcast in 1972 to 300 kg/ha broadcast and 80 kg/ha in the bank in 1973 and finally just 100 kg/ha in the band in 1974. It is noted in the 1972 annual report that maximum yields of 8000 kg/ha were achieved on the P experiment with 100 kg N in split application of 20-40-40, but top yields of the nitrogen experiment that year were only 6310 kg/ha. The lower maximum yields of the N experiment were attributed to the suboptimal application of P. Lime containing 10 percent Mg was applied at the rate of 4T/ha and plowed in when the experiment was established. No further lime additions have been made. In addition 50 kg/ha $MgSO_4 \cdot 7H_2O$ and 50 kg/ha of sodium molybdate were plowed down with the lime. There was debate as to whether the 1975-76 crop suffered from micronutrient deficiencies of Cu and Zn; the 1975-76 crop did not show a response to applications of Cu and Zn (Ritchey, pers. com.). Irrigation was used the first year (1972-73) during a <u>veranico</u>, but was not used in subsequent years.

The site was selected because it was thought to be "typical of extensive areas in the Campo Cerrado" (Annual Progress Report, 1972-73). The site may not, however, be representative of the intended area. One of the reasons for this may be due to a confusion in terminology. "Campo" can be a general term referring to an area covered by scrub savannah (Feuer, 1956) and "Campo Cerrado" is often used to denote the central plateau or Planalta of Brazil, an area reportedly encompassing 600,000 - 1,800,000 Km^2 (Ritchey and Lobato, 1977; Soares, Lobato, Gonzalez and Naderman, 1975). Within the broad classification of scrub savannah, however, various vegetational associations have been recognized and described. Thus, Feuer (1956), citing Waibel (1948), described three types of campo: campo cerrado, campo sujo and campo limpo. Campo Cerrado is characterized by Feuer (1956) as consisting of dense stands of small, 12-30 foot twisted trees with thick bark and leathery hairy leaves and a dense understory growth of grasses 3 to 6 feet tall. Campo sujo is to be distinguished from campo cerrado in that the trees are shorter and more widely spaced in campo sujo than in campo cerrado. Campo limpo is referred to as a steppe, with no trees at all. The Brazilian Ministry of Agriculture's soil survey bulletin describing the Federal District (Boletim Technico No. 8, 1966) distinguishes 6 categories of vegetation in the district, including 5 types of campo. While campo suja and campo limpo are not listed, campo cerrado, campo cerradao, cerradao, campo de varzea, campo de cabeceira de ravina and campo de altitude are itemized. The descriptions of cerrado and campo cerrado are similar to those given by Feuer (1956), above. Species typical of the upper story vegetation are Curatella americana, Caryocar brasiliensis, Stryphnodendron barbatimao, Solanum spp, Anona Coriacea, and Qualea spp, while understory vegetation

commonly consists of Aristida pallens, Attalea exigua, and Melinis minutiflora. Campo Cerradao vegetation is bigger than campo cerrado vegetation, reaching heights of 10-12 meters, with tree trunks which are less twisted than those of the campo cerrado (Boletim Technico No. 8, 1966). Campo de varzea occurs in flood plains (Dos Santos, pers. com.), Campo de cabecira de ravina at the head of ravines and campo altitude occurs on the highest land surfaces. VanWambeke (1971) distinguishes between campo cerrado and campo cerradao on the basis of the density of trees -- campo cerradao being those regions in which the desnity of trees is great enough to prevent the passage of a jeep.

Attempts have been made to explain the variation in vegetation. Feuer (1956) suggested that the variation was due to repeated burning in some areas, with the taller and denser stands of trees existing in those areas where the burning was minimal. Cline and Buol (1973) mentioned that local tradition ascribed higher soil fertility status to those areas with Cerradao vegetation than those areas with cerrado vegetation, and Don Kass, Maria Kass, Dos Santos (pers. com.) suggested that improved water status might explain the vegetational differences. Lopes (North Carolina State University, 1974) collected 528 composite topsoil samples from under natural vegetation of 5 different types: campo limpo, campo cerrado, cerrado, cerradao and forest. The data is reproduced in Table 2. It can be seen that the soils taken from under the Cerradao vegetation had greater values for exchangeable K and extractable P, Zn, Ca , Mg, and had a larger effective CEC than did those sampled from under the campo cerrado vegetation. Cerrado soil samples were intermediate in properties between campo cerrado and cerradao.

The water status of these vegetational areas may also differ.

Table 2. Relationship between type of native vegetation and average topsoil properties in the Cerrado. Numbers of samples for each vegetation class in parentheses.

Soil Property	Campo Limpo (64)	Campo Cerrado (148)	Cerrado (255)	Cerradao (45)	Forest (16)
pH (H_2O)	4.87a*	4.94ab	5.00b	5.14b	5.28c
ΔpH	-0.71ab	-0.69a	-0.76bc	-0.82dc	-0.93d
Organic matter (%)	2.21a	2.33a	2.35	2.32a	3.14b
Exch. Ca** (meq/100 cc)	0.20a	0.33ab	0.45b	0.69c	1.50d
Exch. Mg** (meq/100 cc)	0.06a	0.13a	0.21b	0.38c	0.55d
Extr. K*** (meq/100 cc)	0.08a	0.10ab	0.11b	0.13b	0.17c
Exch. Al (meq/100 cc)	0.74	0.63a	0.66a	0.61a	0.78a
Eff. CEC (meq/100 cc)	1.08a	1.19a	1.43b	1.81c	3.00d
Al saturation (%)	66a	58b	54b	44c	40c
Extr. P** (ppm)	0.5a	0.5a	0.9b	2.1b	1.4c
Extr. Zn** (ppm)	0.58a	0.61a	0.66b	0.67b	1.11c
Extr. Cu** (ppm)	0.60a	0.79ab	0.94b	1.32c	0.95bc
Extr. Mn** (ppm)	5.4a	10.3b	15.9c	22.9d	24.1d
Extr. Fe** (ppm)	35.7a	33.9a	33.0a	27.1b	37.2c
Clay (%)	33a	36a	34a	32a	37a
Silt (%)	20a	16b	15b	16b	16b
Sand (%)	46a	48a	51a	53a	47a
Hue	7.3YRa	6.7YRa	5.4YRb	4.4YRc	4.4YRc
Value	4.3a	4.2a	3.8b	3.5c	3.6bc
Chroma	4.5a	4.7a	4.9a	4.7a	5.7b

*Means for each line not followed by the same letter are significantly different at the 0.05 probability level.

**Extracted by 0.05N HCl + 0.025N H_2SO_4

***Extracted with neutral N KCl.

SOURCE: Agronomic-Economic Research on Tropical Soils, 1974. Annual Report for 1974, Soil Science Department, North Carolina State University, Raleigh, NC.

Dos Santos (pers. com.) reported that cerradao vegetational associations are predominately found at the base of an escarpment. Cline and Buol (1973) mentioned that the field plots for the experimental site at Planaltina are located on a gently sloping geomorphic surface which is about 850-900 meters from the base of a sharp escarpment that rises to an older erosion surface. "Questions could be raised about how representative the site may be of extensive areas of the central plateau. The position of the site relative to the escarpment to higher land could suggest moisture relationships atypical of much of the plateau" (Cline and Buol, 1973).

The experimental site, then, is not typical of campo cerrado soils in the strict sense of soils which occur under cerrado or campo cerrado vegetation, and as the Cerrado and campo cerrado vegetation dominate the region loosely termed "the campo cerrado" of Brazil, the experimental site cannot be said to typify this region. The distinctions recognized by the various names for different vegetational associations appear to be correlated with differences in the soils upon which the vegetation grows. How important these differences would be in high input agricultural systems is not known.

PURPOSE, MATERIAL, AND METHODS

Purpose

The objective of this work was to study the relationship between a maize crop grown in the field and a chemical soil test. The soil test had shown promise in relating soil test values of N with uptake by maize and sorghum grown in pots in the greenhouse (Lathwell et al., 1972). Two procedures were employed -- the chemical soil test which measured a fraction of extractable organic and inorganic ammonium and an incubation procedure which provided a standard for the evaluation of the chemical soil test. If the two methods were comparable, the values of the two methods should have been significantly correlated with each other as well as with N uptake or yield of the crop. The soil test value should also account for much of the variation in yield or N uptake from plot to plot to be useful as a soil test procedure for the evaluation of the ability of a particular soil to supply nitrogen to a crop during a growing season. The amount of mineral nitrogen produced over time in incubations could help to characterize these soils in relation to the wide range of soils studied by other researchers.

Materials and Methods

The Soil: Soil samples were collected from the zero-N check plots of a nitrogen fertilizer experiment at the Estacao Experimental de Brasilia, Brasil in November 1973 and August, 1974. Topsoil samples (0-15 cm) and subsoil samples (15-30 cm) were collected in November 1973 and only topsoil samples (0-15 cm) were collected in August 1974. The samples were

air dried in a greenhouse and stored in plastic bags, first in Brasil and then in Ithaca, New York at room temperature until the time of analysis.

The Crop: The locally produced maize variety Cargill 111 was grown. The crop was planted on November 28, 1973 and harvested on May 6 and 7, 1974.

Incubations: 50 gram samples of air dry soil were placed in 250 ml Erlenmeyer flasks, brought to field capacity with distilled water and covered with Parafilm T. The flasks were put on a lab bench and allowed to sit, undisturbed, at room temperature (≈22 degrees C) for the specified amount of time. All November 1973 topsoil samples were incubated for 2, 4, and 8 weeks, 2 of the November 1973 topsoil samples were incubated for 39 weeks, the November 1973 subsoil samples were incubated for 2 or 4 and 8 weeks, and the August 1974 topsoil samples were incubated for 2, 3, 4, 8, 16, and 39 weeks. There were duplicate incubations of all samples except for one 39 week incubation of a November 1973 topsoil sample. The quantity of soil available for analysis determined the number of time intervals each sample could be incubated.

Analytical methods:

Soil: 1 N KCl extracts of the incubated and non-incubated soils were analyzed for inorganic ammonium and nitrate by the steam distillation procedure using MgO and Devarda's alloy, as described by Bremner (1965). Extracts of the soil samples were also analyzed for total extractable ammonium nitrogen by acid digestion and then steam distillation with 10 N NaOH, as described by Lathwell et al. (1972).

Total N was determined by the macro-Kjeldahl procedure (Greweling, 1976) as well as with a selenium catalyzed auto analyzer procedure (Greweling, 1976). Difficulties were encountered in replicating the

results. The values seemed to vary according to sample size. Since the macro-Kjeldahl procedure is the standard procedure for total N determination, the values obtained by this method were used in the study under discussion. Total C and organic C were determined by the methods of Allison (1961). Due to the difficulties associated with the determination of the N, the values calculated for the C:N ratio should be regarded as rough approximations rather than accurate estimations.

Soil pH was taken in a 1:1 soil to water suspension and in a 1:2 soil to 0.01 M $CaCl_2$ solution, as described by Greweling and Peech (1965).

Terminology:

The amount of mineral N measured after a period of incubation will be referred to as mineralizable nitrogen, and the difference between the amount of mineral nitrogen found at the end of a period of incubation and that which existed before incubation will be referred to as Δmineralizable nitrogen. The nitrogen fraction recovered by the acid digestion technique will be referred to as digest nitrogen (to be consistent with Lathwell et al., 1972) and the difference between the amounts of digest nitrogen found in incubated and nonincubated soil sample extracts will be referred to as Δdigest nitrogen.

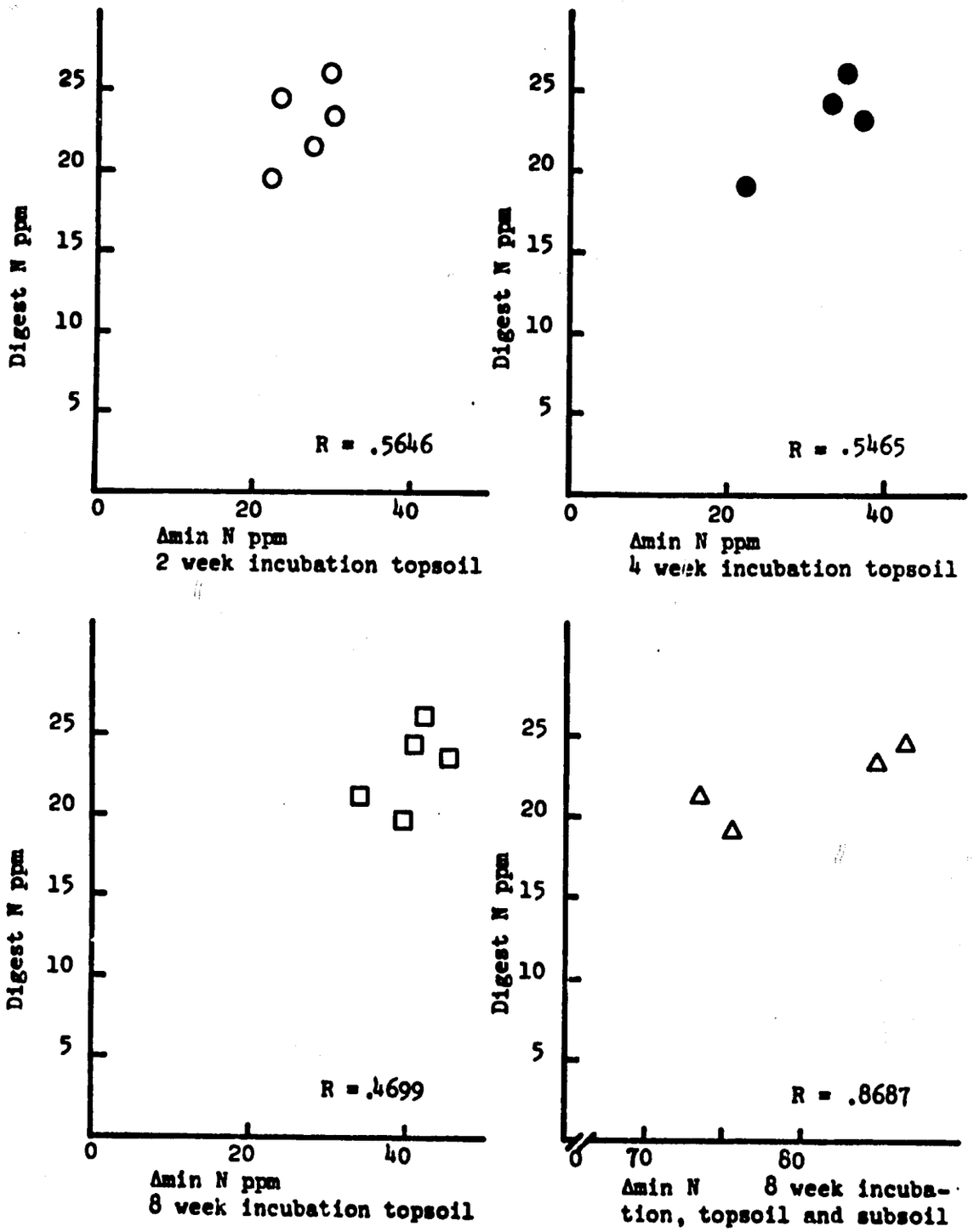
CHEMICAL AND BIOLOGICAL TEST METHODS

Results

Figure 1 shows the relationship between digest N and Δmineralizable N for the November 1973 samples after various periods of incubation. The relationship improves with length of time of incubation, and is most improved by the inclusion of subsoil values as well as topsoil values after 8 weeks of incubation. The correlation coefficients also show that although the test values did not account for more than 32 percent of the variation when only topsoil samples were considered, 75 percent of the variation was accounted for when top and subsoil samples were considered together.

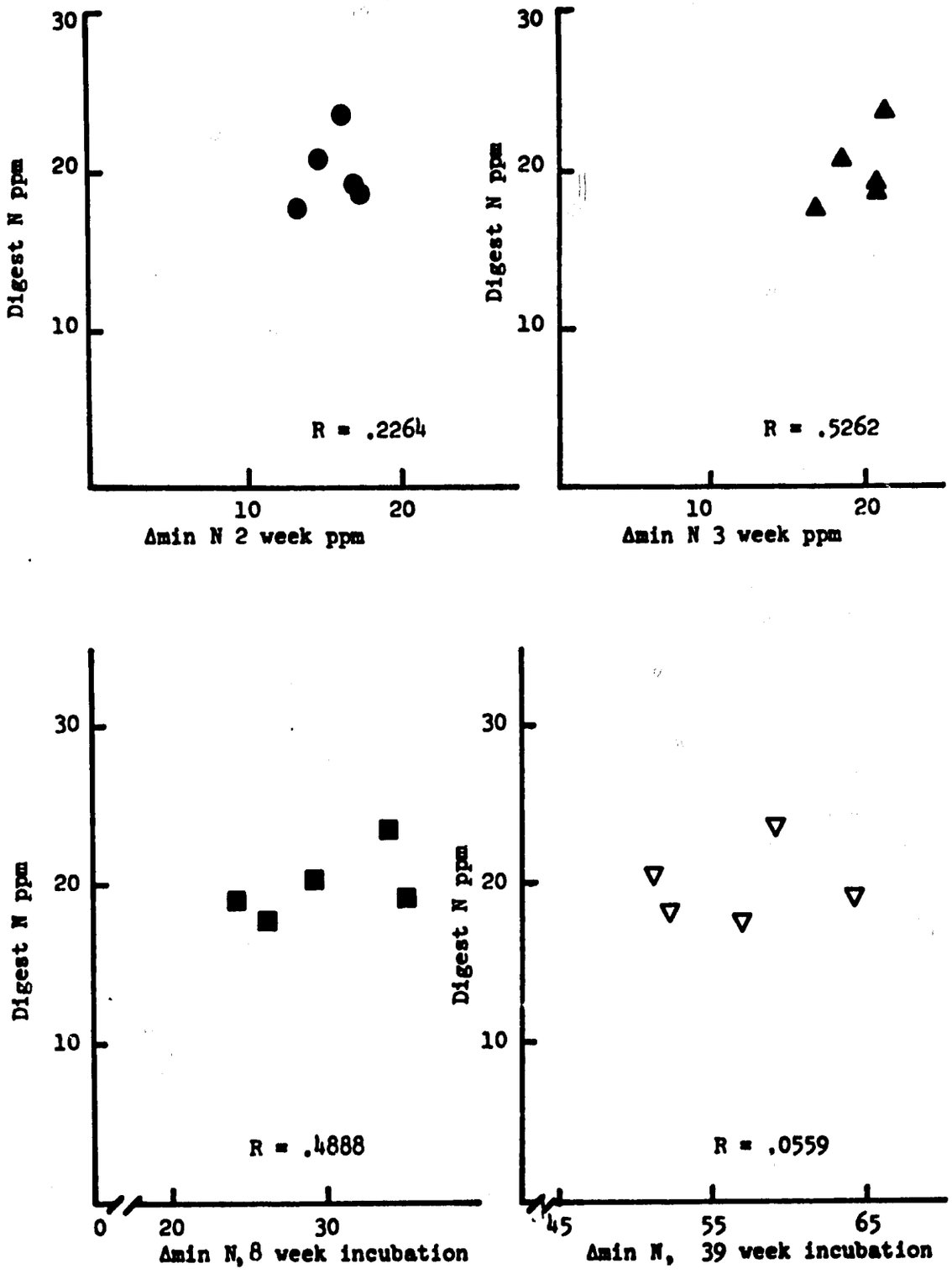
Figure 2 shows plots of the same variables for the August 1974 samples. No significant relationship existed and no trend towards a relationship over time existed. Since no subsoil samples were available from this sampling date, the effect of the inclusion of their values on the correlation remains unknown. The scatter diagram for the 39 week incubations shows that there is no association at this time interval. The data, however, may reflect the water status of the soil samples more than the possible relationship between these two test procedures. No water was added to the soils once the incubations were established, and the soils appeared to be drier at 39 weeks than at 4 or 8 weeks. The 29 week samples were also on the bottom layer of a set of samples, with a glass plate separating the two layers. Conceivably, the glass plate could have inhibited gas exchange, thus subjecting these soils to a different gaseous atmosphere than the soils incubated for a shorter period of time which

Figure 1. Digest N vs Amineralizable N, November 1973, 2, 4, 8 weeks incubation, topsoil and subsoil



R = .9500 for significance at 5% with 4 points
R = .8783 for significance at 5% with 5 points

Figure 2. Digest N vs Δmineralizable N for August 1974 soils, 2, 3, 8, 39 week incubation.



R = .8054 for significance at 5% with 5 points.

were on top of the glass shelf and thus able to have freer gas exchange through the Parafilm T.

It should be noted that some of the graphs contain only four points, requiring a higher value of r than those with 5 or more points for significance at the 5 percent level. For purposes of orientation, it should be noted that significance at the 10 percent level requires values of .8054 for 5 points and .9000 for four points.

Figure 3 shows the plot of Δmineralizable N and Δdigest N after 2, 4 and 8 weeks of incubation for November 1973 topsoils and after 2, 3, 8, and 16 weeks for August 1974 samples. Again, there was no apparent relationship. Figures 4 and 5 show plots of Δmineralizable N against Δdigest N for all incubation periods for each soil. In these figures a definite trend towards significance is apparent. Although these data show no relationship between Δmineralizable N and digest nitrogen at any given incubation time because of the variation from soil to soil combined with the few number of data points, they suggest that digest N measurements were related to the reservoir of N available to microbial populations for the production of mineral nitrogen.

Discussion

From the small number of data points it was impossible to conclude anything about the value of the two test procedures for the Dark Red Latosols of the experiment station in Brazil. There is no simple explanation for the lack of correlation between the chemical test and the incubation procedure. Lathwell et al. (1972) reported a highly significant relationship using 10 Oxisols and Ultisols from Puerto Rico, while Assa (1973) reported correlation coefficients with and without significance

Figure 3. Δmineralizable N vs Δdigest N after different lengths of incubation, November 1973 and August 1974 samples.

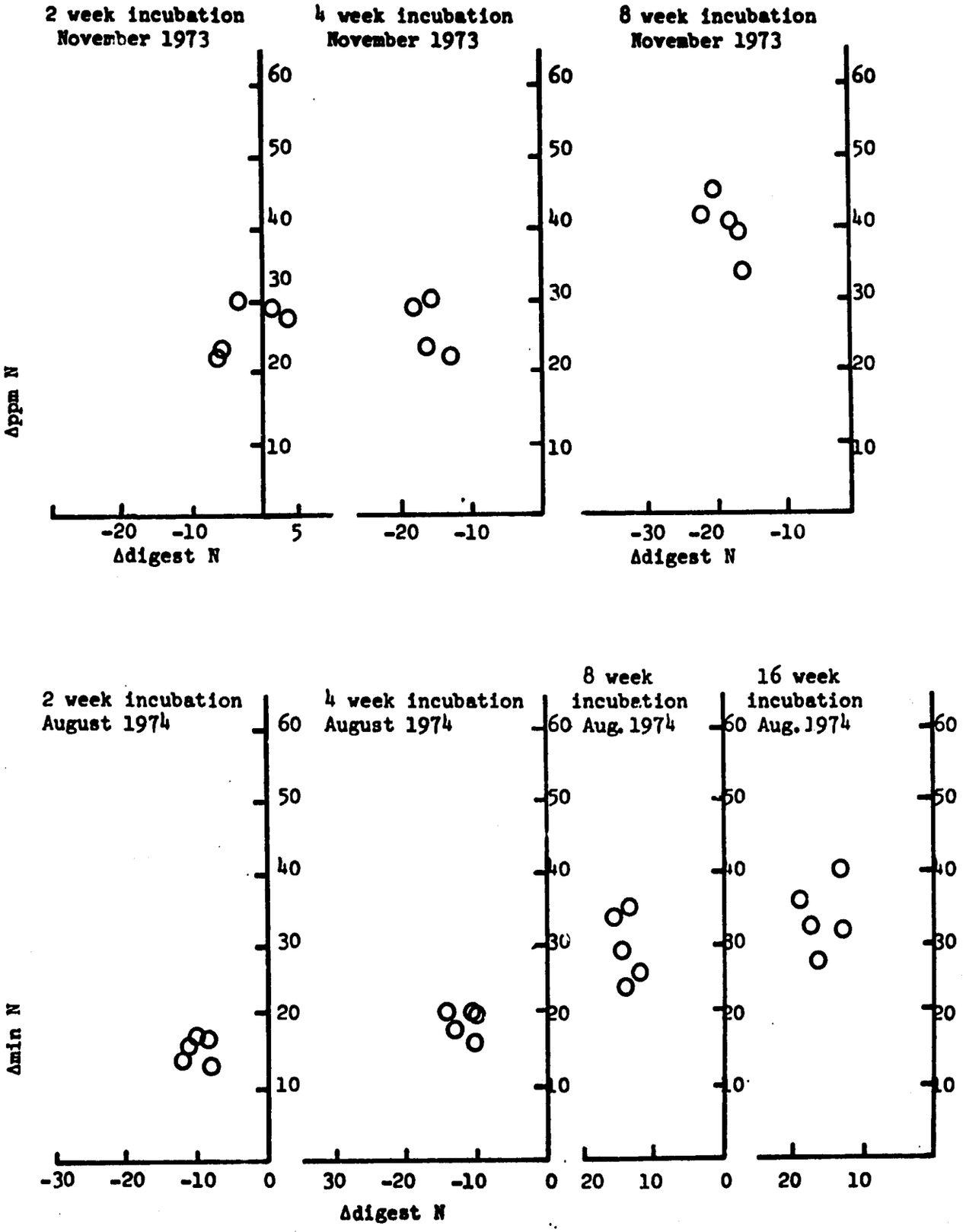


Figure 4. Δmineralizable N vs Δdigest N, August 1974 samples and soil average November 1973

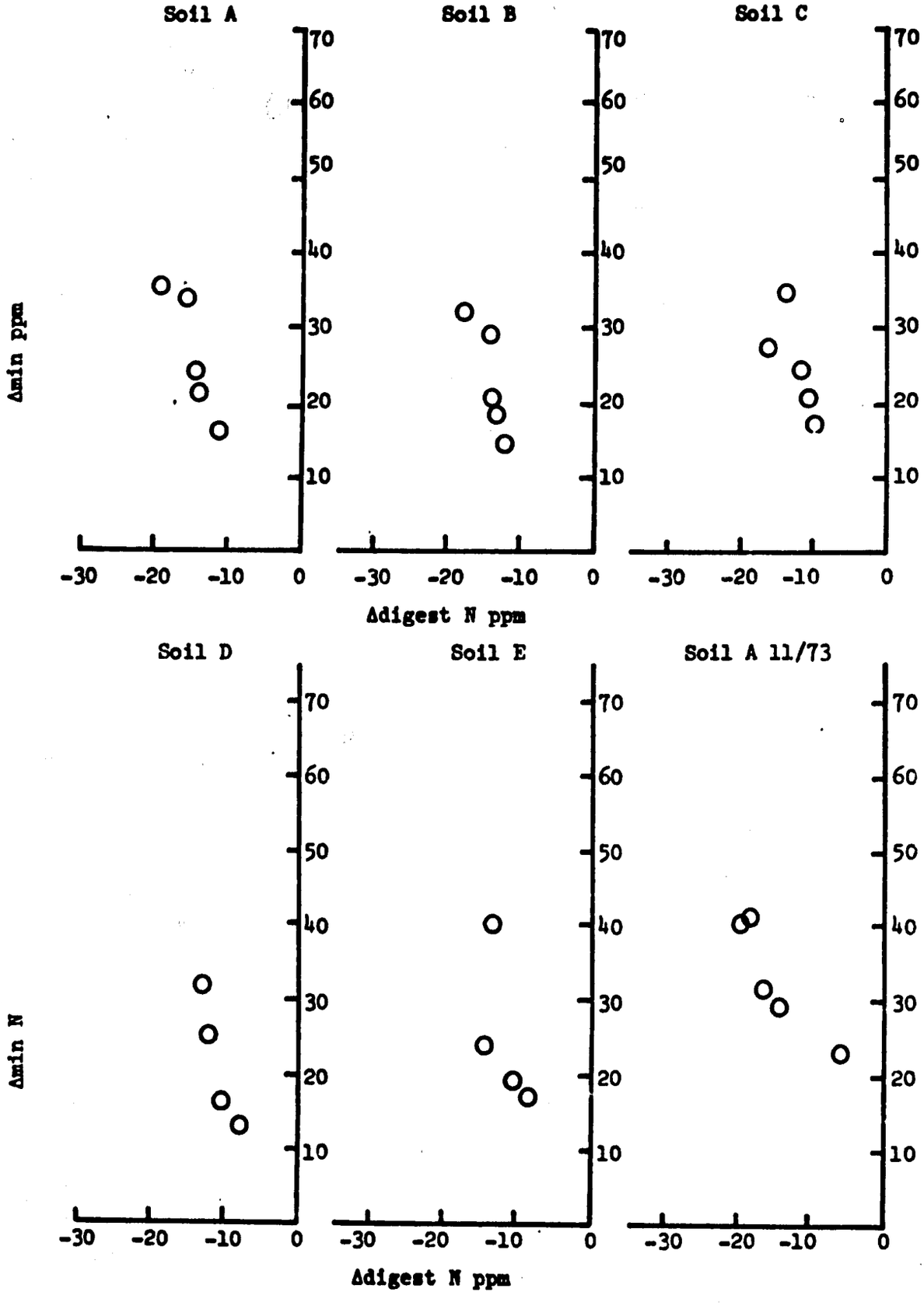
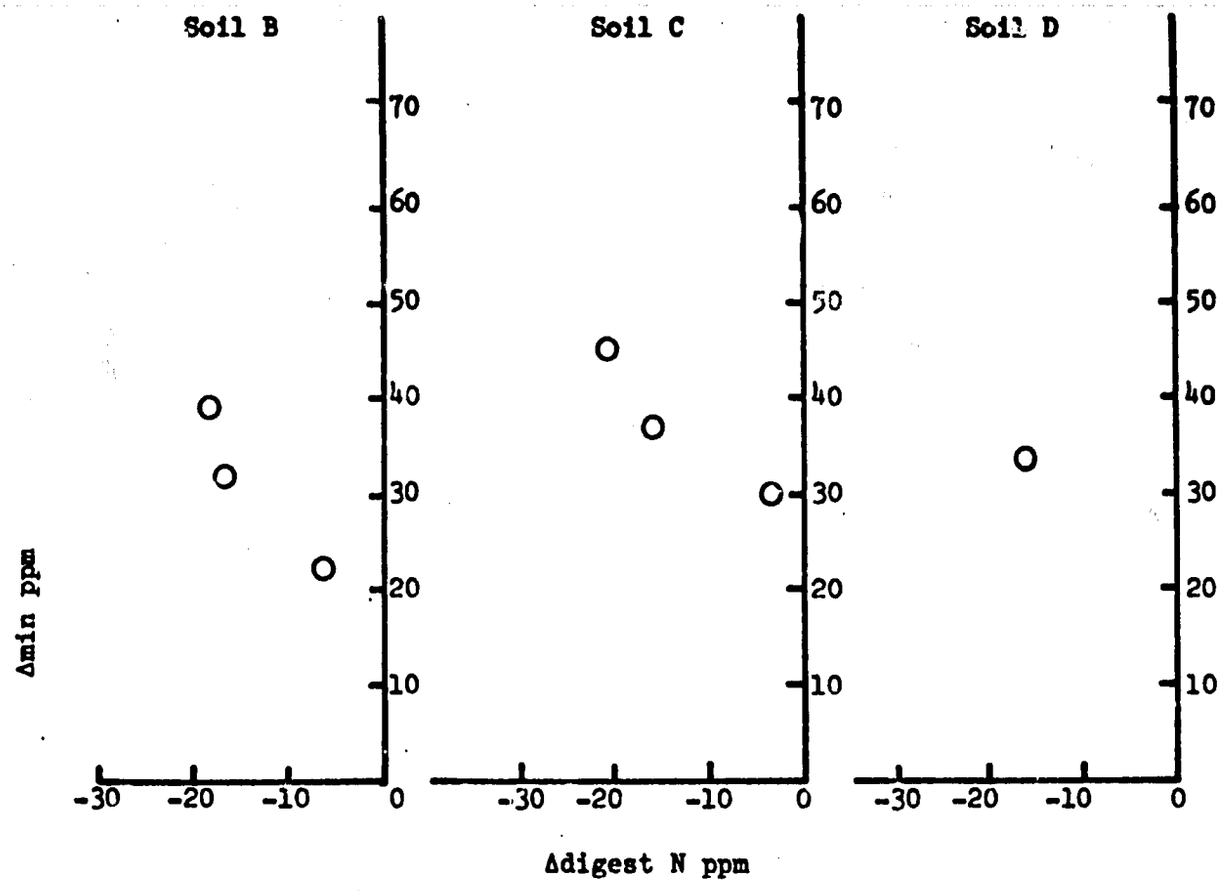
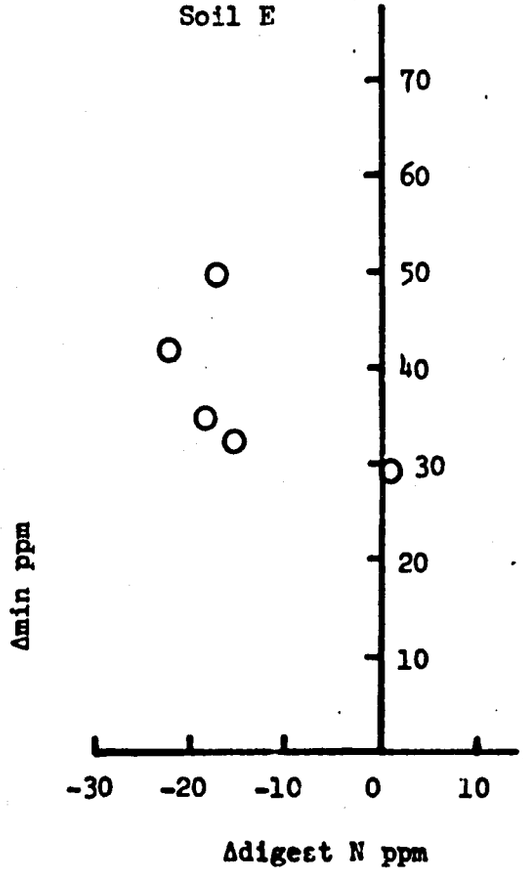


Figure 5. Δmineralizable N vs Δdigest N, November 1973 soils.





between the values of digest N and the values for mineralizable N at 2, 4, and 8 weeks, using a Lima Silt Loam soil from Aurora, New York. Among the factors which could have influenced the relationship between the two sets of test values are the condition of the soil at sampling and the length of storage before analysis.

The soils in this study were air dried in a greenhouse and stored in plastic bags for 2 1/2 years before analysis. There are no data available about the effects of air-drying of soil samples on the values obtained by the 1 N KCl extraction plus acid digestion test procedure which was used in this study, or what the effect of air drying might be on the properties of the specific Oxisols used in this study. Various researchers have reported data concerning the response of a variety of soils to air-drying, and the effect of air drying and storage on various analytical procedures. Eagle and Mathews (1958), working with nine soils from Ontario, Canada, stated that there was no effect of air-drying on soil test results. They did not, however, present any data to support this statement. Birch (1960) reported that drying profoundly affected the ammonifying and nitrifying organisms in the soil. Keeney and Bremner (1966b), using 25 soils from Iowa, studied the effects of air drying on the analytical results of 6 soil test methods and reported a distinct effect on values of 4 of the 6 test procedures. In all cases of a change, the reported means of the 25 soils increased. Since the data on the individual soils was not reported, it is impossible to determine what the nature of the variation in response was by individual soils, or by groups of soils with similar properties. Jenkinson (1968) studied the effects of air drying on mineralizable N and on $Ba(OH)_2$ extractable "glucose" values of some English soils. Air drying was found to increase both the

mineralizable nitrogen and the "glucose" values. Hesse (1971) reported that the water soluble organic nitrogen fraction increased with time and temperature of drying. Lathwell et al. (1972) used freshly air dried soil samples in their study and reported highly significant correlations between digest nitrogen values and mineralizable nitrogen values. There is not clear evidence, then, that air drying the Brazilian soil samples influenced the values of digest nitrogen and mineralizable nitrogen sufficiently to cause a lack of correlation between the two soil tests.

There are reports in the literature on the effects of lengths and temperature of storage on soil test results. Eagle and Mathews (1958) reported that prolonged storage of soil samples before testing caused an increase or decrease in the measured ability of the soil to supply nitrate nitrogen. Keeney and Bremner's 1966 study comparing the effects of field moist, freshly air dried, and air dried plus stored samples on the results of six soil test methods noted a trend towards increased values for some test methods after 8 weeks of storage compared with values for freshly air dried samples, although the increases were not as large as those between field moist and freshly air dried samples. Jenkinson (1968), working with British soils, found an increase in the mineralizable nigrogen values, but little, if any, in the values for the $Ba(OH)_2$ extractable "glucose" after 3 1/2 or 10 years of storage. Nevo and Hagin (1966) were cited in Hesse (1971) as having found that changes during the first three months of dry storage were independent of microorganisms, and that the major factor involved was a change in the physical structure of the organic fraction. Chalk and Waring (1970) reported that storage at room temperature was the main factor in the change. They further reported that the response of soil to storage was not consistent

among methods nor predictable within methods. Freney and Simpson (1969) studied the effects of drying soils at three different temperatures and concluded that there was an increase of nitrogen released with an increase in temperature.

The type of container used to hold the soil in storage may also influence soil test results. Olson et al. (1960) compared the change in ammonium nitrogen status of four soils before and after incubation when stored in glass jars or paper sacks. They reported that the ammonium values were higher for soils stored in sacks than in jars, and that soils with pH of 5.4 and 5.7 had a greater accumulation of ammonium when stored in the sacks than did soils of pH 7.8 or 8.0. These increases in ammonium likely reflect contamination from the storage environment. Hesse (1971) noted the possibility of pollution from certain kinds of plastic containers. In a study of montmorillonite clays, it was found that organic complexes passed from the plastic into the clay minerals, resulting in fundamental changes in the minerals.

Incubation studies and tests for digest N were conducted in 1975 on 4 soils which were samples of the original soils used by Lathwell et al. (1972). The soils had been stored in an air dry state in tightly capped plastic bottles at room temperature for 3 1/2 years. Table 3 shows the ppm nitrogen determined in the original study and by this author in 1975. Inspection of the data lead to a conclusion that there was, in general, no effect of storage. An independent T test performed on the data supported this conclusion. However, there were changes in test values for some soil samples. The Nipe soil (Typic Acrorthox) showed a definite increase in ppm N mineralized at both incubation times after storage, and the Cialitos (Orthoxic Tropohumult) showed a marked

Table 3. Storage of Puerto Rican soils.

Series name	Order	ppm N					
		Digest N		4 week incubation		8 week incubation	
		L*	S**	L	S	L	S
Pina (p) Sample II	Oxisol	28	26	15	20	16	20
Nipe (N) Sample II	Oxisol	21	19	16	30	21	42
Catalina (BC) Sample II	Oxisol	81	57	84	53	95	97
Cialitos (V) [2]	Ultisol	63	65	121	108	149	213
Value independent T test		-.713691					

*Value reported by Lathwell et al. (1972)
**Value determined by Showers.

increase in mineralizable N after 8 weeks of incubation. The Catalina soil (Typic Haplorthox) showed a marked difference between the values for digest N of freshly air dried and air dried plus stored for 3 1/2 years samples. The samples from Brazil are also Oxisols, although they belong to the Great Group Typic Haplustox.

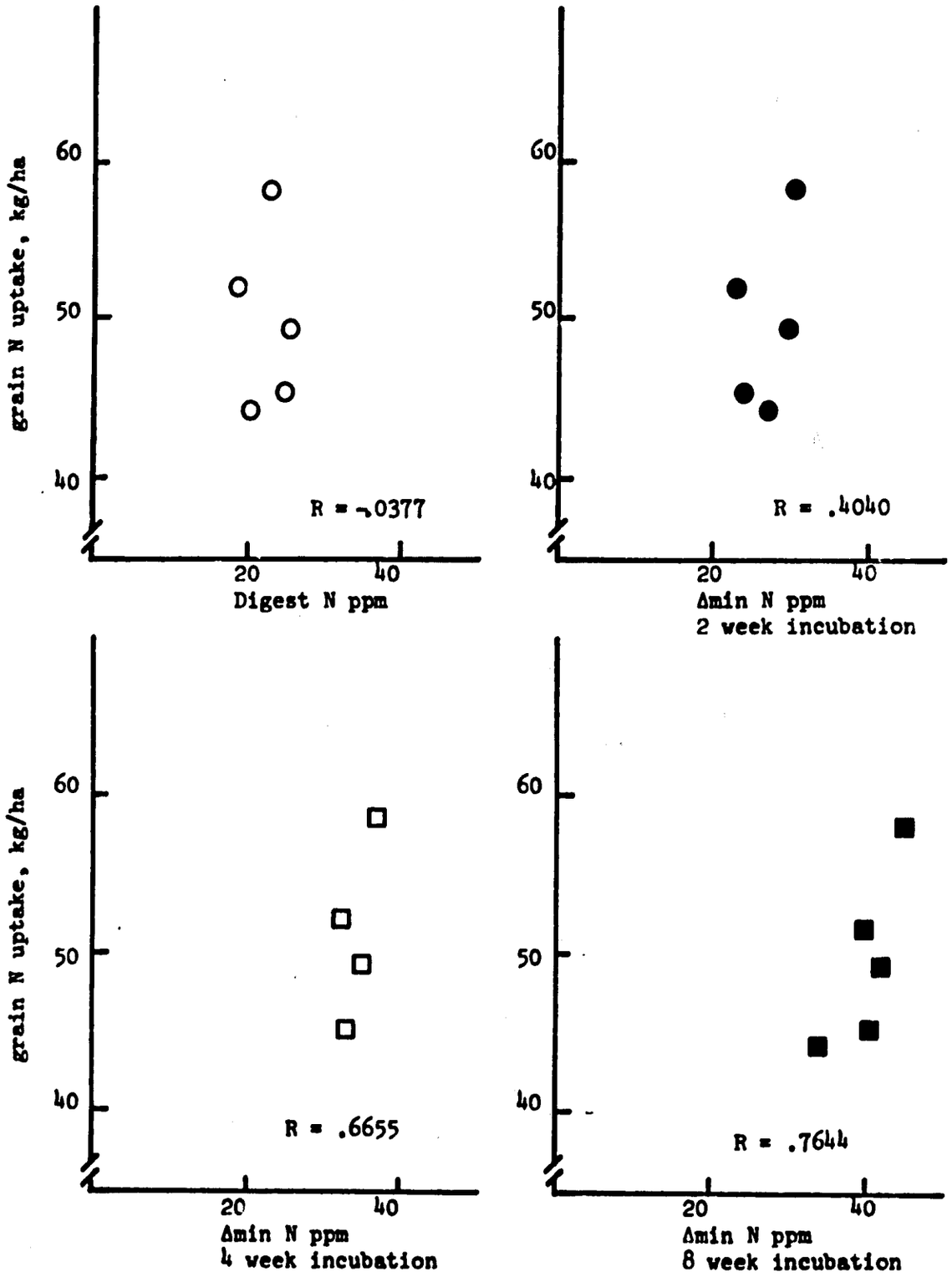
SOIL TESTS AND MEASUREMENTS OF CROP YIELD

Results

Figures 6 through 9 illustrate the relationship between values from the chemical and biological test procedures and nitrogen uptake by the maize crop. As shown in Figure 6, there was no relationship between digest N and N uptake by the grain. A trend towards significance with length of incubation is shown by Figure 6, although the r values do not reach significance at the 5 percent level and the R^2 values account for, at most, 60 percent of the variation. The data in Figure 7 shows there was no relationship between digest N values and values for nitrogen uptake by the stover, and no significant relationship between any of the incubation times and N uptake by the stover. There is no explanation other than chance for why there was an increase in correlation for 2 and 4 weeks and a decrease in correlation with the 8 week incubation time. Figure 8 shows the plots of digest nitrogen and mineralization values against nitrogen uptake by grain plus stover, and, as might be expected from the preceding two figures, there was no relationship of significance with either test. Figure 9 shows the affect of the inclusion of subsoil incubation data in the values for the 8 week incubation experiments when plotted against grain nitrogen uptake, stover nitrogen uptake, and grain plus stover nitrogen uptake. There are only four data points because there were only four subsoil samples available for analyses. The required r value for significance at the 5 percent level is .9500; in no instance is this value approached.

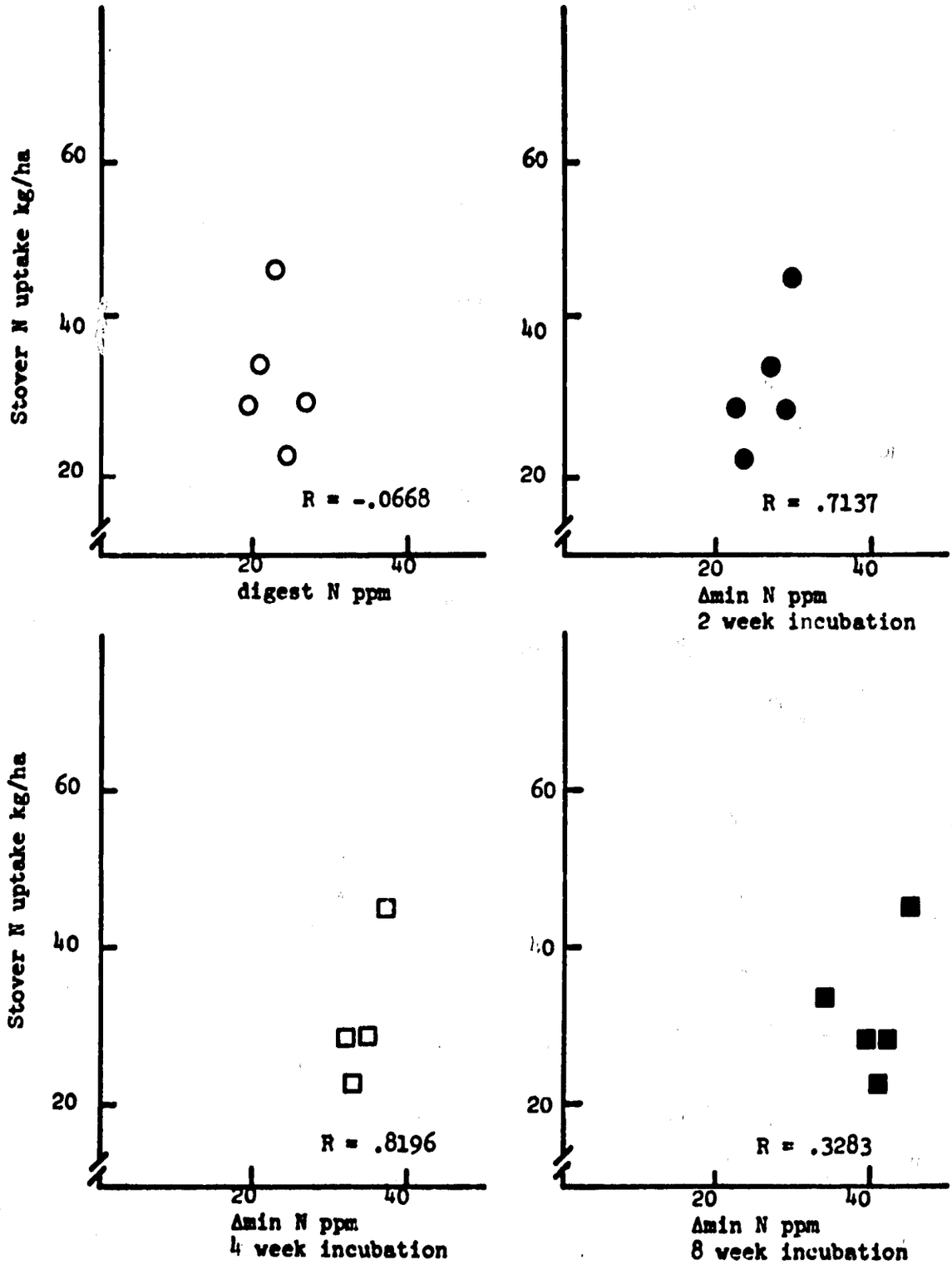
Figures 10 through 13 depict the relationship between the two test

Figure 6. N uptake by grain vs Δmineralizable N and digest N.



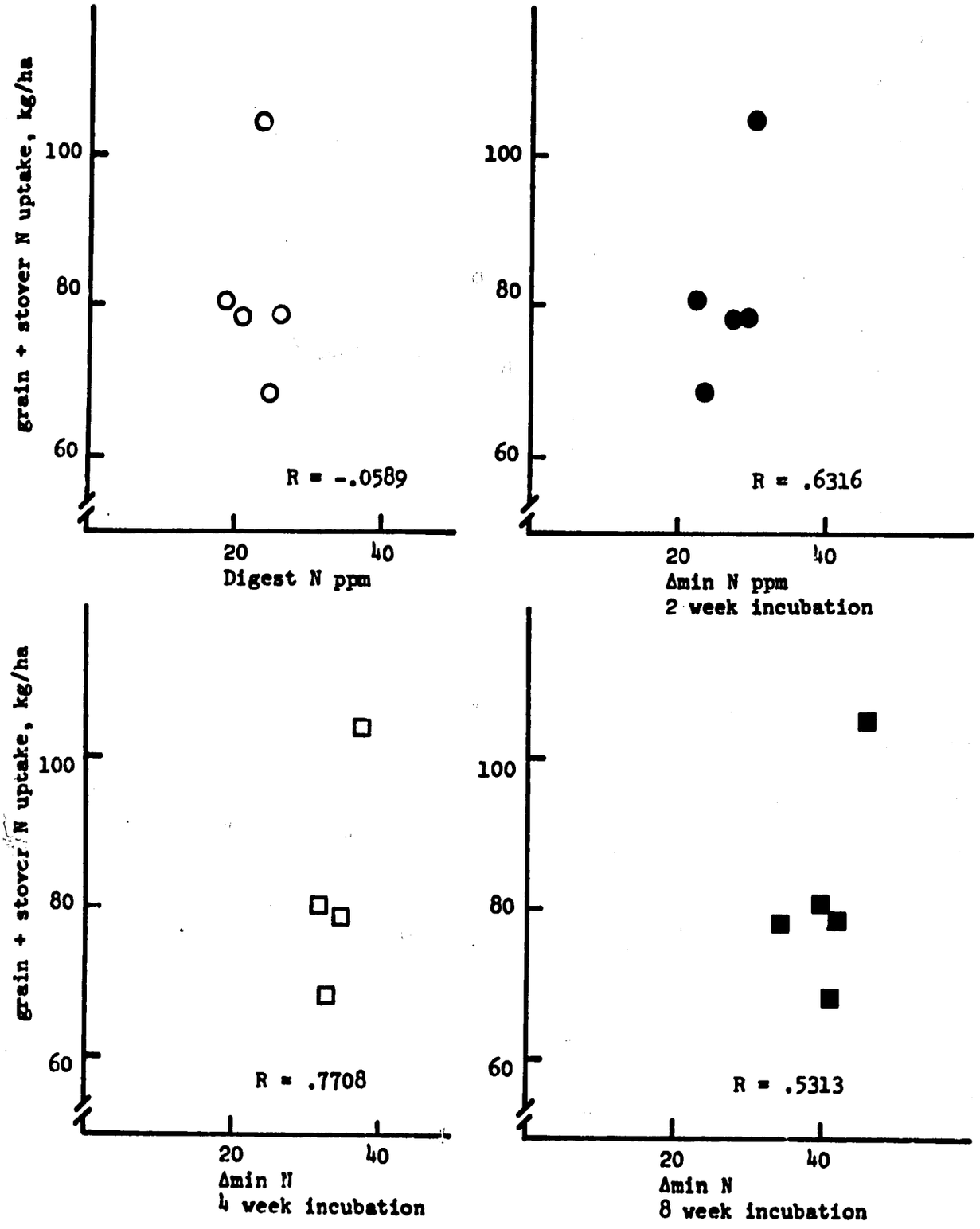
R = .9500 for significance at 5% with 4 points.
R = .8783 for significance at 5% with 5 points.

Figure 7. Nitrogen uptake by stover vs Δmineralizable N and digest N (topsoils)



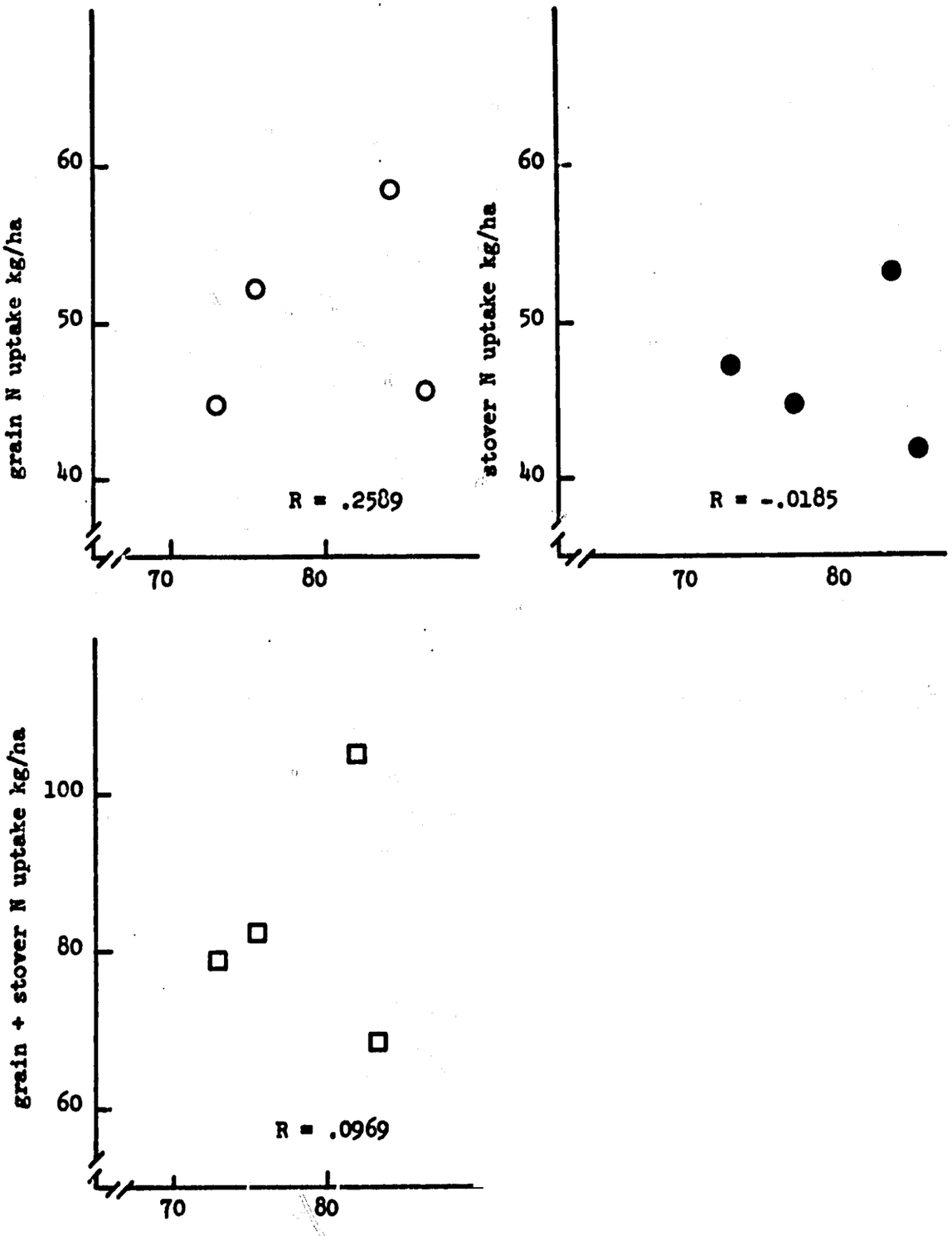
R = .9500 for significance at 5% with 4 points.
R = .8783 for significance at 5% with 5 points.

Figure 8. N uptake by grain + stover vs Δmineralizable N and digest N



R = .9500 for significance at 5% with 4 points.
R = .8783 for significance at 5% with 5 points.

Figure 9. N uptake by grain, stover, and grain + stover vs Δmineralizable N (8 week incubation); topsoil and subsoil.



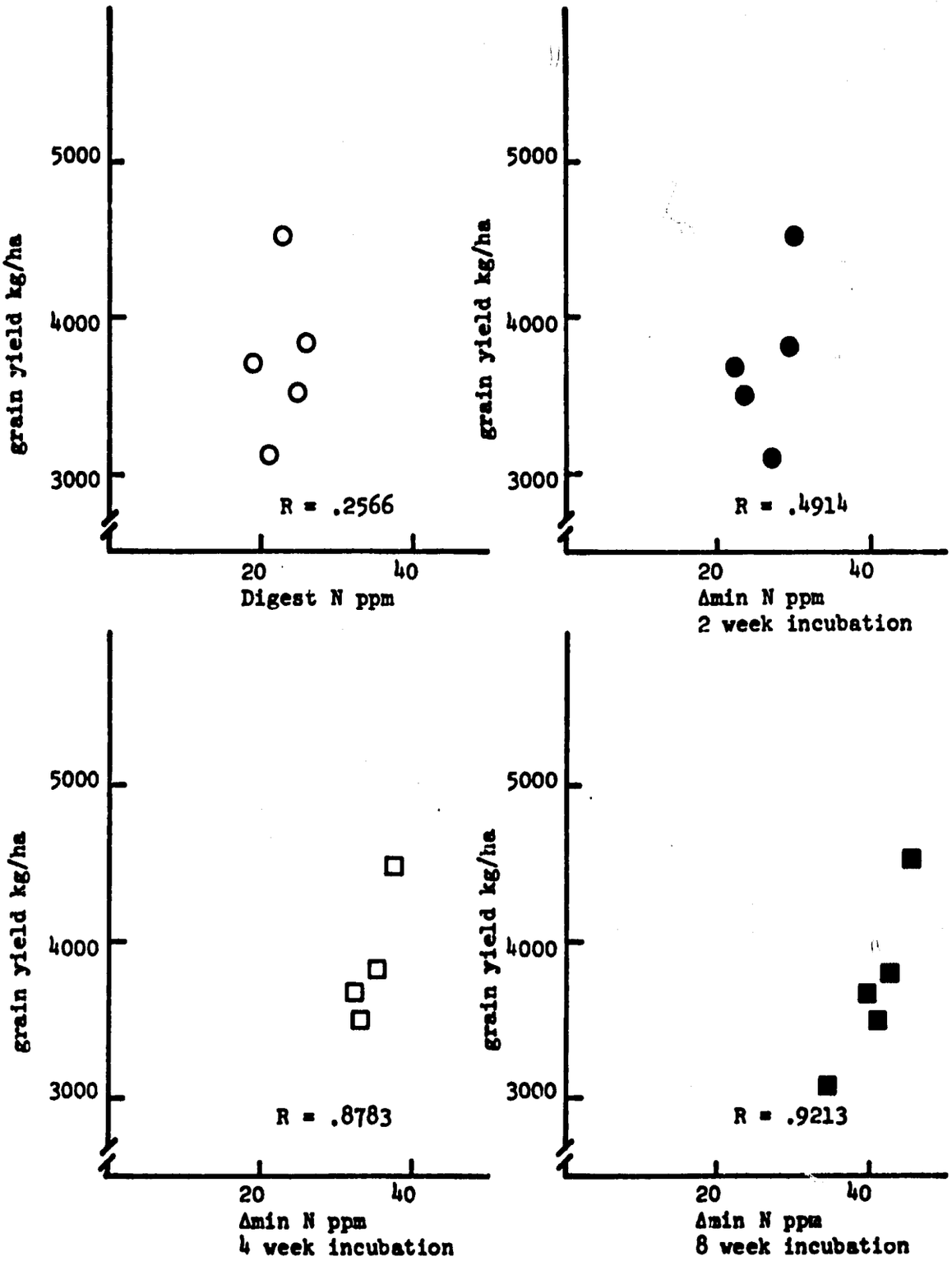
R = .9500 for significance at 5% with 4 points.

methods and various measurements of crop yield. Figure 10 shows the scatter diagram for the test values of the two test procedures and the yield of grain. There was no relationship between digest N and grain yield. There was, however, a trend of increasing correlation with length of time of incubation, culminating in a highly significant relationship between the mineralization values obtained after 8 weeks of incubation and the grain yield. The correlation coefficient is .9213, which exceeds the required r value of .8783 for significance at the 5 percent level, and accounts for 85 percent of the variation. Figure 11 shows that there were no relationships between values obtained by digestion or incubation for any of the three lengths of time and stover yields. Thus, it is of little surprise that Figure 12 shows no relationship between digest or incubation values for grain plus stover yields. Figure 13 shows that, as with nitrogen uptake in Figure 9, inclusion of the subsoil incubation values did not improve the correlation with yield data.

Discussion

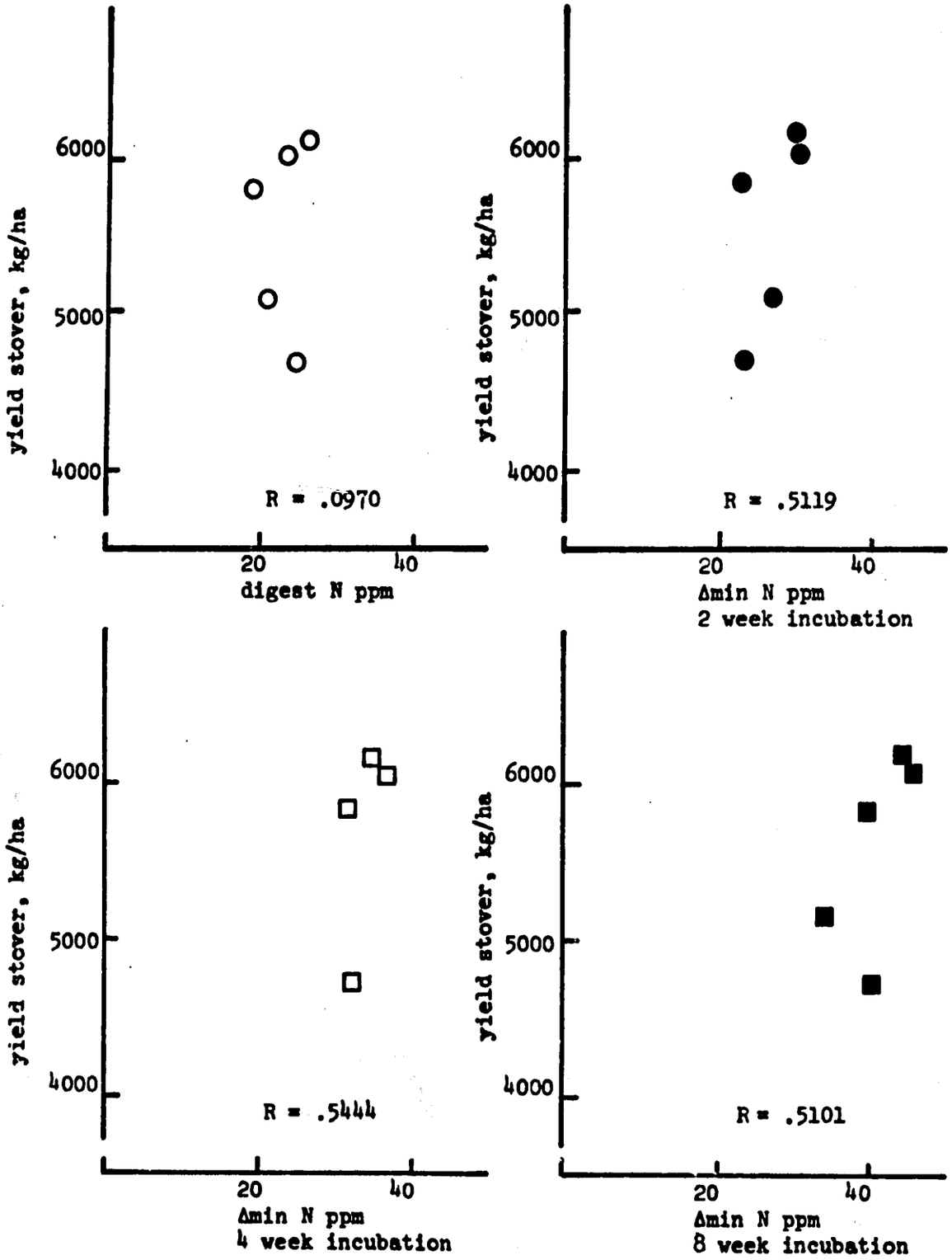
The data presented in Figures 6 through 13 show some trends towards correlation but, with the exception of values for grain yield and 8 week incubations, no significant relationship was shown to exist. A major factor limiting the interpretation of the data from this study is the small number of data points. With only four or five data points, it is difficult to determine a trend or a relationship; individual points can vary considerably from a regression line. Further, since there is a high probability of four or five points indicating a relationship when there is none, the value of r for significance at the 5 percent level must be extremely high. However, the attainment of a high and significant r

Figure 10. Grain yield vs digest N and Δmineralizable N



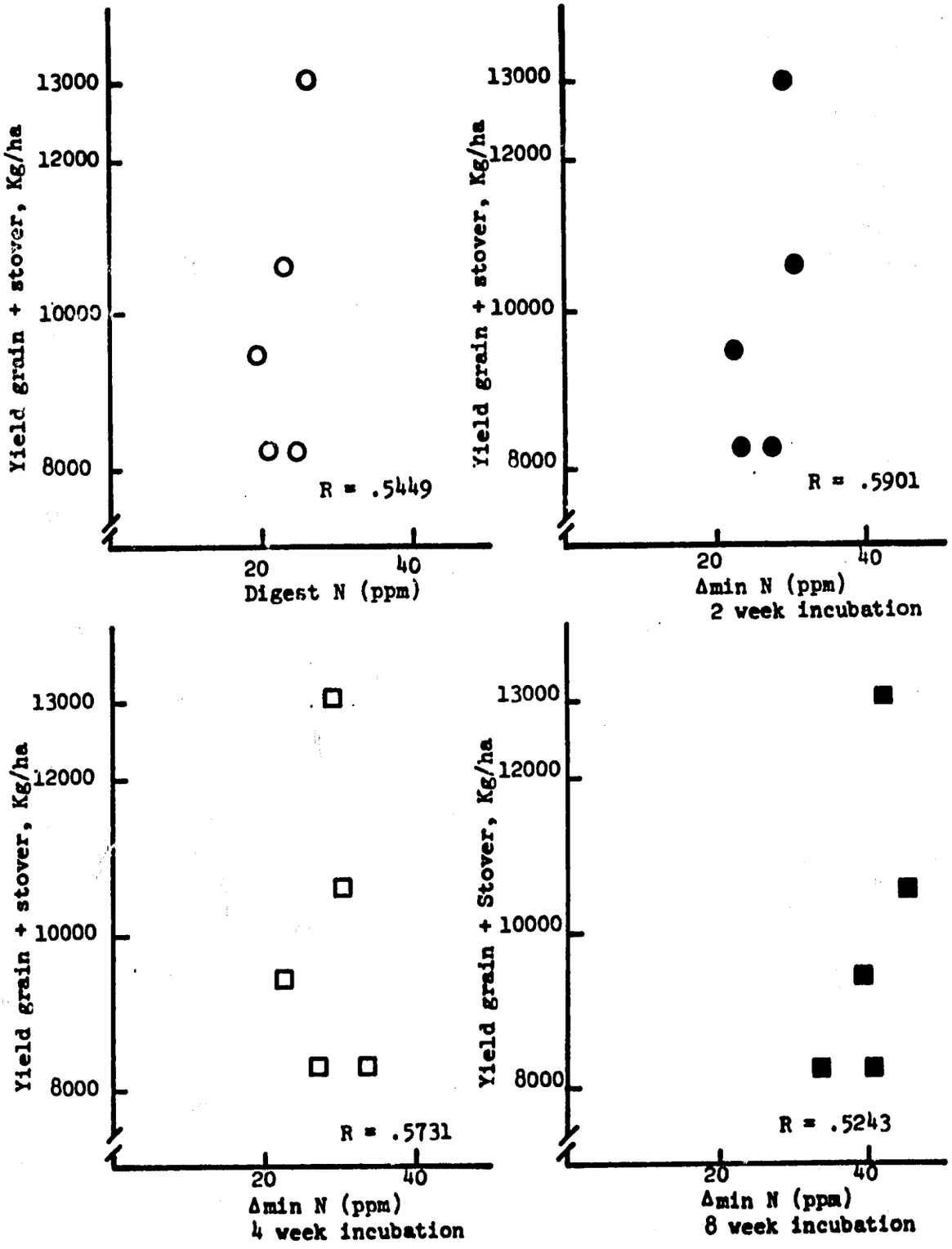
R = .9500 for significance at 5% with 4 points.
R = .8783 for significance at 5% with 5 points.

Figure 11. Stover yield vs digest N and Δmineralizable N.



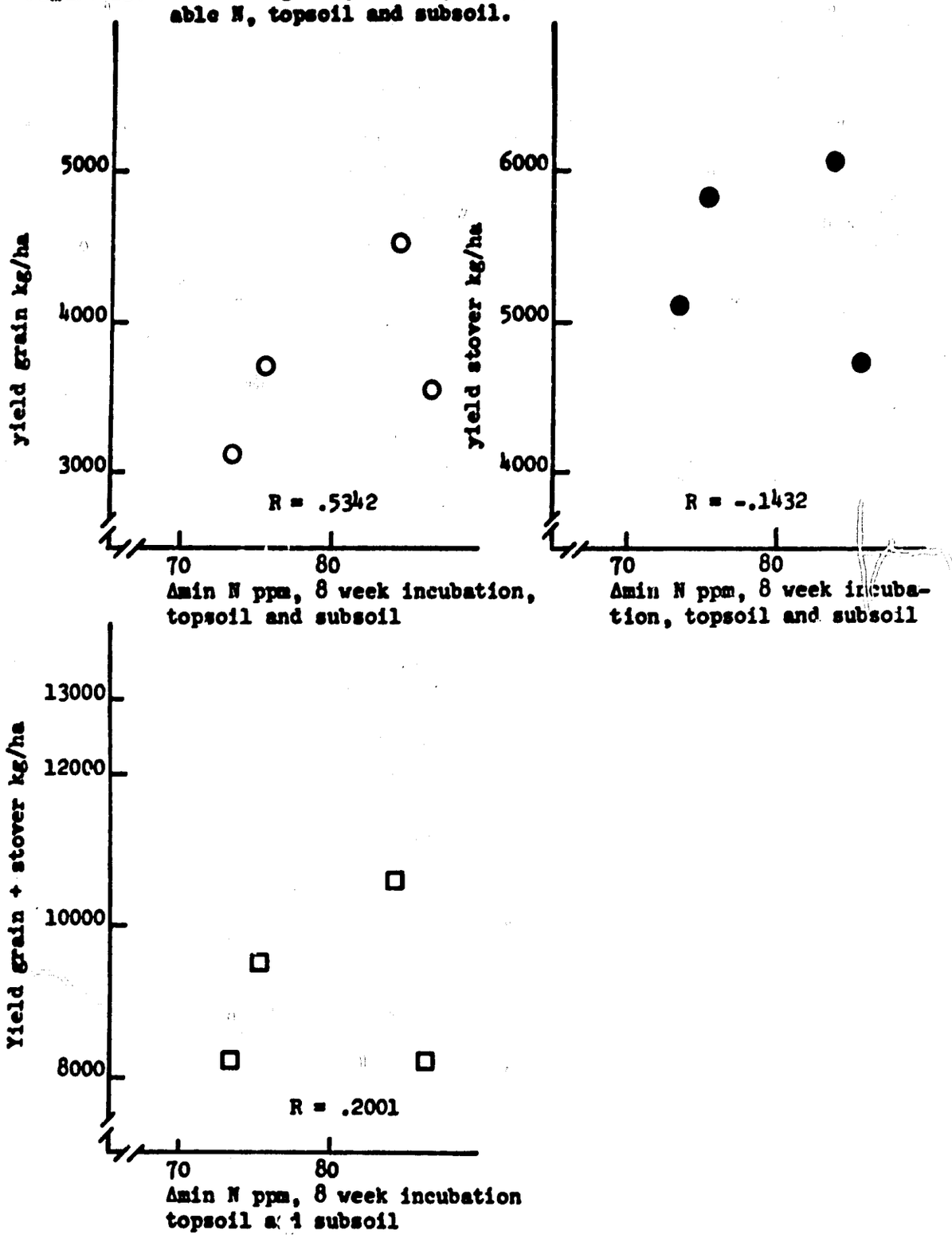
R = .9500 for significance at 5% with 4 points.
R = .8783 for significance at 5% with 5 points.

Figure 12. Yield of grain + stover vs Δmin. N and digest N.



R = .8054 for significance at 10% with 5 points.

Figure 13. Yield of grain, stover, grain + stover vs 8 week Δmineralizable N, topsoil and subsoil.



R = .9500 for significance at 5% with 4 points.

value is not enough evidence to demonstrate the existence of a useful relationship. When evaluating the meaning of the significant r value for the relationship between yield of grain and Amineralizable N at 8 weeks, it is important to consider the slope of the line. The steepness of the slope of the line in this relationship is such that a small error in the x value Amineralizable N would mean a large error in the y value (yield of grain). Thus, the relationship would be of little use in predicting grain yields if there was any possibility of variation in the soil test value. It is also quite likely that this significant relationship is not a reflection of reality but rather an example of data that appears to demonstrate a relationship but in fact is only reflecting a chance configuration of points. Factors other than nitrogen measured may have been more important in determining crop growth, but with only four or five data points and sparse data about the crop environment and handling of the field experiment, it was impossible to perform any data analysis which would take into consideration these other potentially mediating factors.

Several factors may have influenced the values for the soil tests, crop yield and their relationship to each other: time of sampling, pretreatment of the soil sample, growth of the crop in the field and error in analysis. The time of sampling has been mentioned as a critical factor in obtaining meaningful relationships between soil test values and crop yields. It has been reported that the mineralizable nitrogen content of the soil varies in the course of a year in tropical situations (Cornforth, 1971) as well as in temperate regions (Eagle and Mathews, 1958; Olson, 1960; Assa, 1973). It has been suggested that sampling should be done in the spring or late fall in temperate regions, in order to obtain a reliable estimate of the nature of the soil nitrogen reserve.

The best time of the year for sampling has not been suggested for regions like the central plateau or Planalta of Brasil which have a wet/dry moisture regime. Cornforth (1971) studied the variation in mineralization of samples collected at monthly intervals on the island of Trinidad and concluded that mineralizable nitrogen was related to the moisture content of the soil at the time of sampling and to the previous month's rainfall, and therefore that there was no justification for using mineralizable nitrogen in a soil sampled in one season to indicate the amount of available nitrogen in that soil in a different season. Lathwell et al. (1972) introduced a drying period into the cropping sequence in the greenhouse, thus measuring nitrogen flush after a period of drying. They suggested that laboratory and greenhouse techniques might be devised to account for the problem of time of sampling.

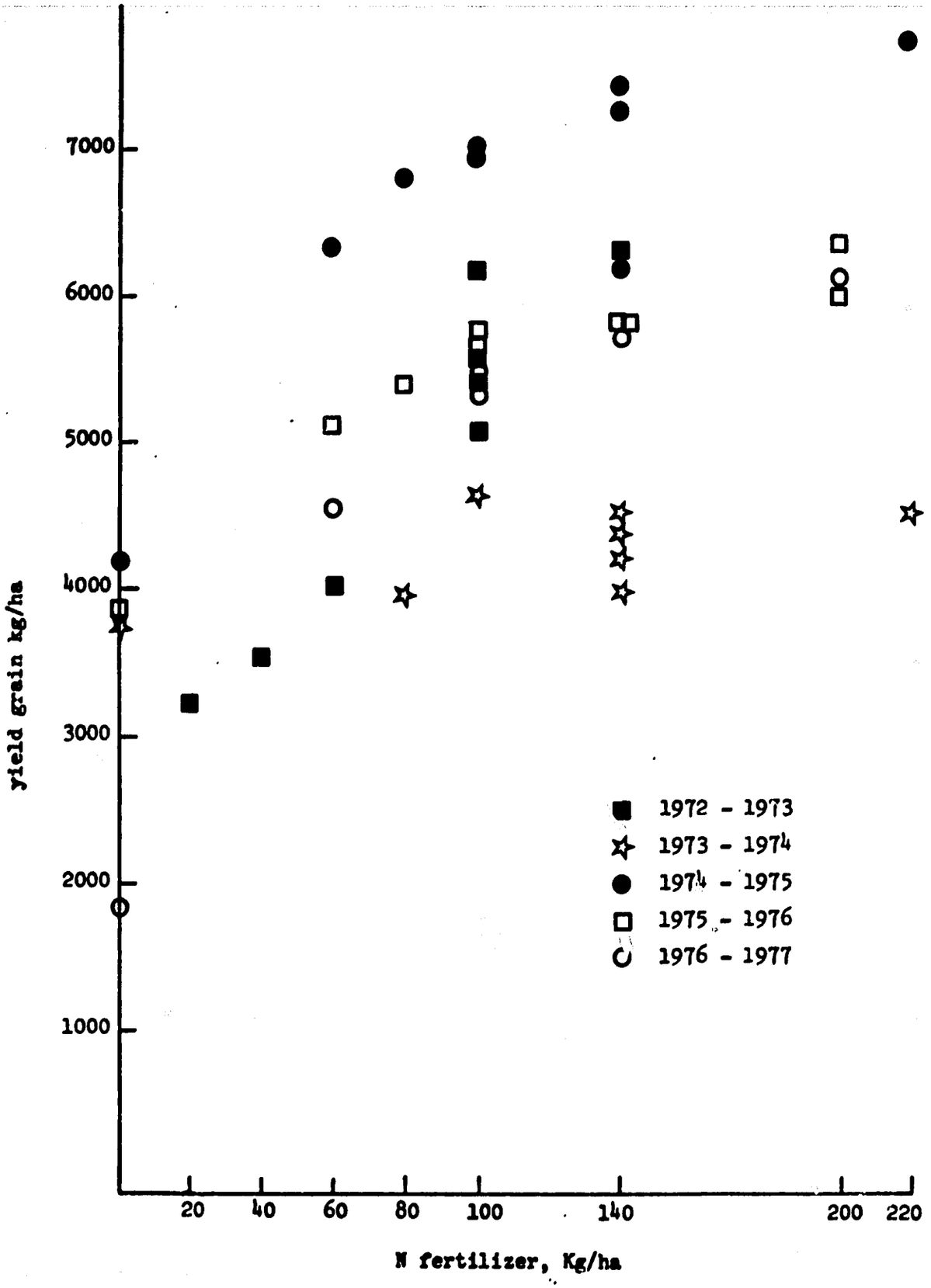
In the earlier discussion of factors affecting soil test procedures, air drying and storage were suggested as influences on the values obtained by various tests. In the study by Keeney and Bremner (1966), storage effects were found on the values of various soil test procedures, but the change in values did not affect the correlation of the soil test with N uptake by the crop. Chalk and Waring (1970) similarly found storage effects on test values but no effect of room temperature storage on the correlation between biological or chemical tests and nitrogen uptake. There was no opportunity to investigate the difference between fresh, air dried, and air dried plus stored samples of the Dark Red Latosol from Brasil.

Another factor which may have influenced the relationship between soil test values and crop yield or nitrogen uptake was the environment of the crop in the field, and its affect on crop growth. According to the

1974 annual report (North Carolina State University), the 1973-1974 year was notable for the second highest amount of rainfall in 47 years of record keeping in September, high rainfall which was well distributed throughout the rest of the growing season, low solar radiation due to the cloud cover in September and March, and high incidences of disease and insect damage. This damage was largely due to Northern and Southern Leaf Blight (Helminthosporium spp) and ear worm and stalk borer (Heliotis zea); insecticide applications were washed out by the daily rains, and the weakened plants were susceptible to wind damage (North Carolina State University, 1974). The nitrogen experiment was reported to have been particularly severely damaged. It might be suggested, then, that the crop performance was low due to environmental conditions, and thus did not reflect the potential of the soil to supply nitrogen, which the tests measure. Figure 14 shows the yields of maize from all plots for the last 5 years. While it is apparent that the crops receiving nitrogen suffered greatly in the 1973-74 growing season, it is also apparent that there was no significant difference between the yield of the check plots in 1973 and in 1974-75, which was considered to be a year with excellent field conditions.

There is one factor in the experiment which may modify the seeming high ability of the soil to supply nitrogen to the check plots. Bouldin (pers. com.) and Ritchey (pers. com.) report that the rooting habit of the maize variety grown is such that, combined with the small plot size, the maize plants in the outside rows of the check plots were able to utilize nitrogen applied to adjacent plots receiving nitrogen treatments. These outside rows grew taller than the inside rows, providing some shade. What affect the interaction of the additional nitrogen and the

Figure 14. Grain yield vs fertilizer application, Planaltina, Brazil 1972-73 - 1976-77.



shading had on the crop yields of the zero nitrogen check plots is not known. Thus, it is possible that the soil samples did not reflect the nitrogen supply which was available to the plants for growth.

Further possibilities for the lack of correlation between crop growth and the soil tests is error in determining the yield of the crop and in the laboratory analyses of the soils and crops. Kass and Drosdoff (1970) discuss possible sources of error in various N measurement procedures.

INCUBATION STUDY

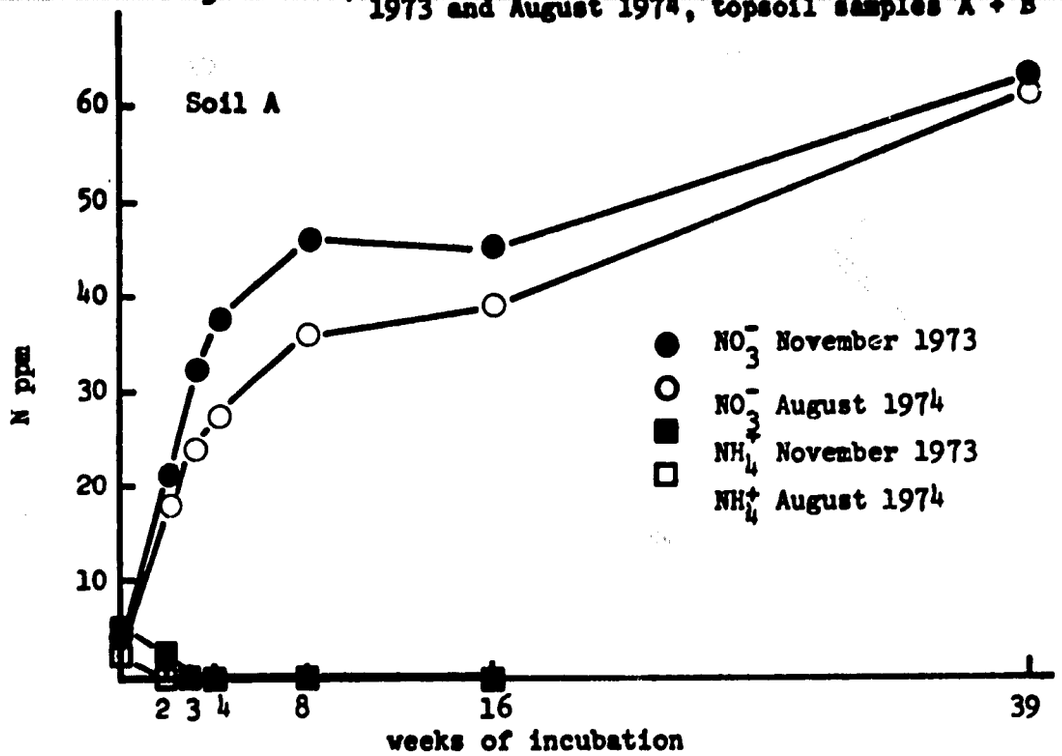
Results

Figures 15 through 17 show the amount of NO_3^- N and NH_4^+ N produced over time by the topsoil samples taken in November 1973 and August 1974. For all soils, the amount of NH_4^+ N declined from the levels originally present in the soil, and disappeared after two or three weeks. Nitrate N showed a sharp increase, with the maximum rate of production in the first 8 weeks. It is evident that in all plots sampled, the November 1973 samples produced more mineral nitrogen than the August 1974 samples. Figure 27 shows the amounts of NO_3^- N and NH_4^+ N produced over time by the subsoils. In contrast with the topsoils, there was a sharp increase in NH_4^+ N production for the first few weeks, and concurrent decrease in NO_3^- N, followed by a rapid decrease in NH_4^+ and increase in NO_3^- N. Table 4 shows the average values of mineral nitrogen produced by the Brazilian soils, and the names, some characteristics, and amounts of nitrogen mineralized upon incubation by 29 other soils which were reported in the literature. Table 5 gives the means of the amount of nitrogen mineralized by various groups of the soils from Table 4. Table 6 gives characteristics of the individual soils from Brazil.

Discussion

The reasons for the difference in the amount of nitrogen mineralized by the samples from the two sampling dates is not clear. The difference could reflect nitrogen uptake by the crop, a change in the energy source available to the microorganisms after a crop, or the seasonal variation in potentially mineralizable nitrogen. The August samples were taken 3 1/2 months after the crop was harvested; it would, therefore, be unlikely that

Figure 15. ΔNO_3^- and ΔNH_4^+ production vs length of incubation, November 1973 and August 1974, topsoil samples A + B



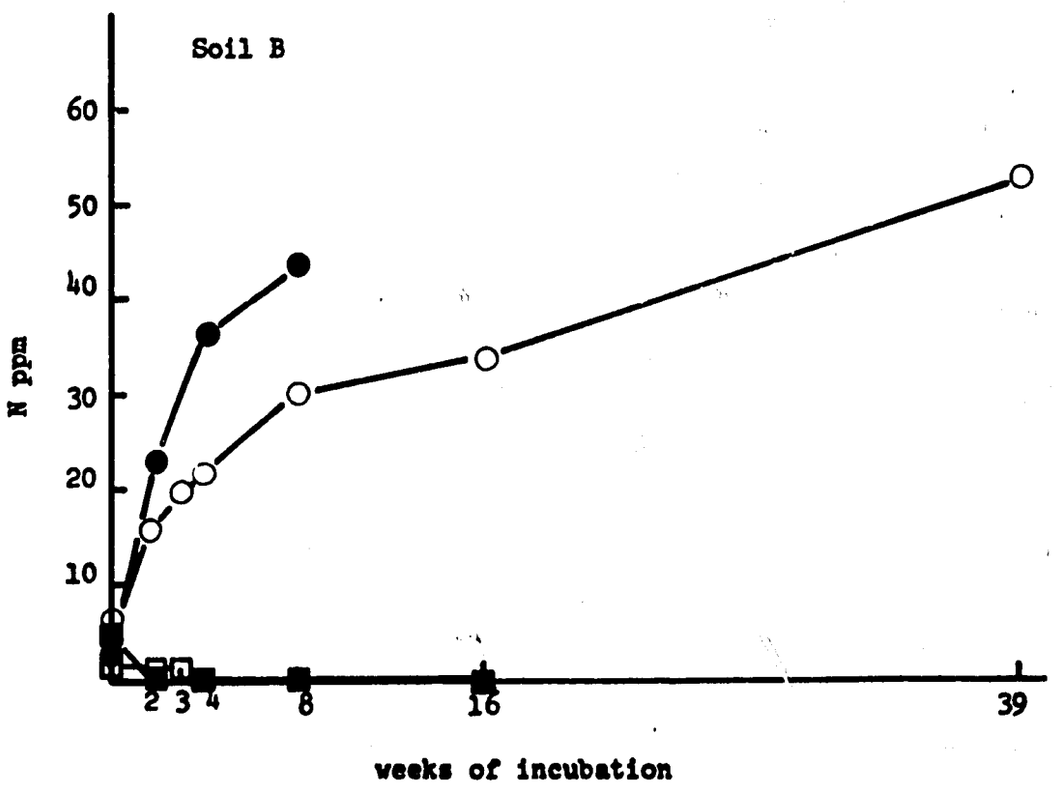
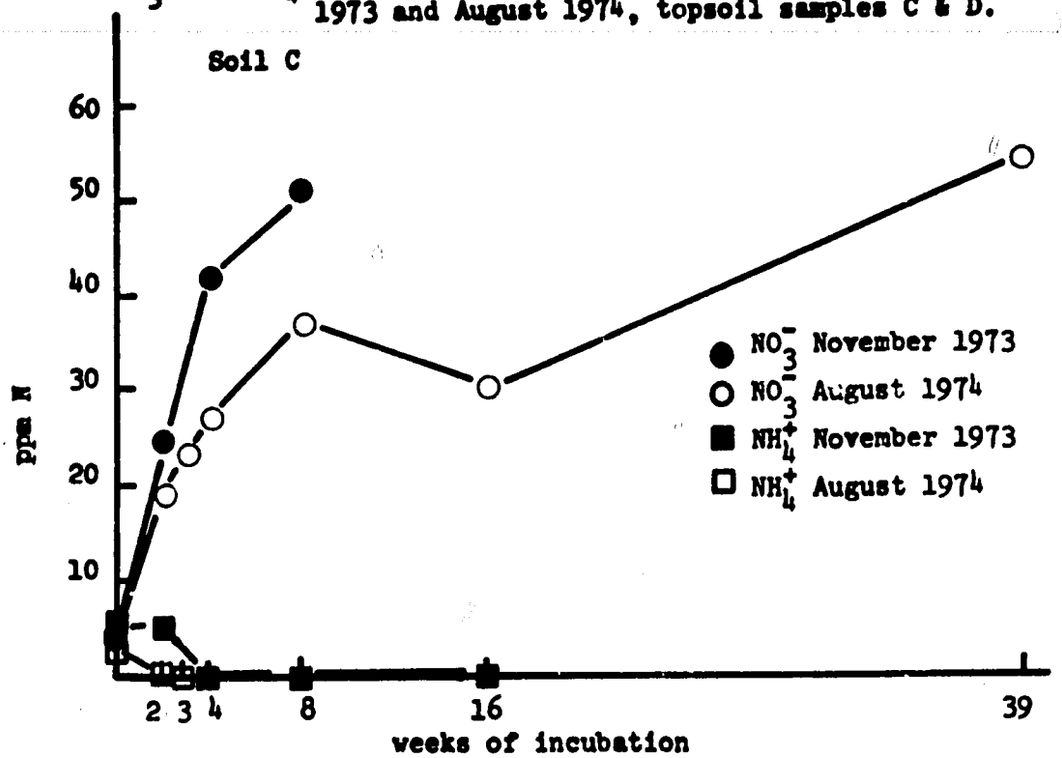


Figure 16. ΔNO_3^- and ΔNH_4^+ production vs length of incubation, November 1973 and August 1974, topsoil samples C & D.



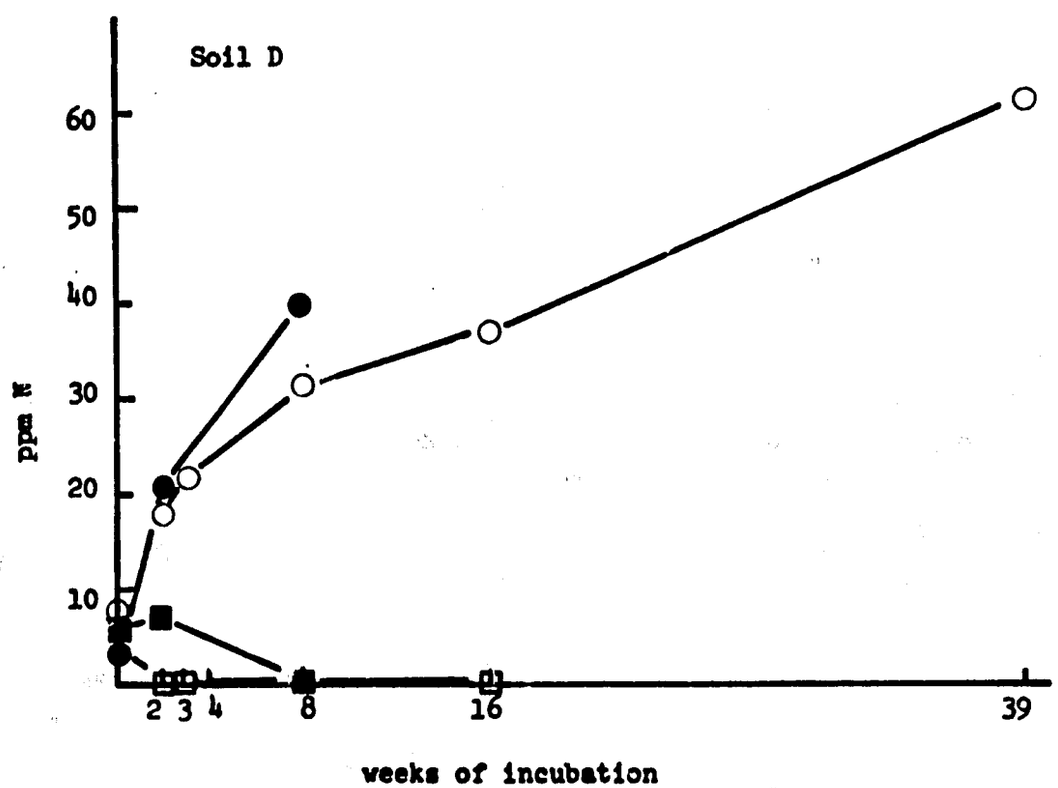


Figure 17. ΔNO_3^- and ΔNH_4^+ production vs length of incubation, November 1973 and August 1974, topsoil sample E.

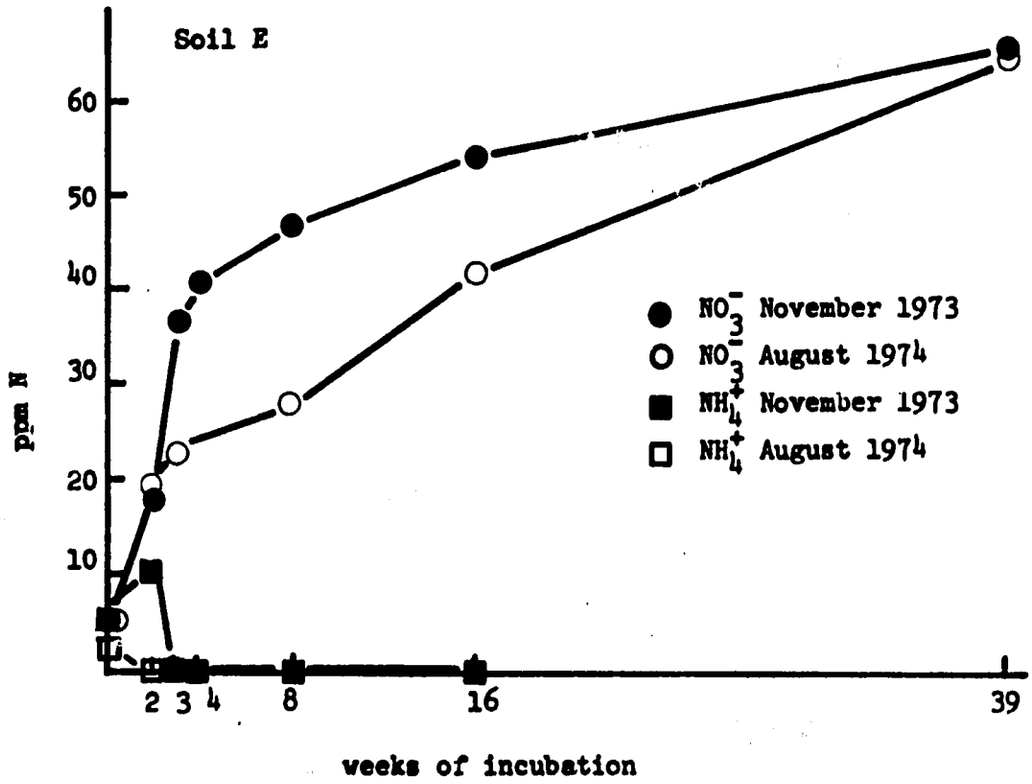
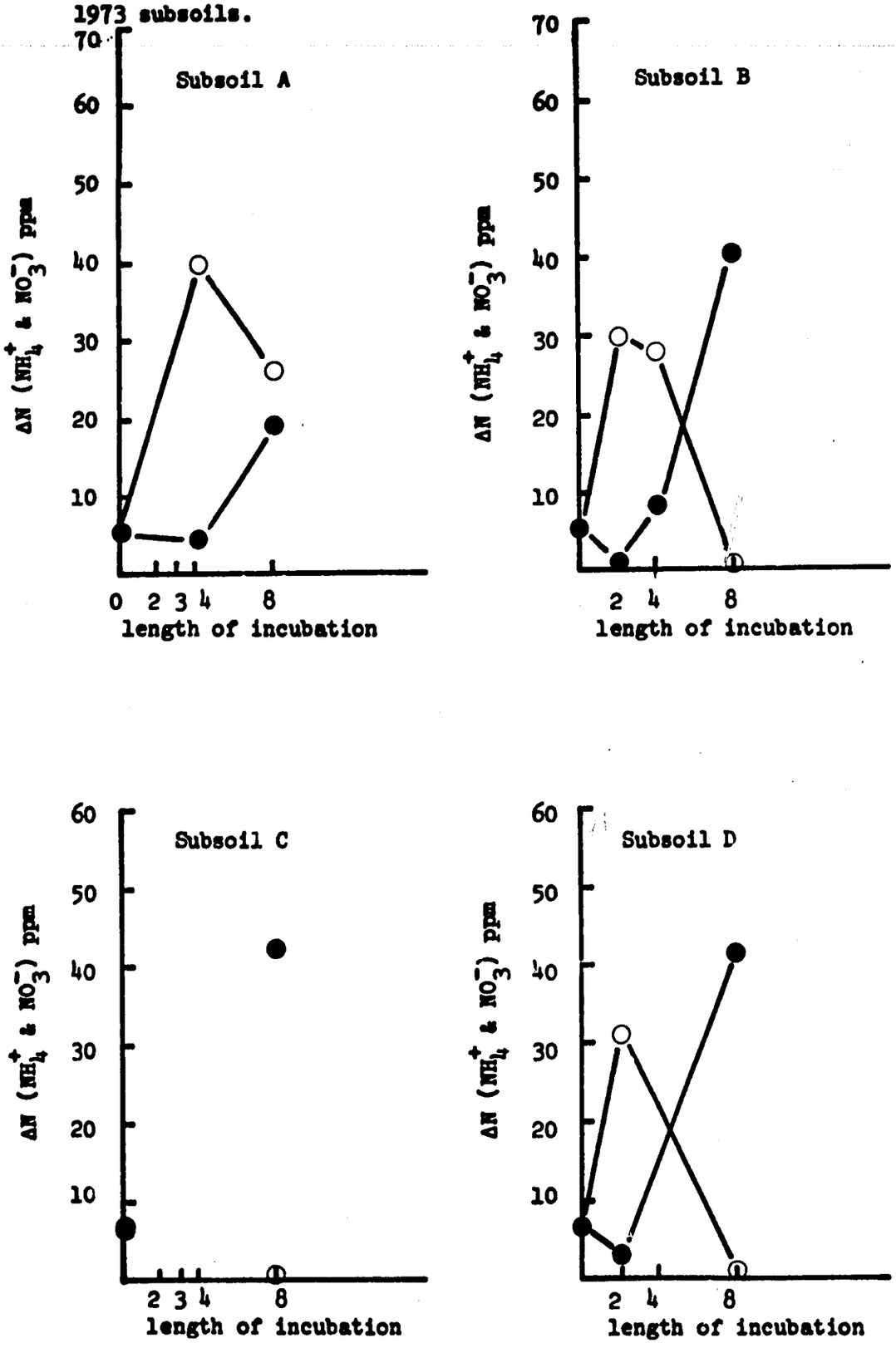


Figure 18. ΔNO_3^- and ΔNH_4^+ production vs length of incubation, November 1973 subsoils.



Lines are for ease of reading graph. No functional relationship is intended.

Table 4. Value of mineralization determined for Oxisols compared with values reported for some temperate and tropical soils.

Soil/source	pH H_2O	pH $CaCl_2$	Org C	Total N	C/N	Amin N, ppm 3 week	Amin N, ppm 4 week	Amin N, ppm 8 week
Showers (1977)								
Planaltina, Brazil								
November 1973								
top (0-15 cm)	6.29	5.83	1.89	.114	16.58	41.66	43.85	50.3
sub (15-30 cm)	5.20	4.74	1.55	.0975	15.9		52.93	53.2
August 1974								
top (0-15 cm) avg.	6.07	5.60	1.79	.116	15.43	29.03	31.60	40.6
Boletim Technico #8 (1966)								
Planaltina, Brazil								
top (0-10 cm)	4.9		1.76	.21	8			
sub (10-35 cm)	4.8		1.16	.08	14.5			
Stanford & Smith (1971)								
Cecil SL, Ga.	5.8		.68	.049	13.88		50.4	
	6.2		.74	.051	14.51		56.4	
	6.5		.36	.031	11.61		29.7	
Goldsboro SL, S.C.	5.3		.66	.039	16.92		18.5	
Greenville FSL, Ala.	5.4		.86	.049	17.55		20.3	
	6.4		.92	.048	19.16		27.6	
Grenada SiL, Miss.	5.9		1.17	.116	10.09		77.4	
	6.4		1.49	.141	10.57		96.9	
Kranzburg SiL, S. Dak.	6.2		2.38	.231	10.30		75.9	
Lakeland LS, S.C.	5.6		.26	.031	8.39		13.1	
Leck Kill SiL, Pa.	5.6		1.51	.115	13.13		87.8	
Norfolk FSL, S.C.	5.5		0.45	.030	15.0		16.8	
Palouse SiL, Wash.	6.0		1.82	.135	13.48		51.8	
Pullman SiCL, Wash.	5.8		1.06	.110	9.63		65.8	
Ritzville SiL, Wash.	6.5		.72	.068	10.59		24.7	
Gasser (1961)								
Sand	5.5		.82	.094	8.7	10		
Silt Loam	6.4		1.62	.143	11.3	26		
Fine Sandy Clay Loam	5.9		2.37	.256	9.3	43		
Fine Sandy Clay Loam	5.3		2.38	.262	9.1	36		
Lathwell, et al. (1972)								
Puerto Rico								
Nipe, Typic Acrorthox	5.7		1.45	.100	14.5		16	21
Pinas, Psammentic Haplorthox	4.9		.71	.072	9.86		15	16
Catalina, Typic Haplorthox	5.4		2.92	.280	10.4		84	95
Cialitos [28], Orthoxic Tropohumult	6.2		1.01	.127	7.95		7	11
Cialitos [4], Orthoxic Tropohumult	5.0		1.67	.196	8.52		42	53

(continued)

Table 4 (continued)

Soil/source	pH H_2O	pH $CaCl_2$	Org C	Total N	C/N	Δmin N, ppm 3 week	4 week	8 week
Cialitos [3], Orthoxic Tropohumult	5.9		2.24	.238	9.41		22	32
Humatas, Typic Tropohumult	4.9		2.50	.220	11.3		58	69
Cialitos [2], Orthoxic Tropohumult	6.4		3.26	.335	9.73		121	149
Cialitos [1], Orthoxic Tropohumult	5.8		3.26	.320	10.2		99	118
Los Guineos, Typic Tropohumult	4.9		3.66	.328	11.2		189	193

Table 5. Summary

Group	# soils	pH(H_2O)	% Org C	% Total N	C/N	ΔMin, ppm 3 week	4 week	8 week
mean of all soils	32	5.8	1.57	.142	11.1	--	--	--
mean of 4 week inc	28	5.8	1.54	.162	9.51	--	53	--
mean of 3 week inc	6	5.9	1.81	.164	11.7	31	--	--
mean of 8 week inc (tropical soils)	13	5.6	2.15	.196	11.6	--	--	69
mean of Oxisols, Puerto Rico	3	5.3	1.69	.151	11.6	--	--	44
Brazil samples								
Topsoil, 11/1973	5	6.29	1.89	.114	16.6	42	44	50
Topsoil, 8/1974	5	6.07	1.79	.116	15.4	29	32	41
Subsoil, 11/1973	4	5.20	1.55	.0975	15.9	--	53	53

Table 6. Soil characteristics Typic Haplustox, Planaltina, Brazil.

Sample	pH H_2O	pH $CaCl_2$	% Org C	% N	C/N
Topsoil 11/73					
A	6.15	5.63	1.64	.11	14.9
B	6.38	5.92	1.88	.10	18.8
C	6.30	5.90	2.13	.11	19.4
D	6.31	5.88	1.95	.11	17.7
E	5.79	5.31	1.83	.11	16.6
Subsoil					
A	4.93	4.47	1.69	.08	21.1
B	5.41	4.89	1.66	.08	20.8
C	5.22	4.78	1.66	.09	18.4
D	5.23	4.80	1.20	.09	13.3
E	no sample available				
Topsoil 8/74					
A	5.79	5.30	1.88	.10	18.8
B	6.18	5.69	1.68	.09	18.7
C	6.22	5.73	1.82	.11	16.5
D	6.30	5.90	1.74	.10	17.4
E	5.86	5.38	1.82	.12	15.2

these samples reflected the condition of the soil at the end of the cropping season. It is more likely that these soil samples, when rewetted after being air dried, produced a nitrogen flush similar to that which occurs at the beginning of the rainy season. It might be more plausible to consider the affect of residues from the crop on the energy supply of the soil microorganisms. It could be hypothesized that root and other crop residues contributed to the carbon supply of the soil, decreasing the amount of mineral nitrogen which would be released to the soil system. However, Table 6 shows that the means of the carbon to nitrogen ratios of all of the plots remained essentially the same. Individual plot to plot variations are likely a reflection of error in sampling and analysis. It has been reported in the literature that acid soils in the temperate region demonstrate a seasonal variation in their ability to produce mineral nitrogen (Olson et al., 1960) and Cornforth (1971) has noted monthly variation in mineralizable nitrogen produced by incubating soils of 2 different moisture regimes, which were collected at monthly intervals for one year on the island of Trinidad. He concluded that the mineralization of nitrogen was related to the moisture content of the soil at the time of sampling and to the previous month's rainfall. The rainy season generally starts in October in the region in which the experiment station is located. In 1973 the rains began early and the amount of rain was greater than usual. The monthly precipitation was 180 mm for November 1973 and 30 mm for August, 1974 (North Carolina State University, 1974; 1975). According to Cornforth's theory, samples taken in November 1973 reflected the high amount of rainfall in the preceeding month and, possibly, a high moisture content at the time of sampling, while those samples taken in August 1974 reflected the conditions of the dry season. It is

not possible to determine, from this data, whether the Brazil samples really did follow Cornforth's model, for Cornforth's samples were frozen until the time of analysis (within one year of collection), while the Brazil samples were air dried and stored for several years. It is not known whether the effects of date of sampling would persist through air drying and storage.

The values in Table 5 show the means of mineralization values reported in Table 4, which were taken from the literature. The soils discussed in the literature were all handled in different ways, and incubations were not conducted according to a standard procedure. Also, error estimates were not reported with all values, making it impossible to determine the variance. Thus, comparisons of the exact numerical values in the literature is not meaningful, and these values should not be used for other than generally descriptive purposes. The striking feature of the data in Table 5 is the similarity of the values obtained from such a geographically diverse group of soils. Differences in experimental technique and sampling error would likely account for any apparent differences. It would be tempting to conclude that there is no difference in the potential of tropical and temperate region soils to supply nitrogen to a crop.

It is important, however, to consider the cropping history of a soil as well as its mineral properties. It is widely accepted that cultivation of a virgin soil disturbs the organic matter equilibrium, inducing an increase in the decomposition of organic matter, with a consequent greater rate of N release. After a given piece of land has been cultivated under a particular management scheme for a period of time, a new equilibrium level is reached in which the rate of organic matter

decomposition and N release is much lower than when the land was first brought into cultivation. The new equilibrium level represents a lower level of both organic matter and organic N than existed in the virgin soil. Further, it has been reported that additions of nutrients and a change in pH can also affect the decomposition of organic matter, leading to increased N mineralization. Sanchez (1976), citing unpublished data from North Carolina State University, reported that P and Ca additions increased N mineralization in an Oxisol from Brazil which was extremely low in these nutrients.

When comparing N mineralization values of different soils, it is thus important to know whether the soils at the time of sampling were at an equilibrium or not, and if so, which one. The soils described in Tables 4 and 5 had varied cropping histories. The Brazilian samples were taken before and after the second year of cropping at a location which had no known history of cropping. The samples used by Stanford and Smith (1971) were collected at various ARS field locations in the United States; most likely these were areas with a history of having been cropped. Gasser's (1961) samples were taken from experimental fields in England where rates of N fertilizer were being evaluated on the growth of barley, potatoes, kale, and grass. Of the 10 soils studied by Lathwell et al. (1972), 9 of the samples came from cultivated fields (two were in pasture at the time of sampling) and one sample was taken from a field that had not been recently cultivated.

The soils in Tables 4 and 5 can thus be divided into two major groups: those which have a history of extensive cultivation and those with no known history of cropping. The Brazilian samples fall into the latter category, and all of the other soils fall into the former category.

One might reasonably assume that samples from the various cultivated fields were at or near their equilibrium with respect to organic matter and organic N content, and thus were at a somewhat stable N mineralization level. The Brazilian samples of this study, however, more likely reflect the dynamic transition time between the stable equilibrium of a virgin soil system and the equilibrium attained under sustained cropping. Taken in this light, one would conclude that the potential of cerradao soils, taken from the Planaltina site the second year of cultivation, to mineralize N was equal to the N mineralization potential of a variety of temperate region soils with similar pH, and organic C and N values which were at an equilibrium state under cultivation.

The next reasonable question to raise would be, how does the potential of cerradao soils at cultivated equilibrium compare with the potential of temperate soils with similar pH organic C and N levels at cultivated equilibrium. There is no data at this time to answer this question. However, if the general theory holds true for these Cerradao soils, then the levels of organic N and organic matter of the equilibrium under cultivation will be less than the amount at equilibrium in the virgin soils. Thus, if the potential for N mineralization of cerradao soils just brought under cultivation is equal to the potential of temperate region soils at cultivated equilibrium, it is reasonable to suspect that the potential to mineralize N will be less for the Cerradao soils than the temperate region soils at the equilibrium of cultivation.

The soils from Puerto Rico which were likely at cropping system equilibrium showed an N mineralization potential similar to both the group of Brazilian samples and the group of temperate region soils. Although the Puerto Rican soils are highly weathered Oxisols and Ultisols from a

tropical climate, it would not be justified to use data from these soils for the prediction of the performance of the cerradao soils under extensive cultivation. Since there is no data available for the N mineralization potential of the Puerto Rican samples under virgin conditions, nothing can be stated about the change in the N mineralization potential of these soils over time with cropping.

SUMMARY AND CONCLUSIONS

Certain problems were associated with the collection of some of the data presented in the preceding three sections of results and discussion. The factor of storage of the soil samples has been adequately discussed elsewhere. As the author did not participate in the conducting of the field experiment, she has no direct information as to the nature and condition of the crop, and therefore of the crop data. Certain problems arose in the laboratory technique. The 39 week samples were drier, by visual inspection, than those samples incubated for a shorter period of time. Thus, the amount of N mineralized after 39 weeks of incubation is not directly comparable to the values for shorter incubation times. Also, the incubation in bottles technique may not be suitable for long-term incubations. Keeney and Bremner (1966) reported gaseous losses of N during the long-term incubations which they conducted. The decrease in nitrate in the subsoil data presented in this paper, if real, may reflect such losses. Stanford (1972) citing Allison and Sterling (1949), reported "appreciable drops in pH" during 23 week incubations, and Harmsen and Van Schrevan (1955) noted the possibility of the accumulation of toxins in long-term incubations in bottles. These factors, then could have influenced the incubation data. One further problem was in the determination of the percent total nitrogen. The soils were analyzed five different times, resulting in five different sets of values. The values seemed to be dependent upon sample size. The values used in this paper were those of the macro-Kjeldhal digestion procedure, which were within ±.02 of the values reported by the autoanalyzer. Because the percent total nitrogen

values may be in doubt, the carbon to nitrogen values may also be suspect.

The number of samples clearly limited the interpretation of this data. The only strong relationship seemed to be that between mineralizable nitrogen and digest nitrogen over time within one plot. This would lend some support to the hypothesis that digest nitrogen does measure some portion of the potentially available nitrogen in the soil. Another observation of possible interest was the difference in the pattern of nitrogen release for the topsoil and subsoil samples from November 1973. To what extent the behavior of soils incubated in the laboratory is a reflection of conditions in the field is not known. However, the behavior of subsoils, and their contribution to the mineral nutrition of plants, especially in areas of low nutrient status soils, is an important area for further investigation. A further point of interest was the similarity of values reported for incubated soils from tropical and temperate regions. Interpretation of this similarity must include a consideration of the history of the land use; the Brazilian samples were taken from land recently brought under cultivation while the other soil samples came from land with a long history of cropping.

It is difficult to determine whether the chemical method used in this study had any more or any less promise than other chemical test procedures proposed in the literature. Since there is so much variation in the pretreatment of soils, and suggestion that time of sampling and condition of the soil at sampling influence the values of soil tests, it might be worthwhile for a team to conduct a series of experiments under uniform conditions in order to evaluate several test procedures. The team should have a minimal composition of a biometrician, an agronomist with knowledge of soils, a plant physiologist and a chemist. The role of the

biometrician is obvious, the chemist would be needed for the laboratory processes and evaluation of techniques, and the physiologist should, among other things, investigate the utility of grouping plants by their patterns and rates of nutrient uptake. It is conceivable that the final calibration of the test methods will require a grouping of both soils and plants, and an interpretation of the interaction of the potential of the soils and the needs of plants. Clearly, the role of the agronomist in such work is one of synthesis. Field trials should ultimately be conducted with a wide range of crops, on a wide range of soils, in many locations so as to evaluate the effectiveness of the various procedures under different mineralogical and meteorological conditions.

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