# NITROGEN-SUPPLYING POWER OF SOILS FROM LAKE CHAD BASIN

By

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## ABSTRACT

Laboratory and greenhouse studies were carried out with soils sampled from Lake Chad Basin in Sudan and Sahel savanna zones of Nigeria to assess their nitrogen-supplying potentials. Soil-nitrogen availability indices that were evaluated included two chemical methods - acidified $KMnO_4$ and alkaline $KMnO_4$ solution extractions and microbiological procedure - (incubation).

For the upland'soils the average N uptake (N-supplying power) from the first, second and third crops of wheat were 27, 16 and 12 mg/pot respectively. The respective values for "fadama" soils were 28, 15 and 13 mg/pot.

The $NH_4$-N extractable by acid $KMnO_4$ method ranged from 47 to 760 ppm. The minimum and maximum values of $NH_4$-N extractable by the alkaline $KMnO_4$ extraction were 16 and 205 ppm respectively. Total N mineralized by incubation procedure ranged from 46 to 301 ppm. The soils ability to supply N was not large and N uptake tended to decrease with subsequent cropping.

The two chemical soil-N availability tests apart from being more rapid appeared to be more superior as indices of soil-N availability than the incubation

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procedure whose correlation coefficients with N uptake and dry matter were not only very poor but erratic.

Of the two chemical methods, the acid $KMnO_4$ extraction seemed much more promising as indicator of soil-N availability than the alkaline $KMnO_4$. procedure. While the alkaline $KMnO_4$ method tended to have positive and general correlation with yield in all the various groupings of the 24 soils, the acid $KMnO_4$ showed significant and positive correlation with N uptake from first and third crops of wheat for soils derived from alluvial sand deposits (r = 0.81* and 0.85* respectively) and also with N uptake from first crop and total dry matter for "fadama" soils (r = 0.60* and 0.52*, respectively).

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# DEDICATION

To the Glory of God the Fount of Knowledge and Understanding and to My Late Mummy.

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# CHAPTER 1

## INTRODUCTION

The soil nutrient which plants require in greatest quantity is nitrogen. The element occupies a unique position in soil-plant nutrition due to the fact that world wide, more crops suffer from its deficiency than any other nutrient. This is probably because it is a major component of the proteinaceous matter of tissues.

In soil, nitrogen is the most unpredictable of all the nutrient elements. It is subject to biological and chemical immobilization, leaching and denitrification. Biological mobilization and immobilization of soil N are dependent on complex interplay of temperature, aeration, water, kind and amount of organic matter.

Practically all the nitrogen in surface soil is found in organic form. Yet despite its key role in plant nutrition, nitrogen is assimilated almost entirely in inorganic state as nitrate or ammonium.

The amount of nitrogen released from organic reservior to inorganic form rarely meets up the crop requirements for any growing season. This is more so in Savanna soils where the organic fraction is generally low. In order to supplement the amount of nitrogen that will be released from organic form to inorganic form for crop nutrition, fertilizers are generally applied.

For efficient and economic nitrogen fertilization, it is not only important that the soils ability to supply native nitrogen to the growing crops is known but also that there should be a method that will provide satisfactory estimate of the soil native nitrogen which will be available for the growing crop. Such a method should permit reasonably accurate prediction of fertilizer nitrogen needed to give a desired crop yield.

Nitrogen uptake or crop yield is a concrete proof of the soil's power to release nitrogen to the growing crop. However soil nitrogen availability can be estimated by several approaches. The approach that has the most appeal for farmers and researchers is soil testing. A reliable soil test must be accurate, rapid, inexpensive and calibrated with field fertilizer trial or related to yield response measured in the field before it can be used as a reliable guide for predicting N fertilizer needs for crop production.

The purpose of this study is to find out the ability of soils from Lake Chad Basin to supply nitrogen to the growing crop and to evaluate some soil nitrogen tests considered reliable for predicting the N-supplying power of soils.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. FORMS OF SOIL NITROGEN

The nitrogen in the soil can generally be classified as inorganic or organic, the greatest part occurring as a part of soil organic matter complex.

### 2.1.1. Inorganic Forms

The inorganic forms of soil N include ammonium, nitrate, nitrous oxide and nitric oxide, and elemental nitrogen which is inert except for utilization by N-fixing bacteria (Rhizobia) (Harmsen and Kolenbrander, 1965).

### 2.1.2. Organic Forms

Organically-bound nitrogen comprises about 98% of total soil nitrogen. These organic forms occur as consolidated amino acids, or proteins, free amino acid amino sugars and other complexes - generally unidentified compounds (Nelson and Tisdale, 1966).

## 2.2. TRANSFORMATION OF SOIL NITROGEN

Growing crops absorb most of their nitrogen in form of ammonium and nitrate. The amount of these two forms present at the root zone depends partly and largely on the amount released from the organically bound soil nitrogen and partly on the amount of inert (elemental) nitrogen fixed by free living bacteria or blue green algae (nonsymbiotic) and symbiotic associations composed of micro-organisms and higher plants (Stewart, 1975).

### 2.2.1. Mineralization

The conversion of organic nitrogen forms to inorganic nitrogen forms (Mineralization) takes place in essentially three step-by-step reaction: aminization, ammonification and nitrification. Ammonification and aminization are effected through the medium of heterotrophs (require organic carbon for their source of energy) and nitrification is brought about by autotrophs (obtain their energy from oxidation of inorganic salts and carbon from $CO_2$ of the surrounding medium).

### 2.2.2. Aminization

The decomposition of organic matter involves several stages one of which is the hydrolytic decomposition of proteins and release of amines and amino acids. This aminization which is effected by heterotrophs can be represented schematically:

$$\text{Proteins} \rightleftharpoons R\text{-}NH_2 + CO_2 + \text{Energy} \quad \text{Other products.}$$

### 2.2.3. Ammonification

The amines and amino acids released are further utilized by other groups of heterotrophs with the release of ammoniacal compounds.

$$R\text{-}NH_2 \quad HOH \longrightarrow NH_3 + R\text{-}OH + \text{Energy.}$$

The ammonia released could undergo any of the following processes: nitrification, absorption by higher plants or immobilized by heterotrophic micro-organisms in further decomposition of organic matter or may be physico-chemically fixed in unavailable form in the lattices of certain clay minerals.

### 2.2.4. Nitrification

The ammonia released during ammonification could be transformed into nitrate - nitrogen. This bio-oxidation is a two step process in which ammonia is first converted to nitrite and thence to nitrate.

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+$$

Obligate autotrophs such as nitrobacter convert nitrite to nitrate.

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$$

### 2.2.5. Nitrogen Fixation

There are two ways in which soil nitrogen could be rendered temporarily unavailable: (a) Physicochemical fixation and (b) immobilizati

### 2.2.6. Physicochemical Fixation

Soil-N in mineral form such as $NH_4^+$ could be trapped within the lattices of 2:1 type clay minerals during the mineral formation or could replace cations on exchange site within the lattice Nitrogen fixed in this way is not regarded lost totally.

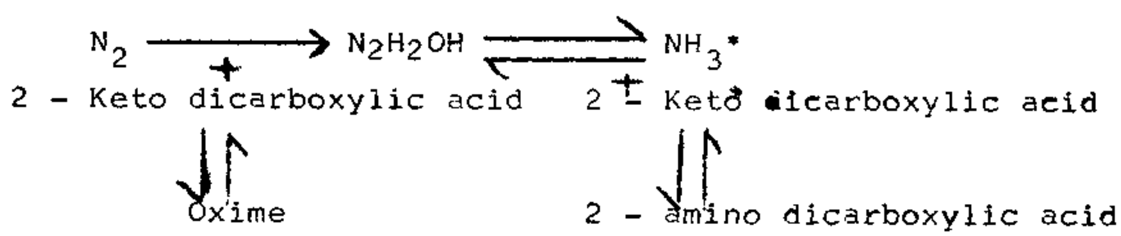
## 2.2.7. Immobilization

Immobilization of soil N is the incorporation of $NH_4^-$ - N and $NO_3^-$ - N into proteins, nucleic acids and other organic complexes contained within microbial cells. Soil N fixed in this way becomes temporarily unavailable until the micro-organisms die and decay (Alexander, 1977). The generally postulated sequence of reactions in assimilation of nitrogen is as follows:

$$NO_3^- \longrightarrow NO_2^- \longrightarrow (H_2N_2O_2) \longrightarrow NH_2OH \longrightarrow NH_3.$$

## 2.2.8. Dinitrogen Fixation

Certain free-living micro-organisms - bacteria or blue-green algae and some in symbiotic associations with higher plants are capable of converting elemental nitrogen into mineral form which the plants absorb. The general scheme for N fixation is:



Certain tropical grasses without the aid of micro-organism have been discovered to be able to stimulate fixation of elemental nitrogen (rhizophere fixation) (Kass et al., 1971; Dobereiner et al., 1972).

2.2.9. Losses of N from the Soil - Plant System

2.2.9.1. Burning

Uncontrolled fires, either accidental or intentional, destroy the vegetation and crop residues and the nitrogen contained in them is lost to the atmosphere. Burning losses in fallow have been estimated to be 20 - 28kg/haN/year (Nye and Greenland, 1960).

2.2.9.2. Erosion

Nitrogen in the soil could be lost as a result of erosion. At Samaru, Kowal (1970) observed that an average of 6.3kg/ha N/year were lost from a graded bench terrace of 0.3% slope containing a mean of 10 ton/ha N/year.

2.2.9.3. Run Off

Kowal (1970) reported that about 7.4kg/ha N/year were lost via run-off in fertilized plots at Samaru.

2.2.9.4. Leaching

Soil N especially in form of nitrate could be lost through leaching beyond the root zone especially in sandy soils. At Samaru, Jones (1976) reported N losses via leaching but felt that the loss did not exceed 25% of applied N in ferruginous tropical soils.

2.2.9.5. Plant Uptake

Continuous cropping/cultivation without addition of nitrogen from external sources or returning the crop residues slowly depletes the soil N reserve. At Samaru, Jones (1971) estimated that more than 4% of total soil N got lost through this way.

2.2.9.6. Gaseous Losses of Soil N

Soil nitrogen could be lost in form of N, $N_2O$, NO, $NO_2$ and $NH_3$ due to some biochemical reactions. Mechanisms suggested to be involved in losses include:

2.2.9.7. Denitrification

This refers to the biochemical reduction of nitrates to nitrites, nitrous oxides and elemental nitrogen under anaerobic conditions.

$$2HNO_3 \xrightarrow[-2H_2O]{+4H^+} 2HNO_2 \xrightarrow[-2H_2O]{+4H^+} H_2N_2O_2 \longrightarrow$$

$$\xrightarrow{-2H^+} N_2 \; +2H^+$$

$$-2H_2O$$

$$\xrightarrow[-H_2O]{} N_2O \pm H_2O$$

Denitrification occurs under the influence of certain micro-organisms, for example, T. denitrificans and T. thioparus.

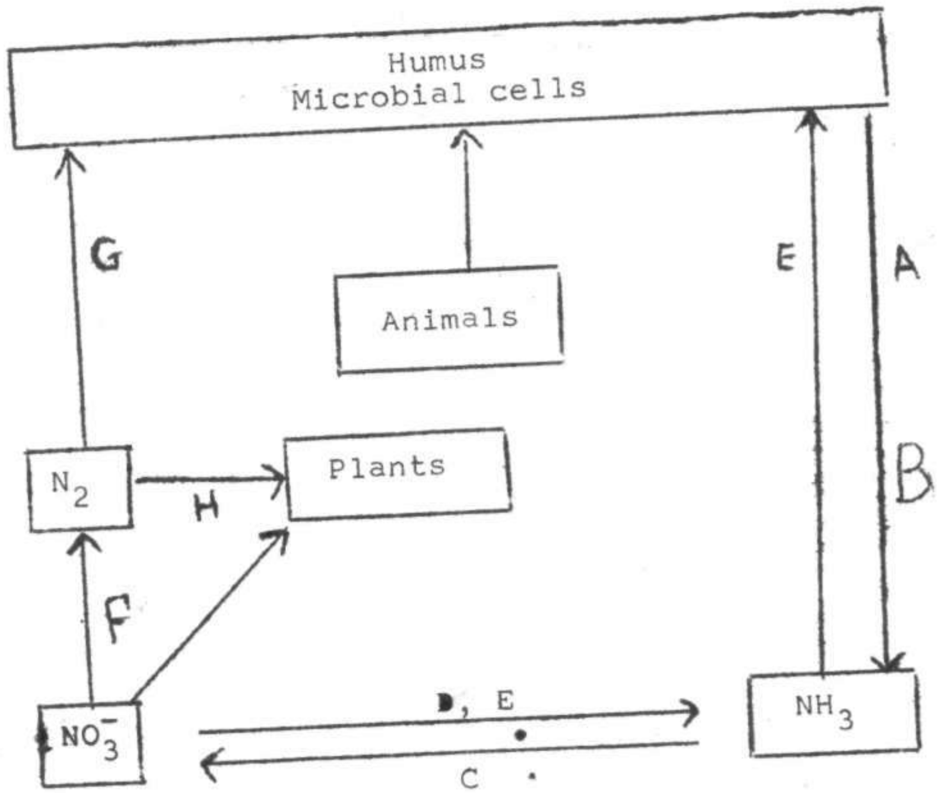
2.2.9.8. Chemical Reactions

Nitrite could be decomposed: $NH_4^+ + NO_2^- \longrightarrow 2H_2O + N_2$. The second step is the van slyke reaction: $RNH_2 + HNO_2 \longrightarrow ROH + H_2O + N_2$.

2.2.9.9. Volatilization of Ammonia

Ammonium salts in alkaline aqueous medium react as follows: $NH_4^+ + H_2O + OH^- \longrightarrow NH_3 + 2H_2O$. The above transformations that involve organic, inorganic and volatile compounds may occur simultaneously but individual steps often accomplish opposite goals. The reactions could be viewed in terms of a cycle in which the nitrogen is shuttled back and forth.

THE SOIL NITROGEN CYCLE*




A: Ammonification

B: Mineralization

C: Nitrification

D: Nitrate reduction

E: Immobilization

F: Denitrification

G: N-Fixation, Non-symbiotic

H: N-Fixation, Symbiotic

*(Alexander N., 1977).

By means of the above reactions, the subterranean microflora regulates the supply and governs the availability and chemical nature of the nitrogen in the soil.

## 2.3. FACTORS AFFECTING THE N LEVELS OF SOILS

In natural ecosystem, the N content tends to have an equilibrium value. The magnitude of this value depends on such factors as climate, vegetation, nature of terrain, physical characteristics of the soil activities of micro-organism as well as human activities.

The soil-N system is a dynamic one; any alteration in the environment such as a change in the climate may lead to a new equlibrium level of N. The diverse combinations in which the above factors operate are attested by the extreme variability in N contents of soils - from less than 0.1% in desert and semi desert soils to as much as 2% in highly organic soils. (Stevenson, 1965).

### 2.3.1. Climate

This is the most important single factor which determines the array of plant species available at any given location; the quantity of plant materials and the intensity of microbial activity. Hence the factor plays a significant role in determining the organic matter and N Level in the soils. Other things being equal increases in rainfall lead to greater plant growth and consequently the production of larger quantities of raw materials for synthesis of humic substances.

### 2.3.2. Moisture

The N content of soils has some close and direct relationship with moisture tension (Reiteimeirer, 1946; Greenland, 1958; Stenford and Smith, 1972; Enyi, 1964; Agboola and Udom, 1967; Reichman et al., 1966; Power, 1967). However excess water from rains or irrigation quickly leaches soluble nitrogen beyond the root zone especially in coarse - textured soils (Lews and Stefason, 1968).

### 2.3.3. Temperature

It has long been noted that tropical soils generally have high mineral N content due to favourable conditions as compared to 2 to 3 times drop in N content per 10 C drop in annual temperaature in temperate soils. (Jenny, 1941). The effect of temperature on the N content of soils is indirect. In cold soils, the activities of most micro-organisms in ammonification and nitrification of N present in organic residues are greatly hampered. In tropical paddy soils of Philippines, the mineralization of soil N is said to be completed in the early stages of the plant growth due to the high ambient temperature (Hito-ich et al., 1976). In general, it has been observed that mineralization occurs favourably between temperatures 0 - 35°C; above and below this range the activities of micro-organisms are adversely affected. (Stanford et al., 1973; Calpage, 1976).

### 3.4. Vegetation

The effect of vegetation on the N level of soils is concerned with the pool of plant species rather than the quantity of vegetation produced (Jenny, 1941). Generally soils developed in areas having plants with extensive root system have higher organic matter and higher nitrogen content than those with restricted root system, other conditions equal. The nature of litter added to the soil from the vegetation also has an effect on the net nitrogen mineralized as will be discussed in subequent sections.

### 2.3.5. Topography

Nitrogen levels of soils are affected by relief through its influence on climate, run-off, evaporation and transpiration. Degree of slope length and shape of slope are all important (Aandahl, 1949).

In mountaineous areas where pronounced changes in elevation occur, differences in soil N result from vertical zonation of plant flora and variation in climate. Soils in elevated areas have lower N content than those from depressions as organic matter is bound to accumulate in depressions without destruction during wet periods due to anaerobic conditions. Higher elevations also result in lower temperatures and hence less organic matter decomposition.

### 2.3.6. Soil Texture/Type of Clay Mineral

Textural properties of soils have marked influence on their nitrogen contents. Heavy textured soils normally have higher N contents than loam soils which in turn have more than sandy soils, generally. Koichiro et al., (1976) reported that N mineralization was increased by grinding the soil samples as compared to those not ground. The retention of N compounds in soils is also affected by the type of clay minerals present. Montmorillonite clays which have high adsorption capacities for organic molecules are particularly effective in protecting nitrogenous constituents against micro-organisms (Jaiyebo and Moore, 1963; Opuwairbo and Odu, 1978). The very close relationship which exists between the N levels of soils and soil types has been observed by several other workers - (Young and Cattani, 1962; Jenny and Raahandhuri, 1970).

2.3.7. Soil Acidity

The effect of pH on the N content of soils has long been recognised. Martin et al., (1967) noted in alkaline soils, a threshold pH value of 7.7$\pm$1 was necessary for nitrification to take place. At very low pH, activities of micro-organisms are adversely affected while at very high pH nitrifiers also die due to ammonia toxicity (Smith, 1964). Although liming in situations of very low pH stimulates the availability of nutrients and directly or indirectly affects nitrification, losses of N through volatilization are increased with increases in pH and drying (Calpage, 1976).

## 2.3.8. Carbon: Nitrogen Ratio

The carbon: nitrogen ratio (C.N. ratio) is an important characteristic of organic residues added to the soil since its ratio determines the rate of release of nitrogen in available form. When the ratio is very high (exceeds 30) during organic decomposition, immobilization rate exceeds mineralization rate. Thus the microbial requirements for N are not met for organic matter and the organisms assimilate soil N into microbical proteins. (Kanapathy, 1974 and 1976). During the decomposition of organic residue with C:N ratio of less than 15, mineralization rate exceeds immobilization rate with a net release of nitrogen. Thus nitrification of organic matter added to the soil is dependent to a large extent on the C:N ratios (Stanford and Smith, 1972; Yoshida et al., 1975).

## 2.3.9. Micro-organisms

Soils vary in type and number of micro-organisms present as these are affected by climate and other local factors. As mentioned in the proceeding section, soil nitrogen transformations are brought about by microbial activities. Meiklejohn (1962) attributed the low mineral N content of grassland soils of Ghana to the absence of nitrifiers and noted that the distribution of nitrogen in the forest region was as a result of mixing of leaf litter with mineral matter through the activities of earthworm and micro-organisms.

### 2.3.10. Interaction with Other Nutrients

Other nutrients have a profound influence on the N content of soils. High levels of P have been reported to increase the total N content in Black Paddy and Tinkinja varieties of rice (Enyi, 1967). It is also known that Mo application stimulates the N-fixing activities of root nodule bacteria. (Koji et al., 1967).

### 2.3.11. Management/Cultural Practices

Nitrogen added to the soil in form of fertilizers may or may not be available to the growing crops depending on certain practices such as method of application, rate of application, time of application and some other factors. Ghinwuba and Fayemi

(1960) and Agboola (1968) reported that the efficiency of applied N fertilizer can be increased by the split application of the nutrient. Good crop residue management has effect on the N levels of soils. Balasubramanian and Nnadi (1977) estimated that about 8.8 kg/ha N was added to savanna soils annually via incorporation of crop residues.

### 2.3.12. Aeration

The nitro-bacteria are obligate autotrophic aerobes. They will not produce nitrate in the absence of molecular oxygen. Nitrate accumulation is therefore to a great extent dependent on adequate aeration. (Nelson and Tisdale, 1966). It has been shown that under anaerobic conditions nitrate accumulated during very favourable conditions is used by certain micro-organisms as a terminal electron acceptor. The reaction results in a dissimulatory reduction which produces elemental nitrogen, nitrous oxide and some other products (Woldendorp, 1963). The effect of oxygen on the break down of organic residues in the soil has also been noted by some other workers (Parr and Reuszer, 1959; Kempner, 1937; and Greenwood, 1961).

## 2.4. ESTIMATION OF N-SUPPLYING POWER OF SOILS

Many approaches have been used to estimate soils ability to supply nitrogen to the growing crops. These approaches fall into one or more of the following broad groups:
Biological, microbiological and chemical methods.

### 2.4.1. Biological Methods

#### 2.4.1.1. Field Plot Technique

This is the most valid method of assessing the nutrient-supplying power of soils. In this method, the crop is grown under natural conditions in field and the yield is a direct measure of the nutrient-supplying power.

Field experimentations are normally fraught with problems and errors: plot dimensions are subject to measurement errors; determinations of yields have their inevitable errors; incidence of diseases, weather vagaries and insect attack are only to a limited degree under man's control and will not be identical from plot to plot. All these cannot be entirely eliminated owing to chance fluctuations and they make up the experimental error. In addition, field plot technique is very tedious, slow and expensive in operation.

Statistical technques are introduced to obtain the expected yield subject to the experimental error as the actual observations are mere estimate of the true yield (Wishart and Sanders, 1955).

2.4.1.2. Greenhouse Method

In order to get over the problems of cost, convenience and time the principle of field-plot technique is employed in the greenhouse experiment. Here, representative samples of soils in question are brought back to the greenhouse, dried, sieved and weighed into pots. Each plot represents a field. A test crop is grown in the pots and yields or nutrient uptakes are taken as the ability of the soils to supply the nutrients. This, unlike the field plot technique can be used to obtain an information in advance of cropping.

The greenhouse method is not without its own shortcomings. The amount of soil required for greenhouse work is still too large for convenient handling and the method does not lend itself for mass processing of soil samples. So it is for special research interest and not for routine soil testing. Besides, greenhouse is a semi-controlled environment and soils in pots may not adequately represent the same soil in the fields as climate is more often than not altered. However, it is often used for calibrating other methods in place of field plot technique.

### 2.4.1.3. $N^{15}$ Studies

Tracer techniques have been used to further knowledge of soil N availability. In a greenhouse investigation, Stanford and Legg (1967), applied N in form of $NaNO_3$ labelled with 9% excess $N^{15}$ at the following rates - 0, 90, 180 and 300mg per pot of 1800g soil samples in three replications. Oat plant was used as a test crop. P and K were applied to ensure that they were not limiting. They obtained total N in harvested plant materials and by using mass spectrometer, they were able to obtain the fraction of the N in plant due to $N^{15}$ fertilizer. The difference between the $N^{15}$-labelled fertilizer and total N uptake was a measure of soil-N uptake. They observed that "A values*" in most cases were independent of N levels applied - and were highly correlated with dry matter yield (r = 0.939) and total N uptake (r = 0.981) from zero - N pots. Their study left no doubt that "A value" was a precise standard for characterising the N-supplying capacities of the soils in question. In another $N^{15}$ study, Legg and Allison (1967) noted that the retention and availability of residual N were related to the N-supplying capacities of twelve soils. Several other investigators have used $N^{15}$ in evaluating the soil N availabilities (Bartholomew and Herlihy, 1966; Broadbent and Norman, 1946; Norman and Krampitz, 1945; Allos and Bartholomew, 1959).

### 2.4.2. Microbiological Methods

The use of micro-organisms as indicators of N-supplying power of soils is based on the assumption that the N requirements of these organisms are the same as those for the higher plants. Scarsbrook

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* "A value" = an index of soil-N availability = $B(I-Y/_{Y})$, where B = fertilizer N rate; Y = fraction of N in plant derived from applied fertilizer.

(1965) while reviewing the work of McCool (1947) reported that N utilisation by the fungus colonies, *Cumminghamella blakesleeana*, closely correlated with N uptake by rye grass grown under field condition.

Estimation of microbial growth or pigment production received some interest as an index of soil-N availability. Boswell et al., (1962) found that the pigment production of the proteinaceous bacterium (*Pseudomonas aeruginosa*) was highly correlated with nitrifying capacity of the soil.

Some microbiological tests for N-supplying capability of soils have involved the measurement of inorganic N mineralized from organic N during a given period of soil incubation.

Stanford and Hanway (1955) proposed a measurement of nitrate production in soils by a method which permitted carrying out a series of incubations with a single set of soil samples. Perior to incubation a mixture of soil and expanded vermiculite placed in a filter tube was leached free of $NO_3$ and excess water was removed under suction. Following incubation for 14 days at 30°C the process of leaching and applying suction was repeated.

Nitrate-nitrogen produced showed some significant correlation with N uptake by crops grown in the greenhouse.

Munson and Stanford (1955) used nitrate-N produced after 14 days of incubation at 35°C as an index of soil-N availability. The leaching techniques as described by Stanford and Hanway (1955) were used in the $NO_3$-release experiments. The $NO_3$-N released after 2 weeks of incubation correlated with N uptake by German millet grown in the greenhouse. $NO_3$-N before and after incubation was determined using phenoldisulfonic acid. Employing rapid Iowa nitrification and standard incubation method in some Indian soils; Kalwande (1964), noted that the $NH_4$-N and $NO_3$-N produced had very close relationship with percentage yield on one hand and N uptake at flowering stage of wheat on the other hand. He incubated the soil samples - ($\frac{1}{3}$ saturation capacity) for 15, 30, 45 and 60 days at 35°C. The samples were periodically leached with 1N NaCl and $NH_4$-N and $NO_3$-N were determined by distillation using Devarda's alloy and MgO.

Keeney and Bremner (1966) were of the view that the total inorganic - N (i.e. $NO_3$ + $NH_4$ + $NO_2$) -N mineralized from the organic N after 14 days of (aerobic) incubation at 30°C was a better estimate of soil-N availability. Their results showed some correlation with N uptake by crops grown in the greenhouse.

Several other researchers have demonstrated that nitrogen mineralized has a good bearing on the soils ability to supply nitrogen to the growing crops (Stanford and Smith, 1972; Lathwell, Dubey and Fox, 1972).

Ammonium - nitrogen produced under anaerobic incubation has also been considered as an indicator of soil-N availability (Waring and Bremner, 1964; Keeney and Bremner, 1966). Waring and Bremner (1964) incubated 5g of soil under waterlogged condition for 2 weeks at 30°C and observed that the $NH_4$-N produced under these conditions correlated with N uptake of rye grass grown in the greenhouse. Keeney and Bremner (1966) employed a modified form of Waring's procedure (1-week at 40°C) and found some positive correlation between the N uptake by rye grass grown in the greenhouse and the mineralized nitrogen.

Another form of incubation test is that of estimation of $CO_2$ production after a readily decomposable organic source is added to the soil (Cornfield, 1961; Bremner, 1965). The method involved treating 10g soil (at 50% water holding capacity) with 0.1g cellulose powder in a vial containing 0.2g barium peroxide ($Ba_2O$). The soil together with the treatment was incubated for 21 days at 28°C. The barium peroxide absorbed the $CO_2$ produced while releasing $O_2$. The $CO_2$ thus produced was found to correlate with the total mineral nitrogen of soil. The defect of this method is that N may not be the only nutrient limiting the mineralization of organic carbon when soils are incubated with nitrogen free-energy-rich materials, and it is known that treatment of soils with such materials promotes fixation of atmospheric nitrogen (Bremner, 1965b).

The general short-comings of incubation tests are that the time (10 - 14 days) makes it prohibitive to handle large volumes of samples and secondly handling of the samples - drying, storage and fineness of grinding affect the amount of N released during incubation (Bremner, 1965b; Munro and Mackey, 1964; Chalk and Waring, 1970b; Harpstead and Brage, 1958).

### 2.4.3. Chemical Methods

A chemical approach to the problem of developin a laboratory test of soil-N availability is not onl more rapid and convenient than biological methods but also more precise.

Total nitrogen and organic matter have been used as indices of nitrogen-supplying power of soil (Smith and Stanford, 1971; Kalbande, 1964). However, Scarsbrook (1965) and Bremner (1965b) have suggested that the total N soil test should be used with caution because of the many factors such as C: ratio, pH, microbial population, temperature and moisture that influence mineralization of total organic N.

Stanford (1968) used the approach that a chemical N test should measure the readily mineralisable portion of organic N. He removed N with mild extractants - hot 0.01M $CaCl_2$ and hot 0.5M $Na_4P_2O_7$. The control and extracted soils were incubated anaerobically for 13 weeks to obtain amounts of mineralizable N in the soils. The difference in amounts of mineraliz ible N between the control and extracted soil was correlated with amount of N removed by the mild extractants. If a high correlation was found between the difference in mineralizable N and N removed by mild extractants, it indicated a close meaaure of readily mineralizable N. Distillable-N was hot water or sodium pyrophosphate hyrolysable N distilled with NaOH, and total N was Kjeldahl digestion after distillation of fraction hydrolysed by hot water followed by distillation with NaOH after digestion. He noted that the distillable portion of both extracts were more closely related to the amounts of mineralizable organic N removed from the soils by the extractants than either the non-distillable N portion or total N portion of the extracts. Stanford concluded that removal of organic N by successive water or dilute salt concentration represented a gradual and somewhat selective dissolution of N forms susceptible to mineralizations.

Stanford and DeMar (1969) simplified distillation by using modified Conway microdiffusion procedure. This procedure allowed diffusion of ammonia into boric acid at room temperature during a 16 - 2? hour period. They extracted organic N by autoclaving with 0.01M $CaCl_2$ (121°C for 16 hours). The relationship between diffusible $NH_3$ was more reliable than the non-distillable or distillable N fractions and suggested that N extracted during shorter time period with boiling water or $Na_4P_2O_7$ may be reliable index for soil N availability.

Smith and Stanford (1971) reported on the evaluation of hot 0.01M $CaCl_2$ (autoclaving at 121°C), total N, and total carbon as indices of N availability for 34 soils. Microdiffusion and distillable N correlated highly with N mineralized under anaerobic incubation ($r = 0.92^{**}$ and $0.96^{**}$ respectively) and with N mineralized under aerobic incubation ($r = 0.88^{**}$ and $.88^{**}$, respectively). Correlation of hot 0.01M $CaCl_2$ with total carbon and total N though significant was not as high as distillable and microdiffusable N ($r = 0.74^{**}$). These data indicated that extraction of organic N with hot water or hot $Na_4P_2O_7$ may be of value in estimating the availability of organic N.

Keeney and Bremner (1966) proposed another hot water soluble N test. Soil samples were boiled for 1 hour with water and after cooling, $K_2SO_4$ was added. It was swirled and filtered under suction. Total N was determined on the aliquots of the filtrates.

The determination of total N instead of the distillable N was the main difference between their hot water test and test suggested by Stanford (1968). Uptake of N by rye grass in second and third cuttings correlated with the hot water or $Na_4P_2O_7$ soluble N test ($r = 0.77^{**}$). Working with 14 soils in a greenhouse investigation, he (Stanford) compared some chemical N tests. The correlation coefficients that he obtained between these tests and N uptake by rye grass were as follows: glucose extracts, $0.70^{x}$; hot water-soluble N, $0.65^{x}$; hot $NaHCO_3$-soluble N, $0.70^{xx}$; $NH_3$ released by hot Ca $(OH)_2$, $0.67^{xx}$; and $NH_3$ released by alkaline permanganate 0.28.

In another study the fraction of soil N extracted by alkaline $KMnO_4$ correlated well with yield of wheat (Kalbande, 1964; Munson and Stanford, 1955).

The method involved distillation of soil N in alkaline $KMnO_4$ solution. Stanford and Smith (1978) noted good relation between $NH_4$-N with acid $KMnO_4$ (Oxidative release of $NH_4$-N) and determining the potentially mineralizable N (by microbiological method of incubation).

Stanford (1978) studied the relation between ammonia released by alkaline permanganate extraction and potentially mineralizable soil N. He recovered $NH_4$-N by steam distillation of 1g soil during extraction with varying concentrations of NaOH, $KMnO_4$ and their combinations. He observed that correlations between the $NH_4$-N released by combination of NaOH and $KMnO_4$ and potentially mineralizable soil N was better than the $NH_4$-N released either by NaOH or $KMnO_4$ alone. He also concluded that it appeared that acid $KMnO_4$ method was superior to alkaline $KMnO_4$ procedure (Stanford and Smith, 1978).

Potassium permanganate is a versatile oxidising agent. Its ability to decompose organic matter is dependent on the pH of the medium. The oxidative reactions of $KMnO_4$ are shown below:-

1(a) Strongly acidic condition:

$$KMnO_4 + 8H^+, + 5e \rightleftharpoons Mn^{2+} + 4H_2O.$$

(b) Weakly acidic or neutral condition:

$$MNO_4^- + 4H^+ + 3e \rightleftharpoons MnO_2 + 2H_2O.$$

2 Strongly alkaline condition:

$$MnO_4^- + e \rightleftharpoons MnO_4^{2-}.$$

Nommik (1976) observed that $CO_2$ and $NH_3$ released on partial oxidation of soil with orthophosphoric acid and chromic acid correlated well with mineral N accumulation in 9 weeks of incubation and hence provided a good estimate of the soil's capacity to supply N.

Fox and Piekielek (1978) tested several chemical N availability indices in field experiments. The chemical methods tested were:

a) 0.01M $CaCl_2$ extractable - N
b) 0.01M $NaHCO_3$ extractable - N
c) Walkley - Black organic matter
d) Autoclave-extractable $NH_4$-N
e) Total soil N
f) Soil $NO_3$-N
g) $H_2SO_4$-extractable N
h) KCl-extractable N

0.01M $CaCl_2$-extractable N was determined by a slight modification of method proposed by Keene, and Bremner (1966). A 10g soil sample and 60ml of 0.01M $CaCl_2$ were refluxed for 1 hour. 40ml of 10% $K_2SO_4$ were added when cool. The suspension was suction-filtered and 20ml aliquot of the leachate was digested with 20ml of $H_2SO_4$ for 1 hour - after clearing in a microk-jeldahl flask. After cooling, 40ml of water and 10ml of 10N NaOH were added and $NH_3$ steam-distilled into 2% boric acid and titrated with 0.005N $H_2SO_4$.

Dilute $NaHCo_3$-extractable N was measured by the method of MaClean (1964). 5g of soil were shaken with 100ml of 0.01M $NaHCO_3$ for 15 minutes followed by the digestion of 10ml aliquot of the filtrate with 0.5ml of $H_2SO_4$ containing 0.33g $K_2SO_4$ for 1 hour. Nessler's reagent was added to the digestion tube followed by addition of NaOH to adjust alkalinity to 0.35M.

The total organic matter was estimated, using Walkley-Black procedure. Autoclave-extractable $NH_4$-N was determined by a method similar to that of Stanford and Demar (1969) as previously discussed. Total soil N(excluding $NO_3$) was estimated by the Macro-Kjeldahl method. The $NO_3$-N in soil was determined in 0.025M $Al_2(SO_4)_3$ extract.

Dilute $H_2SO_4$ (0.07N) extractable N was determined according to the method of Purvis and Leo (1961). 2ml of the dilute $H_2SO_4$ were added to 1g soil and brought to dryness in a steam bath. 50ml of distilled water and 1ml of 5% $Na_3PO_4.12H_2O$ were added. After stirring, it was then filtered. Nessler's reagent (0.2ml) was added to 5ml of the filtrate and shaken. After 20 minutes the $NH_4$-N content was obtained by determining the transmittance at 400g in a colorimeter.

Nitrogen extractable with KCl was measured using the method proposed by Lathwell et al., (1972). A 20g soil sample was shaken with 40ml of 1N KCl for 1 hour. The suspension was filtered and leached with additional 60ml of 1N KCl. 20ml aliquot was digested with 2ml of conc. $H_2SO_4$ for 1 hour - after clearning. The $NH_4$-N content of the digest was determined by steam distillation.

They observed significant correlation between boiling 0.01M $CaCl_2$ and 0.01M $NaHCO_3$-extractable

N and the N-supplying power of the soils as measured by N uptake by field-grown corn. The correlation coefficients were 0.86 and 0.77 at 1% level of significance, respectively. Autoclave extractable $NH_4$-N and total soil N also significantly correlated with the N-supplying capability of the soils (r = 0.70 and 0.68 at 5% level of confidence).

The organic matter, soil $NO_3$-N, $H_2SO_4$-extractable N, and KCl-extractable N were not significantly correlated with the soil potential to supply N under the field conditions.

In another report, Fox and Piekielek (1978) noted that ultraviolet (U.V.) absorption by the 0.01M $NaHCO_3$ soil extract at 260nm was highly correlated with the N-supplying power of the test soils (r = 0.87**, P = 0.01).

The $NaHCO_3$-extractable N was obtained by the method of MaClean (1964). After extraction the suspension was suction-filtered through (Whatman No.42) filter paper. The UV absorption was measured with a spectrophotometer. Two drops of concentrated HCl were added to eliminate the effect of $HCO_3^-$ when UV measurements were made at 205nm to estimate

$NO_3$-N since $HCO_3^-$ also absorbs in that range.

As part of the above study, Fox and Pekielek also measured UV absorption as the wave-lengths were increased from 230nm - 310nm and noted that there were parallel linear decreases in absorbance. Since UV radiation in this range is absorbed by essentially all double or II bonds in organic matter, the UV absorbance of these soils was a measure of concentration of organic matter in the extract. Assuming that the relationship between the absorbance at a particular wave-length and concentration of organic matter is fairly constant for most inorganic soils, the absorption at 260nm (which was at the centre of the linear portion of absorbance versus wave-length curve) was chosen as the indicator of organic matter content of the extract. The value obtained at this 260nm absorption positively correlated with the N content of above-ground portion of the field-grown corn (N-supplying capability of the soil).

Shortcomings of The Chemical Methods

The major pitfall of the chemical extraction methods is that they are completely empirical in the sense that they make no allowance for the fact that the N mineralization - immobilization cycle in soil is controlled by several factors among which is the supply of energy material for microbial processess; that is, they do not measure the well-known depressing effect of straw and other carbonaceous plant residues on the soil N availability. This problem is compounded by the fact that the present knowledge concerning the relationship between the chemical composition of organic matter and availability of the nitrogen in different soils is limited and little information is available on the chemical nature of organic forms of nitrogen which are readily mineralized and are sources of nitrogen for plant growth (Bremner, 1965). Nevertheless, results obtained from data of chemical extractions in many cases have close relations with soil N availability.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1. SOIL SAMPLING AND HANDLING

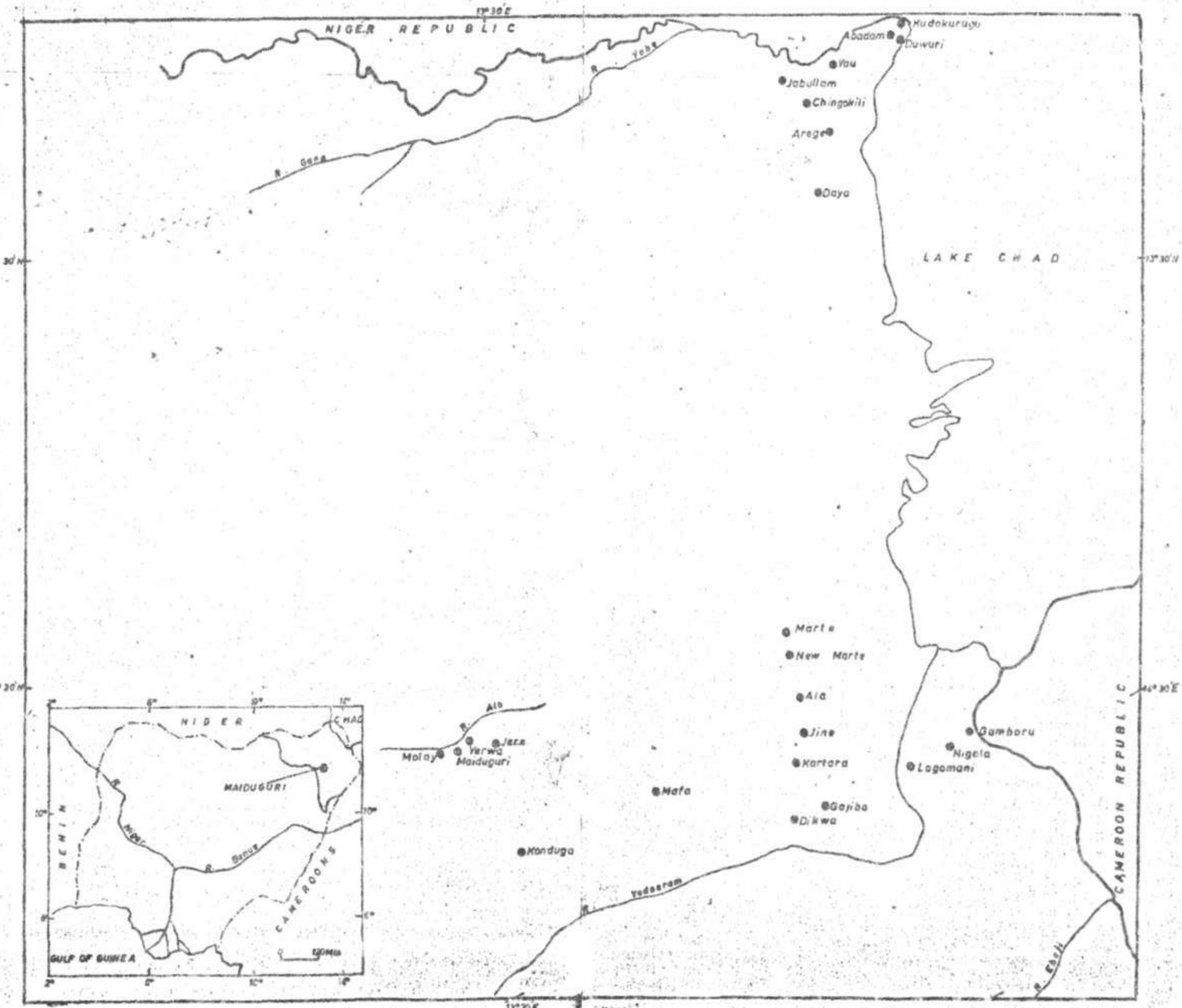
### 3.1.1. Soil Sampling

The soils used in this investigation were sampled from twenty-four sites of irrigated and non-irrigated rice/wheat soils within Lake Chad Basin (Borno State) of Nigeria. In each location about 25kg bulk soil samples were collected from 0 - 15cm depth. In most cases the samples were taken from fallow areas as there were no traces of recent cultivation or any other human activities. Figure 1 and Table 1 depict the locations and the descriptions of the sites respectively.

### 3.1.2. Handling

In each location composite soil sample was taken by bulking together samples collected at different points about 4 - 6 meters apart. The samples were put into clean polythene bags. They were later air-dried, crushed and sieved through 2mm mesh screen and stored in polythene bags.

FIG. I: MAP OF BORNO STATE SHOWING LOCATIONS WHERE SOIL SAMPLES WERE COLLECTED



| Site | Parent Material* | Ecological Zone* | History |
|---|---|---|---|
| Ala | Chad Lagoonal Deposits | Sudan savanna | Fallow "fadama" plot. |
| Gajibo | " " " | " " | Fallow upland plot. |
| Gamboru | " " " | " " | "Fadama" plot; cropped to irrigate wheat 5 years ago |
| Jine | " " " | " " | Fallow upland plot. |
| Kartara | " " " | " " | " " " |
| Logomani | " " " | " " | " " " |
| Marte | " " " | " " | Five-years fallow "fadama" plots. |
| New Marte | " " " | " " | Fallow "fadama" plot. |
| Ngala | " " " | " " | " " " |
| Abadam | Alluvial Sand Deposits | Sahel savanna | Fallow "fadama" plot. |
| Arege | " " " | " " | " " " |
| Chingokili | " " " | " " | " " " |
| Jabullam | " " " | " " | Fallow upland plot. |
| Yau | " " " | " " | Fallow "fadama" plot. |
| Daya | Lacustrine Sand Deposits | Sahel savanna | Upland plot; cropped to rice four years ago. |
| Duwuri | " " " | " " | Fallow "fadama" plot. |
| Kudokurugu | " " " | " " | " " " |
| Dikwa | Fluvial Sand Deposits | Sudan savanna | Fallow "fadama" plot. |
| Konduga | " " " | " " | Upland plot; five years fallow |
| Molay | " " " | " " | "Fadama" plot; cropped to rice three years ago |
| Jere | Aeolian Sand Deposits | Sudan savanna | Upland plot; cropped to rainfed rice, three years. |
| Mafa | " " " | " " | Fallow uplant plot. |
| Maiduguri | " " " | " " | " " " |
| Yerwa | " " " | " " | " " " |

*Bawden; Carroll; and Tuley, (1972).

From each bag, sub-sample was taken and stored in clean plastic bottle for laboratory analyses. Each sample was later crushed to pass through suitable sieves as required by the analytical procedures.

## 3.2. PHYSICAL DETERMINATION

### 3.2.1. Particle Size

Particle size distributions were obtained by the hydrometer method. Fifty grammes of each of 2mm soil samples were dispersed in 100ml of 5% Calgon solution. After about 30 minutes, the contents were transferred to a dispersing cup of an electric mixer and about 400ml of distilled water added. The fractions were then determined by the hydrometer as described by Day (1965).

## 3.3. CHEMICAL DETERMINATIONS

### 3.3.1. Soil pH

The pH was measured in 1:1 soil-water suspension and also in 1:1 soil-salt suspension (0.01M $CaCl_2$) using glass electrode digital pH meter.

3.3.2. Organic Carbon

The organic carbon contents of the soil were determined by the dichromate oxidation procedure as described by Walkley and Black (1934).

3.3.3. Exchangeable Acidity

Ten grammes of the soil (oven-dry basis) were leached with 10ml portions of 1N potassium chloride solution for about 13 minutes each until about 100ml of the leacheate were collected. The titrable acidity was then determined by titrating 50ml of the leacheate with 0.05N sodium hydroxide, using phenolphthalein as indicator (Dewis and Freitas, 1970).

3.3.4. Exchangeable Cations Neutral Ammonium Acetate Method

Twenty grammes of each soil sample were soaked overnight in 100ml of the N neutral ammonium acetate. The soil and the leaching solution were quantitatively transferred to Buchner funnels (with filter papers in place) fitted to 250ml volumetric flasks. The soils were then leached with extra ammonium acetate solution using 20ml at a time until 200ml leachates were collected (Chapman, 1965).

Calcium, magnesium and potassium were detdermined with atomic absorption spectrophatometer. The exchangeable sodium values of the samples were read from a flame photometer.

### 3.3.5. Total Nitrogen in Soils

Ten grammes of each of the soil samples were soaked in 50ml of distilled water for 30 minutes. 50ml of concentrated sulphuric - salicylic acid mixture and 5g of sodium thiosulphate were added to each and heated gently for five minutes. Thereafter about 10g of kjeldahl catalyst (Se, $CuSO_4$ and $Na_2SO_4$ in the ratio of 0.1:1:10 respectively) and four glass boiling beads were added and the mixture digested until the solution became clear. Digestion was continued for one more hour. 100ml of distilled water were added to the digest. The ammonia formed was liberated by adding 50ml of 45% sodium hydroxide solution and distilling into 50ml of 2% boric acid until 150ml of distillate were collected. The ammonia trapped in the boric acid was determined by titrating with 0.1N sulphuric acid using bromocresol green-methyl red indicator (Bremner, 1965a).

### 3.3.6. Total Phosphorus

The vanadate molybdate yellow method as described by Kitson and Mellow (1964) was adopted. Two grammes of each of the soil samples (2mm) were digested with 20ml of 24% per chloric acid until the residue was white in colour and solution filtered through No.1 filter paper. After diluting to 50ml, an aliquot of 10ml was added to 10ml of the colour developing solution (ammonium - vanadate molybdate solution). When the yellow colour was fully developed, the P contents were then read from spectrophotometer 20 at 460um.

### 3.3.7. Electrical Conductivity - By Saturation Extract Method

For the saturated paste, distilled water was added to 250g of 2mm sieved soil in a beaker until the paste glistened and flowered gently when it was tipped. The pastes were then transferred to filter funnels with filter papers in place and vacuum was applied. The extracts were collected in tubes and their electrical conductivities obtained by use of conductivity bridge with temperature control adjusted to 25$^{o}$C (Richards, 1969).

## 3.4. GREENHOUSE EXPERIMENTS

Exhaustive cropping for nitrogen was carried out in the greenhouse. The soils were planted to wheat. Clay pots (with perforated bottoms for drainage of excess water and placed in plastic bowls to collect drained water) of about 5 litre capacity were filled with 4kg of soils. In each pot, twenty-five wheat seeds were planted and thinned down to sixteen stands per pot after seven days.

To eliminate the possibility of deficiencies of other nutrients suspected to be critical in savanna soils the following nutrients were applied in solutions at the rates indicated prior to planting:

P: 80 ppm, (180 kg/ha P) applied as $Ca(H_2PO_4)_2.H_2O$.

K: 60 ppm, (135 kg/ha K) applied as KCl.

Mn: 3.5 ppm, (7.9 kg/ha Mn) applied as $MnSO_4$.

Fe: 4 ppm, (9 kg/ha Fe) applied as $FeSO_4$.

Cu: 1.5 ppm, (3.5 kg/ha Cu) applied as $CuSO_4$.

B: 0.5 ppm, (1.125 kg/ha B) applied as $Na_2B_4O_8.10H_2O$.

Zn: 4 ppm, (9 kg/ha Zn) applied as ZnO

Mg: 4.5 ppm, (10.13 kg/ha Mg) applied as $MgCO_3$.

Each soil was replicated three times and completely randomized. Distilled water was applied as required to keep the soil moist. The plants were harvested after a period of 42 days and dried at 60°C for 2 days. The dry weight per pot was recorded.

After seven days from the first harvest, the soil in each pot was pulverized, watered and once more seeded to wheat. The second cuttings were done after the same period of six weeks and grain dried as in the first cutting. The third and last crop of wheat was obtained as for the second crop. The dried plant samples were later ground for analyses of the N contents.

## 3.5. PLANT ANALYSIS

The ground plant samples were analysed for N by the micro-kjeldahl procedure. 250mg of each sample were digested in a mixture of 8ml of contentraded sulphuric acid and kjeldahl catalyst using a Technicon block digestor. The digest was then made up to 75ml. The distillate arising from the addition of 10ml of 40% NaOH to 10ml of the digest was collected in 2% boric acid. The N values were obtained by titrating with 0.005N $H_2SO_4$.

## 3.6. CHEMICAL METHODS OF SOIL N AVAILABILITY

### 3.6.1. Acid Permanganate Extraction Procedure

1g of each of the soil samples was placed in 50ml centrifuge tubes. 25ml of 1N sulphuric acid were added and the tubes tightly stoppered. The contents were shaken for one hour in a mechanical shaker and then centrifuged. The supernatant liquid was poured out.

25ml of a mixture of potassium permanganate (0.1N) and sulphuric acid (1N) were added to the soil residue and shaken again for an hour and centrifuged. 5ml of 40% sodium hydroxide were added to 10ml of the extract and the ammonium nitrogen released oxidatively determined by distilling into 5ml of 2% boric acid and titrating with 0.005N $H_2SO_4$ (Stanford and Smith, 1978).

### 3.6.2. Alkaline Permanganate Extraction Procedure

1g of each soil sample was placed in 100ml distillation flask and 10ml of a mixture of potassium permanganate and sodium hydroxide (0.25g $KMnO_4$ in 10ml of 0.625N NaOH) added. The contents were steam - distilled for 10 minutes into 50ml Erlenmeyer flask containing 5ml of 2% boric acid until 20ml of distillate were collected. The ammonium-N content was determined by titration with 0.005N $H_2SO_4$. The above procedure was carried out again for 0.625N sodium hydroxide alone to obtain the amount of ammonium - nitrogen released due to hydrolysis by sodium hydroxide.

The amount of $NH_4$-N released by oxidation by $KMnO_4$ was then obtained for each soil sample by the difference between the value of $NH_4$-N resulting from the mixture of $KMnO_4$ and NaOH and the value for NaOH alone (Herlihy, 1978).

## 3.7 MICROBIOLOGICAL METHOD OF SOIL NITROGEN AVAILABILITY

Ten grammes of 2mm air-dried sample of each soil were mixed with 30g of acid-washed sand (30 - 60 mesh) in 100ml beaker and the mixture transferred to 500ml wide-mouth bottles containing 6ml of distilled water. The mixture was evenly distributed over the bottom of the bottles. The surface of each bottle was levelled by tapping the bottle. Each soil was replicated four times. A control (also in 4 replications) containing 30g of the pure sand was also provided.

The bottles were closed and kept in a constant temperature (35°C) incubator. Every other day each bottle was opened for about 3 minutes to let in some air and then closed. The bottles were left in the incubator for two weeks. 100ml of 2N potassium chloride were added to each and shaken in a mechanical shaker for an hour.

20ml aliquot of the extract was pipetted after the soil - sand mixture had settled and ($NH_4$ + $NO_2$ + $NO_3$) - N was determined by distillation of the aliquot. 0.2g each of magnesium oxide and Devarda's alloy were added to the extract and steam-distilled into Erlenmeyer flask containing 5ml of 2% boric acid until about 40ml of the distillate were collected. The distillate was titrated with 0.005N $H_2SO_4$.

The $(NO_3 + NO_2 + NH_4) - N$ in each soil sample before the incubation was determined by the same procedure. The mineralized nitrogen in each soil was obtained from the differences of the two analyses (Bremner, 1965b).

## 3.8. STATISTICAL ANALYSIS

All the data obtained were statistically analysed. The mean, regression and correlation relationships between the N-availability indices and the yields were computed.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1. CHARACTERISTICS OF THE SOILS

Locations from which the soils were sampled for this study as shown in Figure 1. The soils were under grassland or bush-fallow at the time of sampling. Information obtained from the farmers around the sites indicated that most of the soils have been fallow for a considerable number of years.

### 4.1.1. Soil Texture

Observations of the soils during sampling showed marked variations in their textures. Those within Maiduguri areas appeared lighter in texture than others. Particle size distributions as determined in the laboratory later (Table 2) confirmed the observation made in the field. The soil texture varied from sandy loam to clay. The clay contents of most of the soils were relatively high - ranging from 19.4 to 69.4%. Soils derived from Chad Lagoonal deposits parent material appeared to have

TABLE 2: PARTICLE SIZE DISTRIBUTIONS

| Site | Parent Material | % Clay | % Silt | % Sand | Soil Class* |
|---|---|---|---|---|---|
| Ala | Chad Lagoonal Deposits | 65 | 15 | 20 | Clay |
| Gajibo | | 58 | 8 | 34 | " |
| Gamboru | | 69 | 19 | 12 | " |
| Jine | | 26 | 3 | 71 | Sandy clay |
| Kartara | | 34 | 14 | 52 | " " |
| Logomani | | 21 | 4 | 72 | " " |
| Marte | | 38 | 28 | 34 | Clay loam |
| New Marte | | 69 | 16 | 15 | Clay |
| Ngala | | 75 | 9 | 16 | " |
| Abadam | Alluvial Sand Deposits | 35 | 17 | 48 | Sandy clay |
| Arege | | 21 | 7 | 72 | " clay loam |
| Chingokili | | 45 | 19 | 36 | Silty loam |
| Jabullam | | 31 | 13 | 59 | Sandy clay loam |
| Yau | | 28 | 11 | 61 | " " " |
| Daya | Lacustrine Sand | 23 | 14 | 62 | Sandy loam |
| Duwuri | | 33 | 15 | 62 | " clay loam |
| Kudokurugu | | 28 | 14 | 58 | " " " |
| Dikwa | Fluvial Sand | 69 | 15 | 16 | Clay |
| Konduga | | 19 | 8 | 73 | Sandy clay loam |
| Molay | | 48 | 17 | 35 | Clay |
| Jere | Aeolian Sand | 25 | 6 | 69 | Sandy clay loam |
| Mafa | | 45 | 13 | 42 | Silty clay |
| Maiduguri | | 21 | 11 | 68 | Sandy clay loam |
| Yerwa | | 21 | 12 | 67 | " " " |

*International System

highest clay content with a mean value of 51.2% (Table 4). These were followed by those derived from fluvial sand 45.6%, alluvial sand 32.4% with lacustrine sand and aeolian sand having about the same clay contents - 28.5% and 28.4% respectively. The silt contents for most of the soils were relatively low - ranging from 3% to a maximum of 28% (Table 2) with a mean value of 12.6%. However, soils derived from fluvial sand, lacustrine sand and alluvial sand deposits had higher silt contents than either those derived from Chad Lagoonal deposits or aeolian sand (Table 4). Soils derived from aeolian sand had the highest content of sand (62.5%) among all others.

### 4.1.2. Soil pH

The mean values of soil pH measured in 0.01M $CaCl_2$ and in water for all the soils were 5.69 and 7.11 respectively (Table 3). None of the soils was extremely acidic as no samples had a pH value of less than 4.0 in $CaCl_2$ and 5.0 in water below which values exchangeable Al becomes toxic to the growing crops (Kamprath, 1972; Nye and Greenland, 1960; Reeve and Sumner, 1970).

TABLE 3: <u>CHEMICAL PROPERTIES OF THE SOILS</u>

| Sites | pH | | Exchangeable Acidity (EA) me/100g | (E.B) Ex. Bases me/100g | | | | Effective CEC me/100g | Base Satura- tion (% B.S) | Ex. Sodium Percentage E.S.P. | Org.C % | Total N % | Total P ppm | Electrial Conductivity (E.C) mmhos at 25°C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CaCl_2$ | pH | | Ca | Mg | K | Na | | | | | | | |
| Ala | 6.69 | 7.62 | 0.005 | - | - | 1.09 | 2.43 | - | - | - | 0.30 | 0.034 | 120 | 1.6 |
| Gajibo | 5.71 | 6.18 | 0.100 | 17.25 | 10 | 1.84 | 3.48 | 32.67 | 99.70 | 10.6 | 0.40 | 0.042 | 125 | 0.6 |
| Gamboru | 6.25 | 7.25 | 0.100 | 19.50 | 10.66 | 1.60 | 2.61 | 34.47 | 99.50 | 7.6 | 0.25 | 0.027 | 67 | 0.5 |
| Jine | 5.83 | 7.85 | 0.005 | - | - | 1.79 | 7.30 | - | - | - | 0.34 | 0.038 | 80 | 0.4 |
| Kartara | 5.36 | 5.80 | 0.150 | 7.00 | 2.91 | 0.67 | 0.41 | 11.10 | 99.00 | 3.6 | 0.2[illegible] | 0.017 | 85 | 0.3 |
| Logomani | 6.51 | 7.66 | 0.005 | - | - | 0.06 | 80.70 | - | - | - | 0.30 | 0.025 | 165 | 0.6 |
| Marte | 5.78 | 7.85 | 0.005 | - | - | 1.69 | 0.41 | - | - | - | 0.35 | 0.040 | 240 | 0.4 |
| New Marte | 6.45 | 7.06 | 0.150 | 18.75 | 4.16 | 1.79 | 3.74 | 28.93 | 98.00 | 12.9 | 0.30 | 0.029 | 125 | 1.1 |
| Ngala | 5.92 | 6.52 | 0.050 | 18.75 | 4.25 | 0.61 | 1.56 | 25.25 | 99.80 | 6.2 | 0.45 | 0.050 | 175 | 0.5 |
| Abadam | 6.59 | 7.15 | 0.05 | 9.25 | 1.42 | 0.66 | 1.80 | 13.18 | 99.60 | 13.7 | 0.30 | 0.025 | 596 | 0.6 |
| Arege | 5.33 | 6.81 | 0.150 | 4.50 | 1.58 | 0.27 | 0.42 | 6.91 | 97.80 | 4.3 | 0.45 | 0.048 | 165 | 0.6 |
| Chingokili | 5.30 | 7.14 | 0.150 | 7.75 | 2.83 | 0.69 | 0.52 | 11.94 | 98.70 | 4.3 | 0.50 | 0.053 | 65 | 0.7 |
| Jabullam | 5.45 | 5.57 | 0.100 | 8.10 | 3.17 | 0.72 | 0.35 | 12.44 | 99.20 | 2.8 | 0.15 | 0.019 | 80 | 0.4 |
| Yau | 5.90 | 6.05 | 0.005 | 9.50 | 2.50 | 0.63 | 0.70 | 13.43 | 99.98 | 5.2 | 0.36 | 0.036 | 600 | 0.6 |
| Daya | 5.45 | 5.90 | 0.100 | 4.75 | 1.67 | 0.52 | 0.30 | 7.39 | 98.60 | 4.0 | 0.35 | 0.045 | 183 | 0.4 |
| Duwuri | 5.96 | 6.52 | 0.005 | 9.95 | 3.75 | 1.00 | 0.43 | 15.23 | 99.90 | 2.8 | 0.40 | 0.035 | 120 | 1.0 |
| Kudokurugu | 4.51 | 7.40 | 0.100 | 3.75 | 1.25 | 0.67 | 0.21 | 5.98 | 98.30 | 3.5 | 0.30 | 0.027 | 250 | 0.4 |
| Dikwa | 5.01 | 5.66 | 0.005 | 6.25 | 2.17 | 0.59 | 1.09 | 10.25 | 99.90 | 10.6 | 0.40 | 0.035 | 313 | 0.3 |
| KonCuga | 5.51 | 6.55 | 0.100 | 2.40 | 0.92 | 0.27 | 0.23 | 4.02 | 97.50 | 5.7 | 0.84 | 0.082 | 112 | 2.0 |
| Molay | 4.66 | 5.05 | 0.200 | 6.70 | 3.10 | 0.60 | 0.50 | 11.10 | 98.20 | 4.5 | 0.25 | 0.030 | 240 | 0.4 |
| Jere | 5.95 | 7.24 | 0.050 | 5.25 | 1.42 | 0.61 | 0.18 | 7.10 | 99.30 | 2.5 | 0.45 | 0.046 | 125 | 1.2 |
| Mafa | 5.45 | 5.57 | 0.100 | 9.90 | 3.30 | 0.64 | 0.37 | 14.31 | 99.30 | 2.5 | 0.05 | 0.005 | 80 | 0.6 |
| Maiduguri | 5.46 | 6.28 | 0.100 | 3.20 | 2.10 | 1.18 | 0.40 | 6.98 | 98.60 | 9.2 | 0.40 | 0.038 | 190 | 2.0 |
| Yerwa | 5.79 | 5.84 | 0.100 | 1.75 | 0.83 | 0.36 | 0.19 | 3.23 | 96.90 | 5.0 | 0.25 | 0.029 | 185 | 0.8 |

**TABLE 4:** **MEAN ($\bar{X}$) OF SOIL PROPERTIES**

| Soil Parent Material | Soil Properties | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % Clay | % Silt | % Sand | pH ($CaCl_2$) | pH ($H_2O$) | % Organic Carbon | % Total | Eff.CEC me/100g | Total P ppm | EC mmbos/cm at 25°C |
| Chad Lagoonal Deposit | 51.2 | 11.1 | 37.7 | 5.90 | 6.7 | 0.30 | 0.034 | 27.69 | 164 | 0.66 |
| Alluvial Sand Deposit | 32.4 | 13.2 | 54.4 | 5.96 | 7.2 | 0.36 | 0.036 | 11.58 | 301 | 0.56 |
| Lacustrine Sand | 28.5 | 13.4 | 58.1 | 5.31 | 6.5 | 0.35 | 0.036 | 9.50 | 143 | 0.78 |
| Fluvial Sand | 45.6 | 13.6 | 40.8 | 5.56 | 6.4 | 0.43 | 0.040 | 8.50 | 221 | 0.91 |
| Aeolian Sand | 28.4 | 9.1 | 62.5 | 5.46 | 6.2 | 0.29 | 0.030 | 7.65 | 145 | 1.20 |

The pH in water was consistently higher than the corresponding pH in salt solution indicating that the soils have net negative charges and hence anions like $NO_3^-$ will not be adsorbed on their exchange sites (Van Raiji and Peech, 1972). Four of the soils had pH above 7.50. These soils (Ala, Jine, Logomani and Marte) showed positive reaction (effervescence reaction on addition of dilute HCl) to carbonate test showing that they were calcerous. A look at Table 5a would show that on the average the upland and "fadama*" soils had about the same pH values. Generally, most of the soils were slightly acid to slightly alkaline in reaction.

Though the effect of parent material on the soil reaction did not appear to be pronounced, these soils derived from aeolian deposits were observed to be more acid in reaction than any of the others. On the whole it did not appear that the pH would limit production of these soils.

*"fadama" denotes lowland.

### 4.1.3. Organic Carbon and Total Nitrogen

The organic carbon content of the soils ranged between a minimum of 0.15% to a maximum of 0.84% (Table 3). Values for most soils were in the vicinity of 0.3%. The low levels of the organic matter might not be unrelated with the sparse vegetation and relatively low rainfall of the ecological zone from where the samples were collected. (Jones, 1973). Total N figures were low. The range for total N was between 0.005% and 0.082% and these might be linked with the generally low levels of organic matter.

### 4.1.4. Effective Cation Exchange Capacity (ECEC)

It has been noted that the cation exchange capacity (CEC) of most tropical soils are pH dependent (Coleman and Thomas, 1967). Therefore the neutral CEC determined at a particular pH which might not reflect the actual soil pH could be higher than the effective CEC. Because of the above observation the present trend is to use effective CEC in evaluating the fertility of tropical soils, (Balasubramanian et al., 1980). Hence the ECEC for each soil was obtained by summation of the exchangeable cations and exchangeable acidity instead of the neutral CEC. Attempts made to get plausible data on the exchangeable Ca and Mg for the four calcerous soils ended in excessively very high values indicating the presence of free carbonates or execess soluable salts. Since the determination of exchangeable Ca and Mg in this type of soil is discouraged (Walter, 1965), effective CEC of these soils were not obtained. The discussion on CEC is therefore based on twenty of the twenty-four soil samples under study.

The range for effective CEC was from 3.2 me/100g for Yerwa to 34.47 me/100g for Gamboru (Table 3). On average, these soils from Chad Lagoonal complex/deposits which were shown to have highest clay contents had also highest ECEC with a value of 27.69 me/100g (Table 4). The same trend was not observed among soils derived from alluvial sand, fluvial sand and lacustrine sand deposits. The soils derived from fluvial sand which had highest clay content among the three appeared to possess lowest ECEC.

### 4.1.5. Exchange Acidity

This value ranged from 0.005 (trace) to a maximum of 0.2 me/100g. Majority of the soils exhibited exchangeable acidity of 0.1 me/100g and below (Table 3). It would therefore appear that the problem of exchange acidity would not be severe in these soils.

### 4.1.6. Total Phosphorus (P)

Many of the soils had relatively low total P values - ranging from a minimum of 65 ppm to a maximum of 600 ppm (Table 3). "Fadama" soils generally tended to have higher P contents than the upland soils with average values of 276 ppm and 123 ppm respectively (Table 5a).

### 4.1.7. Electrical Conductivity

Generally the soils exhibited low electrical conductivity. The minimum was 0.21 mmhos/cm. at 25$^{o}$C and maximum was 2.02 mmhos/cum. It therefore seemed that the problem of salinity would not arise in the soils studied if they were not mis-

TABLE 5a: THE MEANS ($\bar{X}$) OF VALUES OF SOIL PROPERTIES FOR "FADAMA" & UPLAND SOILS

| | Soil Properties | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | % Clay | % Silt | % Sand | pH $CaCl_2$ | $H_2O$ | Org.C % | Total N % | ECEC me/100g | EA me/100g | Total P ppm | EC mmhos/ at 25oC |
| "Fadama" | 52 | 13.5 | 5.4 | 5.40 | 6.86 | 0.33 | 0.03 | 15.20 | 0.09 | 276 | 0.70 |
| Upland | 29 | 10.3 | 60.7 | 5.20 | 6.43 | 0.33 | 0.03 | 14.00 | 0.09 | 123 | 0.83 |

TABLE 5b: THE MEAN ($\bar{X}$) OF VALUES OF N INDICES, N UPTAKE AND DRY MATTER FOR "FADAMA" AND UPLAND SOILS

| | N-Index Method (ppmN) | | | N Uptake (mg/pot) | | | | Dry matter (g/pot) | |
|---|---|---|---|---|---|---|---|---|---|
| | A* | B* | C* | 1st crop | 2nd crop | 3rd crop | Total | 1st crop | Total |
| "Fadama" | 303 | 66 | 142 | 28 | 14.3 | 12 | 543 | 1.8 | 3.3 |
| Upland | 307 | 68 | 174 | 26 | 16.0 | 13 | 550 | 1.7 | 3.0 |

A* Acid $KMnO_4$ procedure

B* Alkaline $KMnO_4$ procedure

C* Incubation method

managed as none of these soils had electrical conductivity value up to 4 mmhos/cm at 25°C above which value it is accepted generally that salinity problem would set in (Richards, 1969).

4.1.8. Exchangeable Sodium Percent (ESP)

The range of the ESP was between a minimum of 2.5% and a maximum of 13.6% (Table 3). The maximum value was below the value of 15% accepted by the U.S. Salinity laboratory staff as alkali soil (Richards, 1969). The soils were therefore non-alkali types.

4.1.9. Percent Base Saturation (% B.S.)

The percent base saturation on effective CEC basis was above 90% with a mean of 99% (Table 3) for all the soils. Therefore the exchange complexes of these soils were highly saturated with bases.

## 4.2. THE N-SUPPLYING ABILITY OF THE SOILS

The maximum values of N uptake from the first, second and third crops of wheat were 61, 26 and 19 mg/pot, respectively, for upland soils (Table 8). The minimum values for the same soils were 17, 9 and 9 mg/pot (first, second and third crops respectively). The mean values of N uptake from the first, second and third crops were 27, 16 and 12 mg/pot, respectively. The maximum, minimum and mean values of total N uptake for these soils were 96, 35 and 55 mg/pot respectively.

For "Fadama" soils, the maximum values of N uptake from the first, second and third crops for these soils were 28, 15 and 13 mg/pot respectively. The maximum, minimum and mean values of total N uptake were 78, 40 and 57 mg/pot respectively. None of the maximum values of N uptake from the first crop was close to 115 mg/pot noted by Purvis and Leo (1961) from their first crop of wheat grown in the greenhouse. Similarly the mean values of N uptake of 27 and 28 mg/pot from the first crop for upland and "fadama" coils, respectively, were in no way near the average value of N uptake of 65 mg/pot reported by Purvis and Leo (1961). Also the mean value of N uptake of 25 mg/pot from the third crop observed by Purvis and Leo (1961) was quite

**TABLE 6:** THE N VALUES (ppm) FOR THE AVAILABILITY INDICES

| Location | Acid $KMnO_4$ | Alk-$KMnO_4$ | Incubation |
|---|---|---|---|
| Abadam | 240 | 44 | 217 |
| Ala | 300 | 47 | 210 |
| Arege | 450 | 86 | 126 |
| Chingokili | 480 | 86 | 105 |
| Daya | 380 | 25 | 301 |
| Dikwa | 160 | 27 | 140 |
| Duwuri | 345 | 23 | 186 |
| Gajibo | 380 | 119 | 185 |
| Gamboru | 260 | 74 | 91 |
| Jabullam | 185 | 205 | 182 |
| Jere | 420 | 118 | 217 |
| Jine | 362 | 35 | 189 |
| Kartara | 160 | 57 | 203 |
| Konduge | 760 | 48 | 144 |
| Kudokurugu | 260 | 80 | 46 |
| Logomani | 205 | 107 | 179 |
| Mafa | 47 | 51 | 189 |
| Marte | 360 | 69 | 185 |
| Maiduguri | 350 | 70 | 182 |
| Molay | 280 | 74 | 67 |
| New Marte | 280 | 52 | 154 |
| Ngala | 400 | 104 | 102 |
| Yau | 306 | 53 | 56 |
| Yerwa | 280 | 16 | 91 |
| Mear | 319 | 67 | 156 |

TABLE 7: THE MEAN OF THE VALUES OF N INDICES, N UPTAKE AND DRY MATTER FOR THE SOILS FROM THE FIVE GROUPS OF PARENT MATERIALS

| Soil Group | N Index Methods (ppm N) | | | N Uptake (mg/pot) | | | | Dry Matter (g/pot) | |
|---|---|---|---|---|---|---|---|---|---|
| | Acid $KMnO_4$ | Alk. $KMnO_4$ | Incubation | 1st crop | 2nd crop | 3rd crop | Total | 1st crop | Total |
| Chad Lagoonal Deposit | 301 | 73 | 166 | 30 | 20 | 12 | 62 | 1.4 | 2.8 |
| Alluvial Sand Deposit | 352 | 84 | 147 | 38 | 26 | 15 | 79 | 2.4 | 4.2 |
| Lacustrin Sand Deposit | 329 | 43 | 178 | 29 | 18 | 13 | 60 | 1.7 | 3.5 |
| Fluvial Sand Deposit | 346 | 50 | 134 | 25 | 17 | 13 | 55 | 1.4 | 2.8 |
| Aeolian Sand Deposit | 274 | 46 | 161 | 23 | 14 | 10 | 47 | 1.2 | 3.0 |
| Mean | 322 | 59 | 137 | 22 | 17 | 13 | 61 | 1.6 | 3.3 |

higher than the mean N uptake of 12 and 13 mg/pot (for upland and "fadama" soils, respectively) noted from the third crop of wheat in this study. However, the soils studied by Purvis and Leo (1961) had higher total N content (0.13% mean) than those under present study which had an average total N content of 0.06%. Secondly while sixteen seeds of wheat per pot of 4kg were planted in this investigation, Purvis and Leo (1961) planted ten seeds of wheat per pot of 2kg.

Apart from the work of Purvis and Leo (1961) the basis for comparison between the N-supplying ability of these soils from Lake Chad Basin and N-supplying power of soils in U.S.A. or India cited in literature review did not seem to exist. The actual values of the N-supplying ability of those soils were not reported rather the correlation relationships between the values of N-supplying power and some measures of N-supplying ability (which differed from the indicators of N-supplying ability in this tudy) were reported. Moreover, the studies of the earlier workers differed from the present study in one or more of the following -

soil type, test crop, where the crops were grown (field or greenhouse) treatment, for instance, application of fertilizer.

Generally, the N-supplying ability (N uptake) of these soils decreased from the first to the third crop of wheat. The crops started showing slight symptoms of N deficiency from the second crop of wheat. The third crop developed N deficiency symptoms within two weeks of emergence on all soils and symptoms became more severe with time. The respective mean value of percentage N in crops for the first, second and third crops were 2.06, 1.60 and 1.20. The N-supplying power of these soils was far from being large possibly due to the low native N content of the soils.

## 4.3. SOIL-N AVAILABILITY INDICES

Tables 6 and 7 show data of N-availability indices for the 24 soils and the mean of the N-indices and yields (N uptake and dry matter) for the five groups of soils according to their parent material. Data of the N indices and yields when soils were grouped according to their topographical

TABLE 8: N-AVAILABILITY INDICES, N UPTAKE AND DRY MATTER FOR UPLAND SOILS

| Site | N Index Methd (ppm) | | | N Uptake (mg/pot) | | | | Dry Matter (g/pot) | |
|---|---|---|---|---|---|---|---|---|---|
| | A* | B* | C* | 1st crop | 2nd crop | 3rd crop | Total | 1st crop | Total |
| Daya | 381 | 25 | 301 | 35 | 23 | 14 | 72 | 2.1 | 4.0 |
| Chingokili | 480 | 86 | 105 | 51 | 26 | 19 | 96 | 3.0 | 5.2 |
| Gajibo | 380 | 119 | 185 | 61 | 12 | 13 | 86 | 1.4 | 5.2 |
| Jabullam | 185 | 205 | 231 | 35 | 16 | 12 | 64 | 3.0 | 4.7 |
| Jere | 420 | 32 | 126 | 33 | 21 | 19 | 73 | 1.8 | 3.2 |
| Jine | 260 | 35 | 189 | 15 | 14 | 10 | 39 | 1.7 | 3.5 |
| Kantara | 160 | 57 | 203 | 24 | 20 | 17 | 61 | 1.0 | 2.1 |
| Konduga | 760 | 48 | 144 | 18 | 9 | 10 | 37 | 1.1 | 2.1 |
| Logomani | 205 | 107 | 179 | 21 | 13 | 9 | 44 | 2.0 | 3.7 |
| Mafa | 47 | 51 | 182 | 37 | 9 | 9 | 55 | 1.6 | 2.7 |
| Maiduguri | 350 | 70 | 154 | 17 | 16 | 11 | 44 | 1.8 | 2.8 |
| Yerwa | 280 | 16 | 91 | 18 | 17 | 10 | 35 | 1.0 | 2.1 |
| Mean | 326 | 71 | 174 | 27 | 16 | 12 | 55 | 1.8 | 3.4 |

A* Acid $KMnO_4$ Method

B* Alkaline $KMnO_4$ Method

C* Incubation.

**TABLE 9: N-AVAILABILITY INDICES, N UPTAKE AND DRY MATTER FOR "FADAMA" SOILS**

| Site | N-Index Method (ppm) | | | N Uptake (gm/pot) | | | | Dry Matter (g/pot) | |
|---|---|---|---|---|---|---|---|---|---|
| | A* | B* | C* | 1st crop | 2nd crop | 3rd crop | Total | 1st crop | Total |
| Abadam | 240 | 44 | 217 | 27 | 14 | 13 | 53 | 1.5 | 2.9 |
| Ala | 300 | 37 | 210 | 19 | 17 | 12 | 48 | 1.3 | 2.9 |
| Arege | 450 | 27 | 126 | 41 | 16 | 16 | 71 | 2.3 | 4.1 |
| Dikwa | 160 | 23 | 140 | 27 | 18 | 15 | 60 | 1.4 | 3.0 |
| Duwuri | 345 | 74 | 186 | 28 | 17 | 17 | 62 | 1.4 | 3.6 |
| Gamboru | 260 | 80 | 91 | 17 | 10 | 13 | 40 | 2.3 | 2.4 |
| Kudokurugu | 260 | 140 | 46 | 24 | 14 | 15 | 52 | 1.3 | 2.9 |
| Ngala | 400 | 106 | 185 | 30 | 11 | 11 | 52 | 1.7 | 3.7 |
| Marte | 360 | 69 | 67 | 37 | 9 | 9 | 55 | 1.7 | 2.6 |
| New Marte | 280 | 52 | 189 | 22 | 11 | 11 | 43 | 1.7 | 3.2 |
| Yau | 306 | 53 | 56 | 33 | 16 | 15 | 63 | 1.7 | 3.0 |
| Molay | 280 | 74 | 106 | 31 | 31 | 16 | 78 | 2.3 | 4.0 |
| Mean | 303 | 56 | 134 | 28 | 15 | 13 | 57 | 1.7 | 3.2 |

A* Acid $KMnO_4$ Method

B* Alkaline $KMnO_4$ Method

C* Incubation procedure.

positions (upland or "fadama") are presented on Tables 8 and 9.

The mean value of $NH_4$-N extractable by the acid $KMnO_4$ method for the 24 soils was 319 ppm. The average value obtained by the alkaline $KMnO_4$ procedure was 67 ppm. The mean value of the total N mineralized by incubation was 156 ppm. When soils were grouped according to positions the average values of $NH_4$-N extractable by acid $KMnO_4$ were 326 and 303 ppm for upland and "fadama" soils respectively (Tables 8 and 9). Average values of $NH_4$-N released by oxidation in alkaline $KMnO_4$ were 71 and 56 ppm for upland and "fadama" soils respectively. The mean values of total N mineralized after 14 days of incubation for upland and "fadama" soils were, respectively, 174 and 134 ppm.

For both upland and "fadama" soils the total N uptake progressively decreased from the first to the third crop of wheat. The mean values of N uptake from the first, second and third crops were 27, 16 and 12 mg/pot, respectively (for upland soil). For the "fadama" soils (Table 9) the average values of N uptake for the first, second and third crops were respectively, 28, 15 and 13 mg/pot.

4.3.1. Correlation Relationship Between N-Availability Indices and Yields and Regression of Yields on N Indices

Data of the correlation relationships between each of the methods of soil-N availability and the actual power of the soils to supply nitrogen are shown on Tables 10a and 10b.

4.3.2. Acid $KMnO_4$ and Yields

When the twenty-four soils were put together, the $NH_4$-N extractable by acidified $KMnO_4$ showed positive but non-significant relationship with the N uptake and dry matter ($r$ = 0.13; 0.08, 0.03, 0.12; 0.23 and 0.33 for 1st, 2nd, 3rd total N uptake and 1st and total dry matter, respectively.

The correlation coefficients between $NH_4$-N released by oxidation in acidified $KMnO_4$ and N uptake and dry matter for soils derived from Chad Lagoonal deposits were relatively higher than the values obtained when the 24 soils were grouped together. Though not significant, the highest correlation coefficients were observed between this N-index method and N uptake from the second crop of wheat (r = 0.54) and the total dry matter (r = 0.51).

Good correlations were noted between $NH_4$-N extracted by acid $KMnO_4$ and N uptake from the first crop and third crop of wheat (r = 0.81* and 0.85*, respectively) for soils derived from alluvial sand deposits. The observations made here were in agreement with the earlier findings of Stanford and Smith (1978).

For soils derived from aeolian sand deposits, high but non-significant correlation coefficients were noted between acid $KMnO_4$ extraction procedure and N uptake from second and third crops of wheat (r = 0.71 and 0.73, respectively). The regression lines of N uptake from the 1st and 3rd crops of wheat on $NH_4$-N released by oxidation in acidified $KMnO_4$ are shown in Figures 2 and 3. The regression equations are also shown in the Appendix.

Correlation and regression analysis were not carried out for soils derived from lacustrine sand, and fluvial sand deposits on individual groups as

Fig.2 Regression line of N uptake(1st Crop)on $NH_4$-N released by acid $KMnO_4$ for soils derived from alluvial *sand deposits*

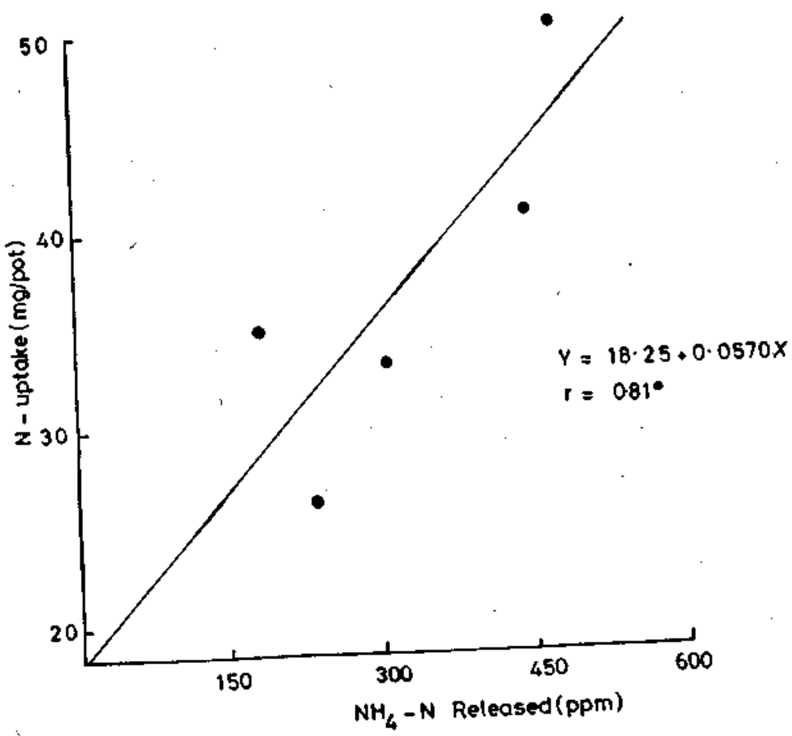
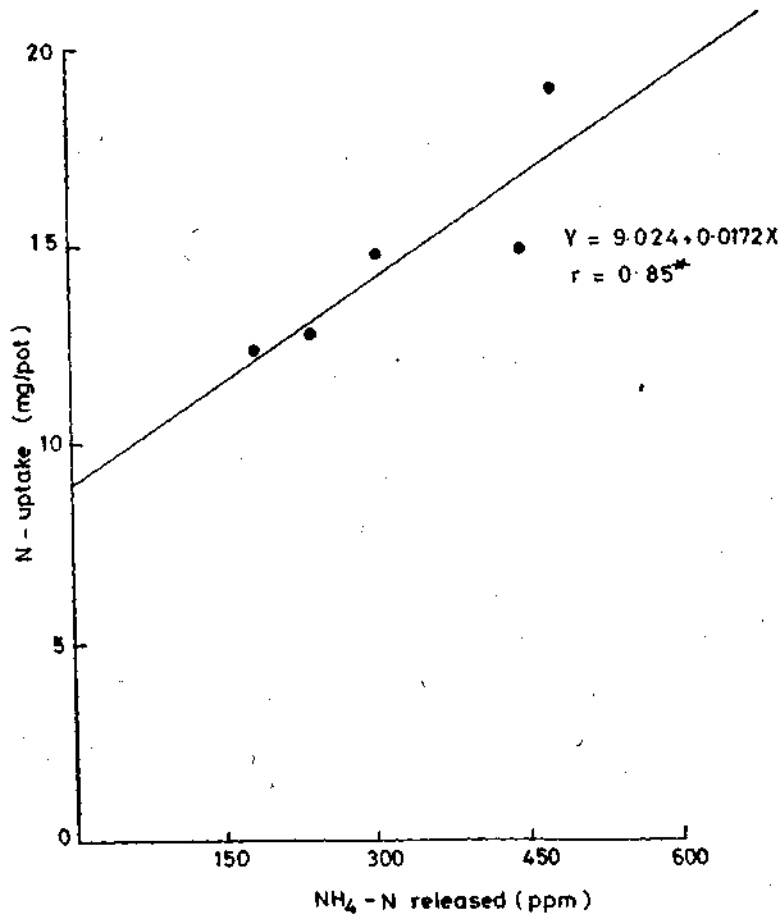


Fig.3 : Regression line of N uptake ( 3rd crop ) on $NH_4$ - N released by oxidation in acid $KMnO_4$ for soils derived from alluvial sand deposits.



each had only three observations. When the samples are very small, the variances for estimated intercept and slope are very large and hence highly biased (Johnston, 1972).

When soils were grouped on basis of their topographical positions ("fadama" or upland) the correlation relationships between $NH_4$-N extracted by acid $KMnO_4$ and N uptake (1st crop) and total dry matter were significant (r = 0.60* and 0.52*, respectively) for "fadama" soils (Table 10b).

Regression lines of N uptake and dry matter on $NH_4$-N released by acid $KMnO_4$ are shown in Figures 4 and 5. For the upland soils there were very poor correlation relationships between this acid $KMnO_4$ extraction procedure and yield.

### 4.3.3. Correlation Relationship Between Alkaline $KMnO_4$ and Yield and Regression of Yield on $NH_4$-N Extracted by the Alkaline $KMnO_4$ Procedure

Correlation coefficients between $NH_4$-N released by oxidation in alkaline $KMnO_4$ solution and yields (N uptake and dry matter) were generally low no matter how the soils were grouped (Tables 10a and 10b). The generally low correlation relationships

Fig. 4 : Regression line of N Uptake ($1^{st}$ crop) on $NH_4$-N released by acidified $KMnO_4$ ('Fadama' soil)

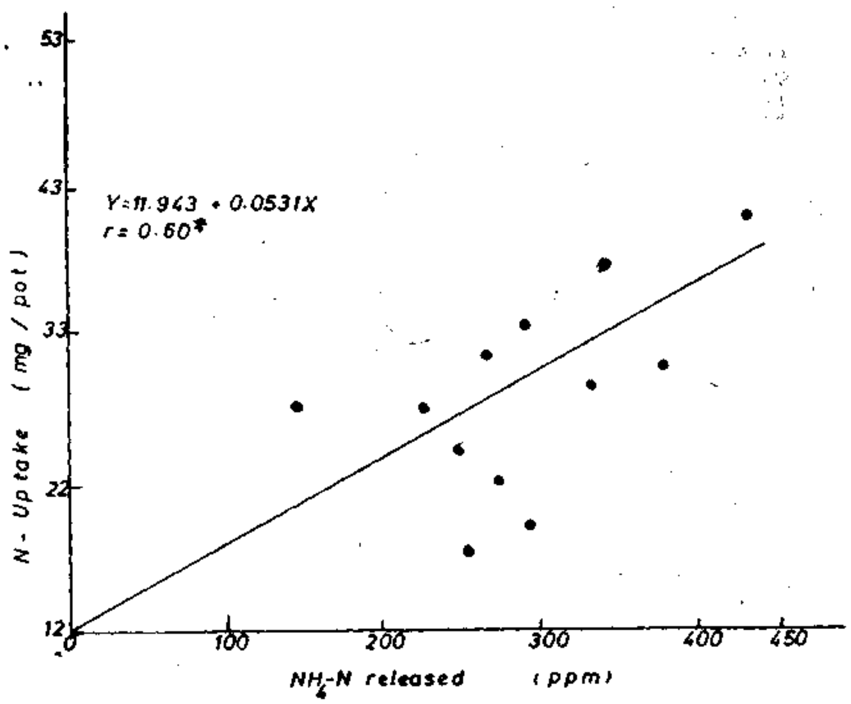


Fig.5: Regression of dry matter (total) on $NH_4$-N released by acidified $KMnO_4$ for 'fadama' soils

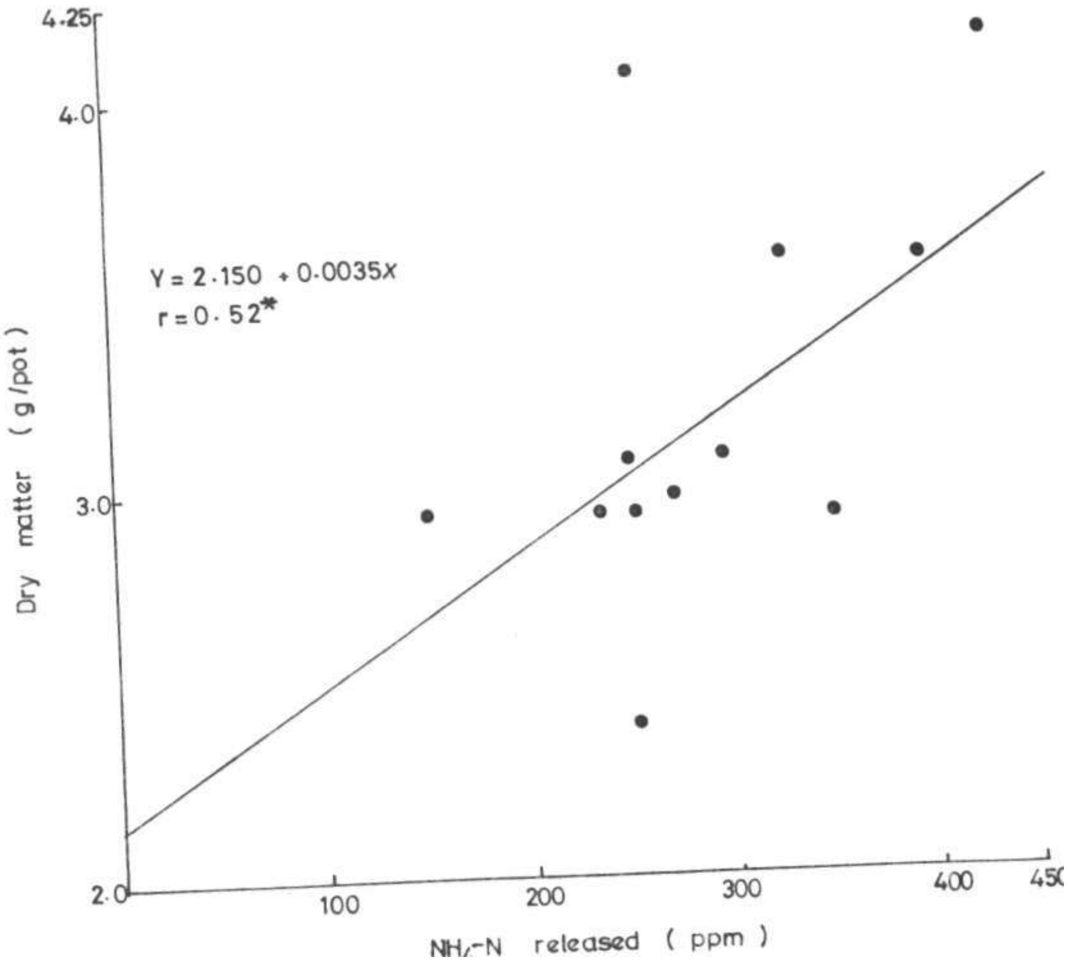


TABLE 10a: CORRELATION COEFFICIENTS BETWEEN N INDICES, N UPTAKE AND DRY MATTER FOR VARIOUS SOIL GROUPS

| Soil Group | Variable | N-Index Method: Acid $KMnO_4$ | Alk. $KMnO_4$ | Incubation |
|---|---|---|---|---|
| A | N Uptake (1st crop) | 0.13 | 0.2 | -0.01 |
| | " (2nd crop) | 0.08 | 0.24 | -0.04 |
| | " (3rd crop) | 0.03 | 0.04 | -0.03 |
| | " ( Total ) | 0.12 | 0.14 | -0.12 |
| | Dry matter (1st crop) | 0.23 | 0.21 | -0.22 |
| | " ( Total ) | 0.33 | 0.24 | -0.06 |
| B | N Uptake (1st crop) | 0.34 | 0.12 | 0.44 |
| | " (2nd crop) | 0.54 | 0.39 | -0.46 |
| | " (3rd crop) | 0.39 | 0.07 | 0.36 |
| | " ( Total ) | 0.24 | 0.25 | 0.03 |
| | Dry matter (1st crop) | 0.04 | 0.27 | -0.59 |
| | " ( Total ) | 0.51 | 0.59 | 0.33 |
| C | N Uptake (1st crop) | 0.81* | 0.64 | -0.43 |
| | " (2nd crop) | 0.56 | 0.44 | -0.35 |
| | " (3rd crop) | 0.85 | 0.39 | 0.64 |
| | " ( Total ) | 0.67 | 0.22 | -0.46 |
| | Dry matter (1st crop) | 0.25 | 0.68 | 0.13 |
| | " ( Total ) | 0.41 | 0.54 | 0.66 |
| D | N Uptake (1st crop) | 0.44 | 0.42 | 0.53 |
| | " (2nd crop) | 0.71 | 0.29 | 0.53 |
| | " (3rd crop) | 0.73 | 0.23 | -0.26 |
| | " ( Total ) | 0.22 | 0.63 | 0.30 |
| | Dry matter (1st crop) | 0.22 | 0.62 | 0.46 |
| | " ( Total ) | 0.35 | 0.42 | 0.45 |

* : Significant at 5%

A : 24 soils grouped together

B : Soils derived from Chad Lagoonal deposits (9 samples)

C : Soils derived from Alluvial sand (5 samples)

D : Soils derived from Aeolian sand (4 samples)

TABLE 10b: CORRELATION COEFFICIENTS BETWEEN THE N INDICES, N UPTAKE AND DRY MATTER FOR "FADAMA" AND UPLAND SOILS

| Soil Grouping | Variable | N-Index Method | | |
|---|---|---|---|---|
| | | Acid $KMnO_4$ | Alk. $KMnO_4$ | Incubation |
| Upland | N Uptake (1st crop) | 0.07 | 0.20 | 0.06 |
| | " (2nd crop) | 0.10 | 0.06 | -0.30 |
| | " (3rd crop) | 0.20 | -0.02 | -0.09 |
| | " ( Total ) | 0.30 | 0.14 | -0.02 |
| | Dry matter (1st crop) | 0.24 | 0.23 | 0.08 |
| | " ( Total ) | 0.22 | -0.45 | 0.24 |
| "Fadama" | N Uptake (1st crop) | 0.60* | 0.04 | 0.30 |
| | " (2nd crop) | 0.16 | 0.16 | -0.03 |
| | " (3rd crop) | 0.20 | -0.46 | 0.10 |
| | N Uptake ( Total ) | 0.46 | -0.08 | 0.20 |
| | Dry matter (1st crop | 0.32 | 0.22 | 0.32 |
| | " ( Total ) | 0.52* | 0.34 | 0.20 |

* Significant at 5%

noted between this N-index method and yields are in contrast with the earlier observations of Kalbande (1964), Munson and Stanford (1955). However, the low correlation relationships between the N-index method and yield noted above were in agreement with the report of Jenkinson (1968), Keeney and Bremner (1966).

Although the alkaline $KMnO_4$ extraction procedure had no significant correlation with yield no matter how the soils were grouped in relation to parent material, the relation was poorer and more erratic when the soils were grouped as "fadama" or upland or when there was no grouping. This observation could be due to swamping effect, (Clarke, 1969). The soils not only varied in type but also in their sources of origin. The amount of mineral nitrogen released from organic N is known to be affected by soil texture and type of clay among other factors (Kiochro et al., 1976; Opuwaribo and Odu, 1978; Jaiyebo and Moore, 1963; Jaiyebo, 1967). Possibly those soils whose N uptake by the crop and dry matter had little or no bearing with the $NH_4$-N released by alkaline $KMnO_4$ dominated the effect of those that had slightly fairer relationships. Secondly organic N mineralization is a function of several factors such as aeration (Nelson and Tisdale, 1966), microbial number (Meiklejohn, 1962), apart from the afore-mentioned factors. No chemical extraction procedure has been shown to measure the dynamic relationships existing among the soil organic N, mineral N and these factors that influence soil-N mineralization. Lack of very good relationships between $NH_4$-N extracted by either of the chemical procedures and N uptake when these different soil types were grouped together could thus be explained.

### 4.3.4. Correlation Relationships Between Microbiological Method of Soil N Availability (Incubation) and Yields

No matter how these soils were grouped, the correlation coefficients between mineralized-N and N-uptake values or dry matter were extremely poor. They did not at all approach the high coefficients reported by Robinson (1968a), Kalbande (1964), or Keeney and Bremner (1966). It could be that the manual openings of the incubation bottles every other day to let in some air due to lack of Rescap or Polyethylene fil. (Plastic closure device which is very effective in maintaining aerobic conditions and preventing loss of moisture from soil during incubation) did detract from the efficiency of the methodology (Bremner, 1965b). The effect of oxygen in the breakdown of organic residues needs little or no elaboration (Kempner, 1937; Greenwood, 1961; Nelson and Tisdale, 1966; and Woldendorp, 1963).

Possibly the air enclosed in the incubation bottle every other day might have been quite inadequate for the activities of the micro-organisms in the breakdown of soils organic matter before the next opening of the bottles. This could have led to reduction of nitrate (already produced) to elemental N and nitrous oxide (Woldendorp, 1963) resulting in unreproducible results.

## 4.4. CORRELATION RELATIONSHIPS BETWEEN N-AVAILABILITY INDICES AND SOME SOIL PROPERTIES (ORGANIC CARBON AND TOTAL N)

The correlation coefficients between each of the N indices and organic carbon and total N are shown in Tables 11 and 12.

TABLE 11: CORRELATION COEFFICIENTS BETWEEN N INDICES ORGANIC CARBON AND TOTAL N WHEN SOILS WERE GROUPED ON PARENT MATERIAL

| Parent Material | Soil Parameter | Correlation Coefficient |
|---|---|---|
| Chad Lagoonal Deposit | Acid $KMnO_4$ and organic carbon | 0.87** |
| | Acid $KMnO_4$ and total N | 0.93** |
| | Alkaline $KMnO_4$ and organic carbon | 0.45 |
| | Alkaline $KMnO_4$ and total N | 0.29 |
| | Incubation and organic carbon | 0.05 |
| | Incubation and total N | -0.08 |
| Alluvial sand Deposit | Acid $KMnO_4$ and org. C | 0.96** |
| | Acid $KMnO_4$ and total N | 0.99** |
| | Alk. $KMnO_4$ and org. C | -0.71 |
| | Alk. $KMnO_4$ and total N | -0.04 |
| | Incub. and org. C | -0.72 |
| | Incub. and total N | -0.73 |
| Aeolian sand Deposit | Acid $KMnO_4$ and org. C | 0.98** |
| | Acid $KMnO_4$ and total N | 0.99** |
| | Alk. $KMnO_4$ and org. C | 0.03 |
| | Alk. $KMnO_4$ and total N | -0.10 |
| | Incub. and org. C | -0.42 |
| | Incub. and total N | -0.53 |

** Significant at 1%

* Significant at 5%

TABLE 12: CORRELATION COEFFICIENTS BETWEEN N INDICES AND ORGANIC CARBON AND TOTAL N FOR "FADAMA" AND UPLAND SOILS

| Soil Parameter | Correlation Coefficients | | |
|---|---|---|---|
| | "Fadama" Soils | Upland Soils | All Soils |
| Acid $KMnO_4$ and organic carbon | 0.90** | 0.97** | 0.34 |
| Acid $KMnO_4$ and total N | 0.96** | 0.96** | 0.36 |
| Alkaline $KMnO_4$ and organic carbon | 0.45 | 0,46 | -0.34 |
| Alkaline $KMnO_4$ total N | 0.43 | 0.45 | 0.24 |
| Incubation and organic carbon | 0.09 | -0.22 | -0.03 |
| Incubation and total N | 0.02 | -0.25 | -0.20 |

** Significant at 1%

* Significant at 5%

### 4.4.1. Acid $KMnO_4$ and Organic C and Total N

Very high correlation existed between acid $KMnO_4$-extractable $NH_4$-N and organic carbon for soils derived from Chad Lagoonal deposits, alluvial sand deposits and aeolian sand deposits (r = 0.87**; 0.96** and 0.98**, respectively, Table 11). Similar high correlation relations were also noted between this chemical index of soil N availability and organic carbon for upland and "fadama" soils (r = 0.90** and 0.97** respectively, Table 12).

These observations were in line with the results of Robinson (1969a), Smith and Stanford (1971) though Smith and Stanford evaluated hot 0.1M $CaCl_2$-extractable soil organic N and total carbon instead of acidified $KMnO_4$ and organic carbon. Very high correlation existed also between $NH_4$-N extracted by acidified $KMnO_4$ and total N for soils derived from Chad Lagoonal deposits, alluvial sand deposits, aeolian sand deposits, "fadama" and upland soils (r = 0.93**; 0.99**; 0.99**; 0.96** and 0.96**, respectively). Similar observations were also made by Robinson (1968c), Smith and Stanford (1971). Regression lines and equations of organic carbon on acid $KMnO_4$-extractable $NH_4$-N are depicted on Figures 6, 7, 8, 9 and 10. Those of total N on $NH_4$-N are shown on Figures 11, 12, 13, 14 and 15.

### 4.4.2. Relationship Between $KMnO_4$ Extractable $NH_4$-N, Organic Carbon and Total N

The correlation coefficients between alkaline $KMnO_4$-extractable-N and organic carbon or total N (Tables 11 and 12) were not significant. These observations were quite in contrast with the report of Keeney reported by Stanford (1978). However, the high correlation coefficients credited to Keeney was between alkaline $KMnO_4$ $NH_4$-N and total organic N and not total (inorganic and organic) N. The non-significant correlation coefficients observed here seemed to agree with the results of Robinson (1968a) who noted low correlation between $NH_4$-N mineralized and organic carbon and total N ($r = 0.53$ and $0.56$, respectively).

Fig.6 Regression line of organic carbon on $NH_4$-N released by acidified $KMnO_4$ for soils derived from Chad lagoonal deposits.

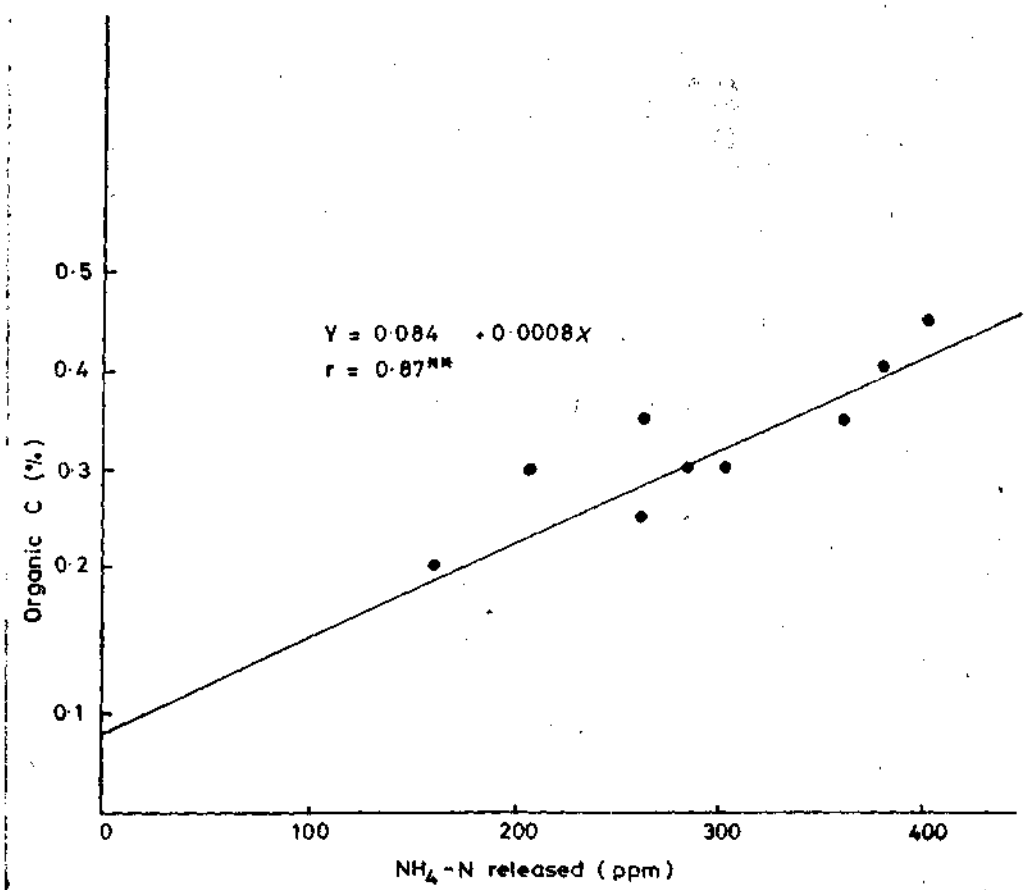


Fig. 7 : Regression line of organic carbon $NH_4^+$-N released by acid $KMnO_4$ for soils derived from alluvial sand deposits

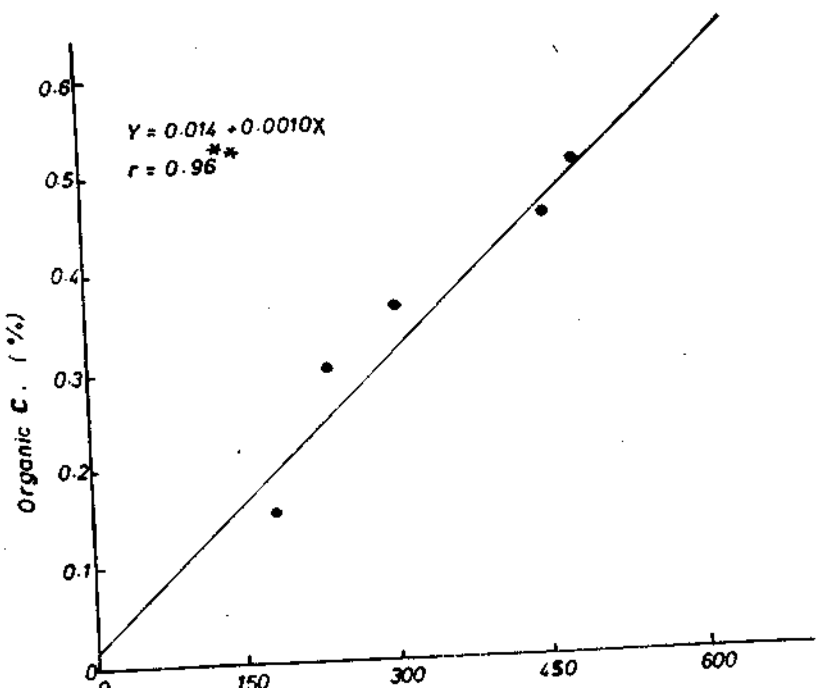


Fig. 8 : Regression line of organic carbon on $NH_4$-N released by acid $KMnO_4$ for soils derived from aeolian sand deposits

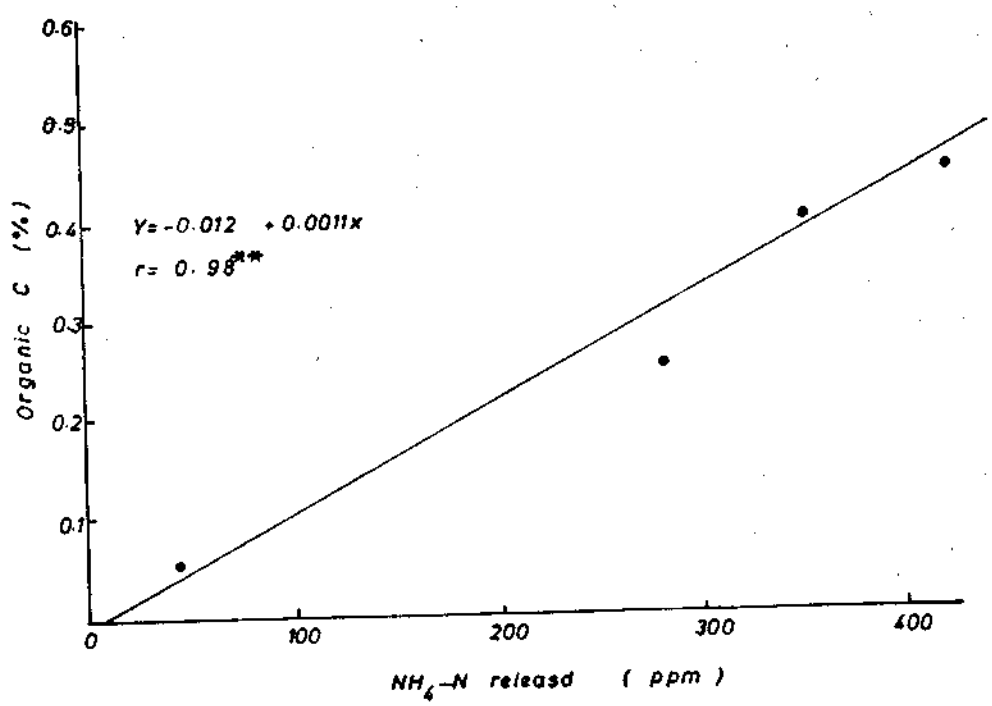


Fig. 9 : Regression line of organic carbon ('Fadama' soils) on $NH_4$- N released by acidified $KMnO_4$

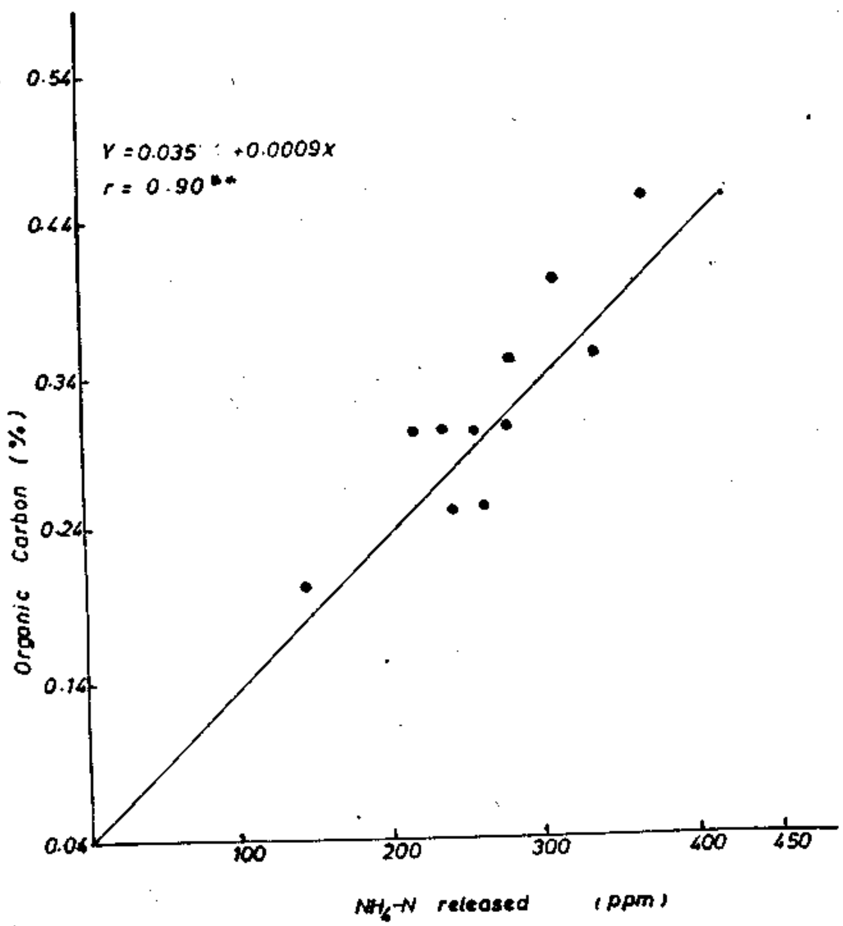


Fig. 10 : Regression line of organic carbon on $NH_4$-N released by acidified $KMnO_4$ (Upland soils)

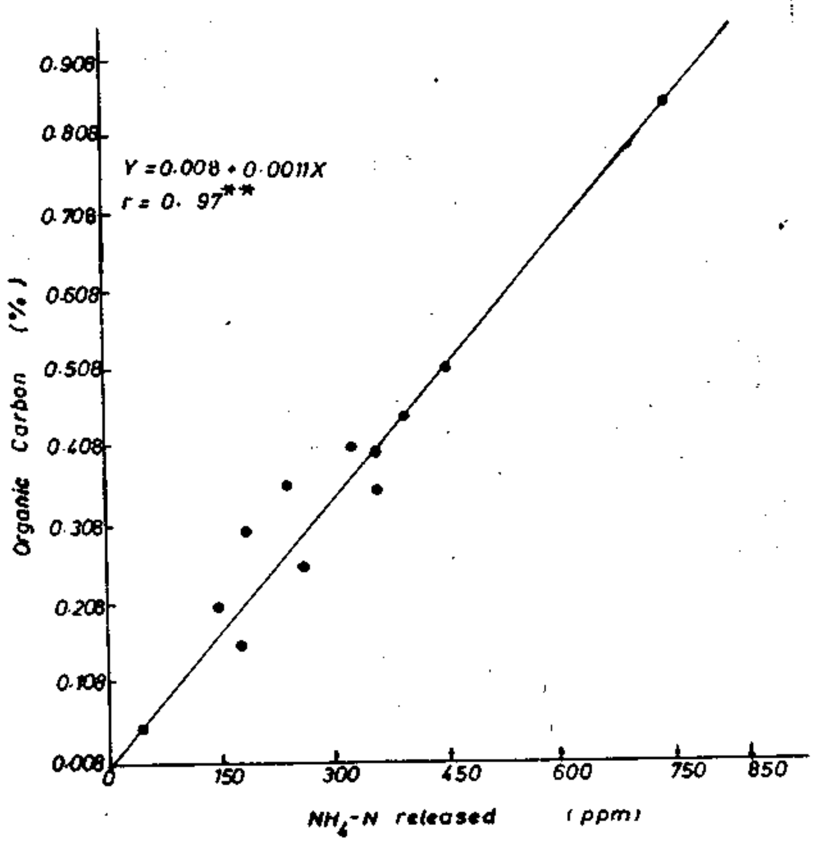


Fig. 11 : Regression line of total N (%) on $NH_4$-N released by acid $KMnO_4$ for soils derived from Chad lagoonal deposits

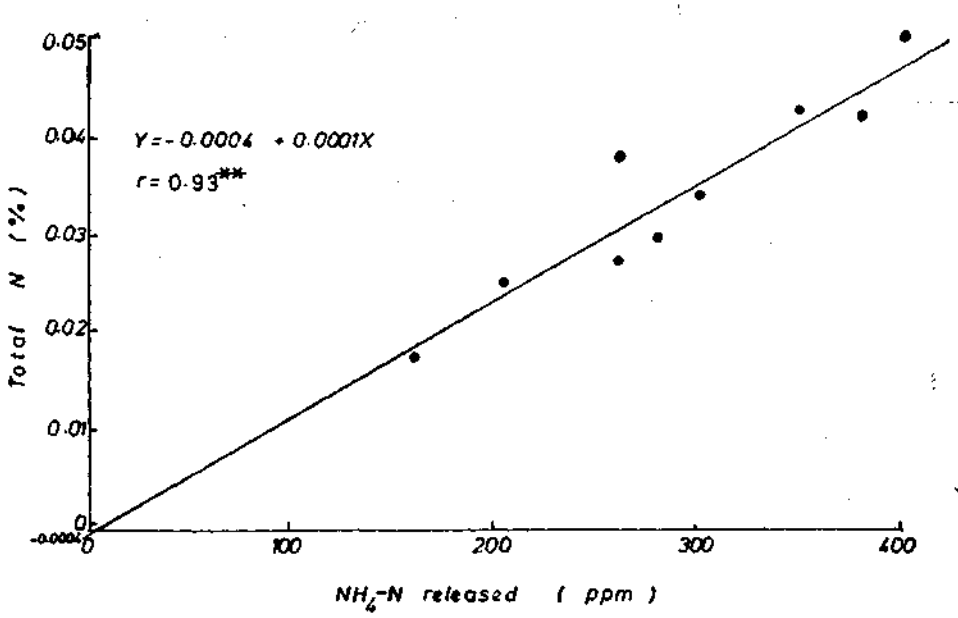


*Fig.12: Regression line of total N on $NH_4$-N released by acid $KMnO_4$ for soil derived from alluvial sand deposits*

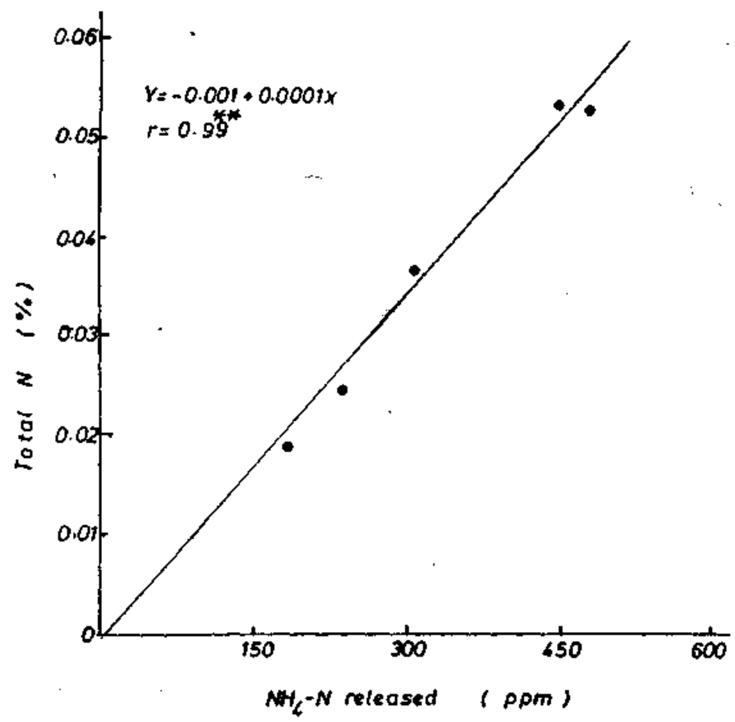


Fig. 13 : Regression of total N on $NH_4$-N released by acid $KMnO_4$ for soils derived from aeolian sand deposits

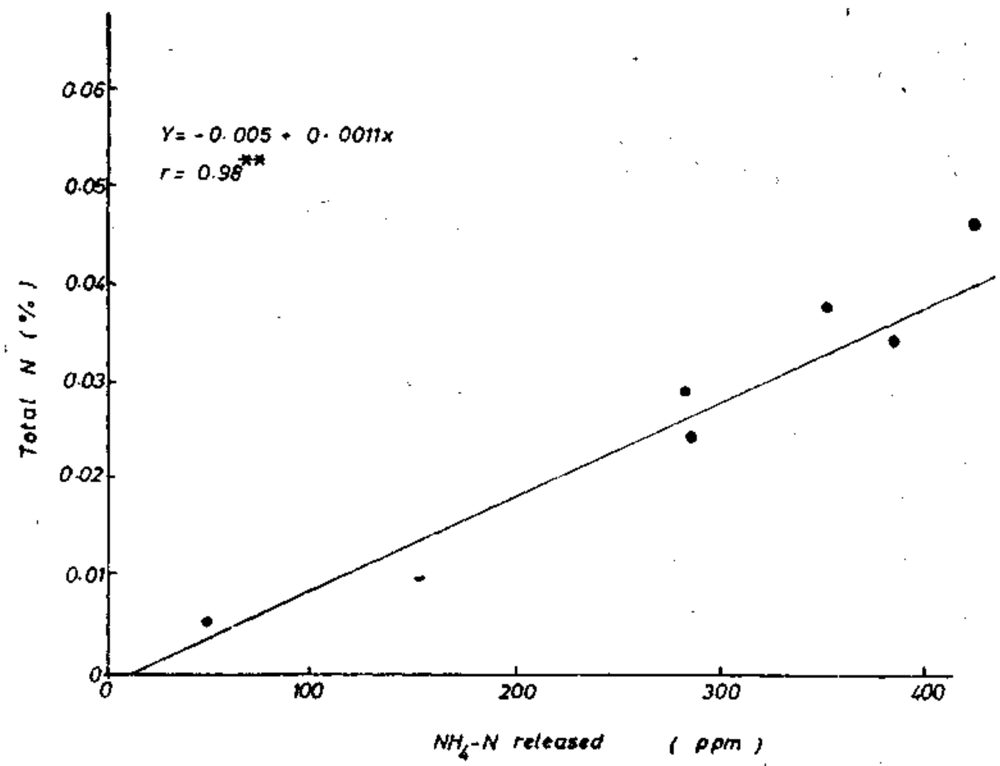


Fig. 14 : Regression line of total N ('Fadama' soil ) on $NH_4$-N released by acidified $KMnO_4$

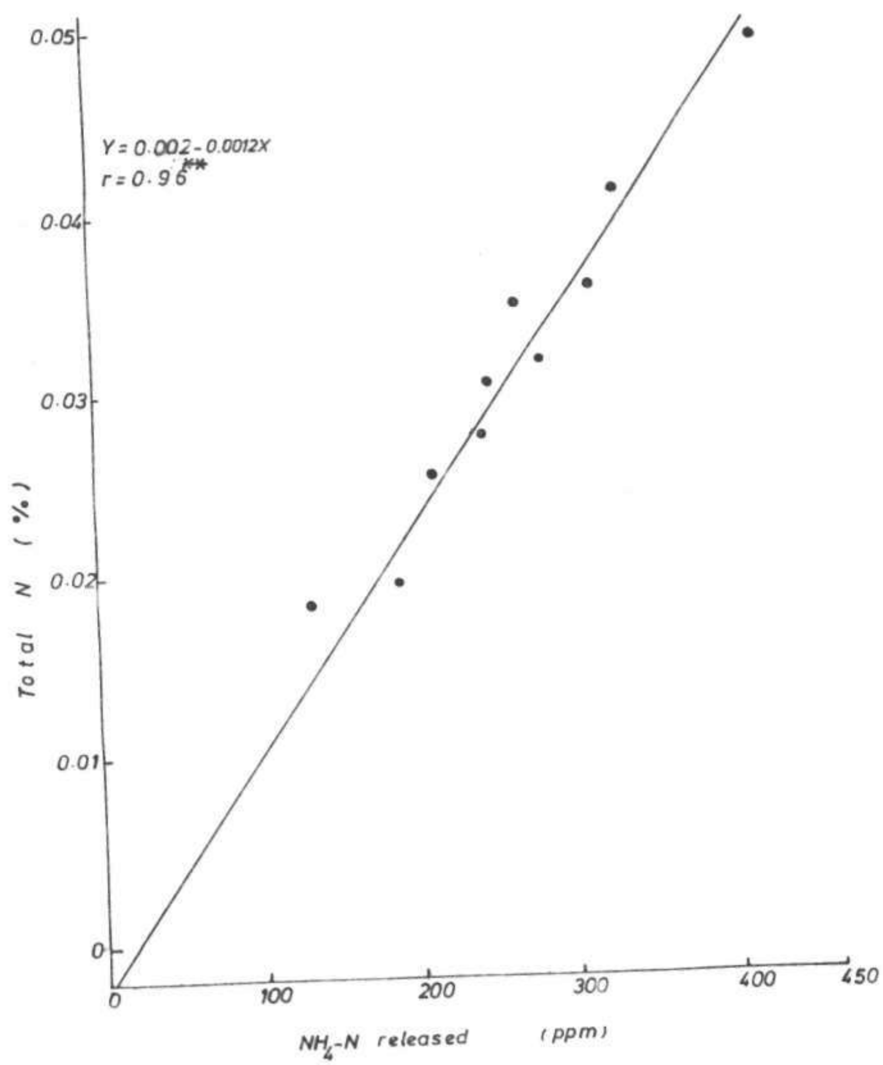
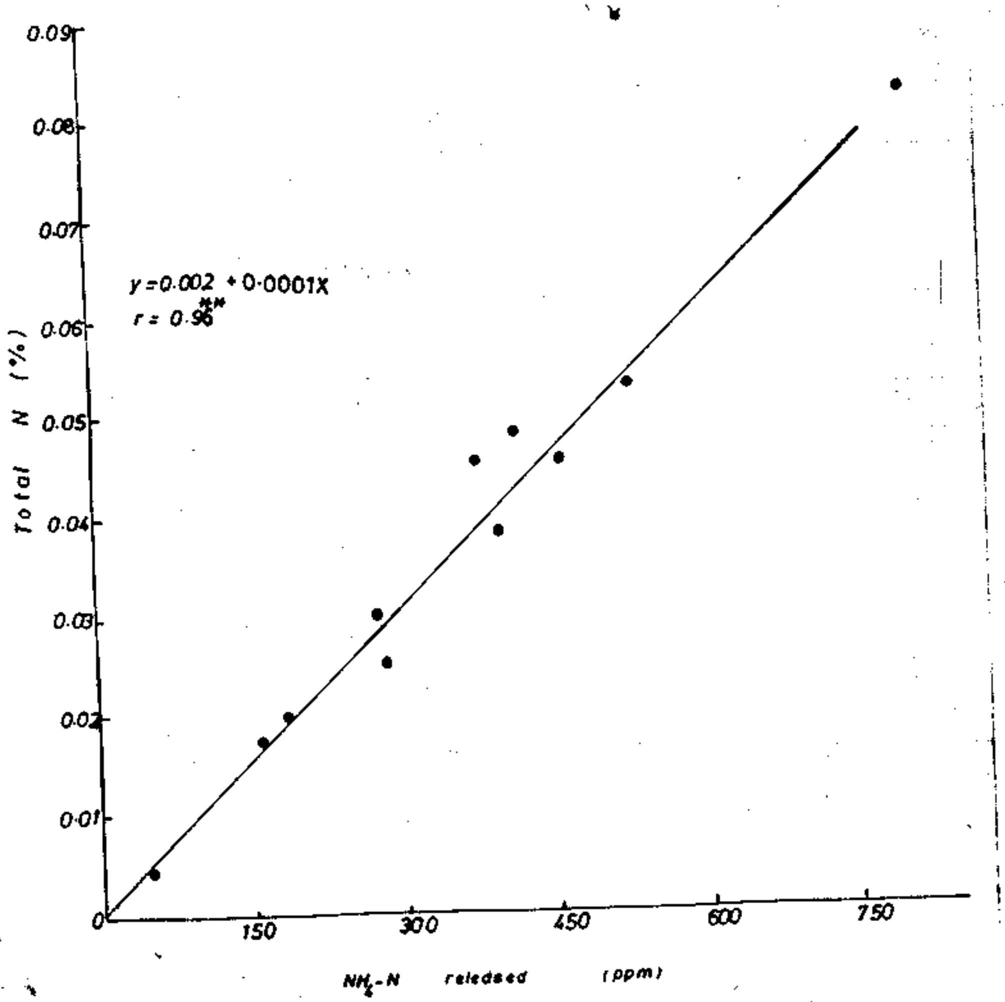


Fig.15 : Regression line of total N on $NH_4$-N released by oxidation in acidified $KMnO_4$ ( Upland soils )



### 4.4.3. Correlation Between N Index by Incubation, Organic Carbon and Total N

As in the case of the relationship between mineralized N and N uptake and dry matter, the total N mineralized had no bearing with either the organic carbon or total N (Tables 11 and 12) possibly for the same reasons given for lack of good correlation between N uptake and incubation method.

## 4.5. CORRELATION BETWEEN ORGANIC CARBON, TOTAL N AND N UPTAKE AND DRY MATTER

Correlation coefficients between organic C or total N and N uptake and dry matter are presented in Table 13. Except for "fadama" soils - (1st crop and total dry matter) the relationships between organic carbon or total N and N uptake, though positive, were insignificant even at 5% level of significance. Robinson (1968b) made similar observation between organic C and maize yield (r = 0.42). He, however, noted high correlation between total N and N uptake (r = 0.87**).

Lack of high and significant correlation coefficients between organic C or total N and N uptake could be linked to the many factors such as microbial population, C:N ratio, temperature, moisture as earlier discussed that are associated with organic N mineralization. In fact, Scarsbrook (1965) and Bremner (1965b) advised that the use of organic carbon or total N as an index of the N-supplying potential of soils should be with caution because of the afore-mentioned factors and other that influence soil organic N mineralization.

TABLE 13: CORRELATION COEFFICIENTS BETWEEN SOME SOIL PROPERTIES (ORGANIC C AND TOTAL N) AND N UPTAKE AND DRY MATTER

| Soil Property | | Correlation Coefficients | | | | | |
|---|---|---|---|---|---|---|---|
| | | N Uptake | | | | Dry matter | |
| | | 1st crop | 2nd crop | 3rd crop | Total | 1st crop | Total |
| (A) | Organic C | 0.23 | 0.18 | 0.30 | 0.26 | 0.24 | 0.21 |
| | Total N | 0.19 | 0.14 | 0.21 | 0.20 | 0.22 | 0.27 |
| (B) | Organic C | 0.60* | 0,30 | 0.10 | 0.40 | 0.36 | 0.50* |
| | Total N | 0.60* | 0.20 | 0.30 | 0.38 | 0.45 | 0.50* |
| (C) | Organic C | 0.20 | 0.10 | 0.14 | 0.36 | 0.38 | 0.02 |
| | Total N | 0.10 | 0.10 | 0.20 | 0.26 | 0.41 | 0.05 |

A : All soils

B : "Fadama" soils

C : Upland soils

* : Significant at 5%

# CHAPTER 5

## SUMMARY AND CONCLUSIONS

Assessment of native soil N which will be released to crops during a growing season has not been given appropriate attention if any at all in Savanna soils. The ability of any soil to supply N in adequate amounts and how long the native soil N will sustain high yields will depend among other things on the total N content and the part of organic N that will be released during growing seasons. A soil's power to supply N is large when it can release N in adequate amounts to the growing crops for several croppings.

At the moment, no universal soil-N availability test has been found. The success of each procedure varies from one soil type to the other and sometimes it is a matter of conjecture. There is no information that the ability of soils from Lake Chad Basin to supply N has been determined and that any of the soil-N availability indices tried elsewhere has been tested on these soils from Lake Chad Basin -

in Sudan and Sahel Savanna of Nigeria. Some soil-N availability indices are thought to be promising in predicting N uptake in other areas. This study was designed to ascertain the extent to which soils from Lake Chad Basin will relase N to the growing crops and how far three N-availability tests would be capable of estimating the soil-N uptake.

Soil samples were collected from 0 - 15cm layer at 24 different locations in the Sudan and Sahel Savanna zones (around Lake Chad Basin) of Nigeria. Chemical and physical properties of the soils were determined. With wheat as a test crop, exhaustive croppings for N were carried out in the greenhouse and N uptake and dry matter obtained. Two chemical extraction procedures - acid $KMnO_4$ and alkaline $KMnO_4$ solutions and a microbiological technique involving a two-week incubation at a constant temperature of $35^{o}C$ were the soil-N indices evaluated.

Correlation and regression analyses were carried out between $NH_4$-N released by oxidation in acidified or alkaline $KMnO_4$ solution and N uptake and dry matter and also between total N mineralized after the incubation and N uptake and dry matter. Each N-availability index was related to two soil properties which were also related to N uptake and dry matter.

The texture of the soils varied from sandy loam to clay. Generally, most of the soils were slightly acid to slightly alkaline in reaction and the mean values of pH in 0.01 $CaCl_2$ and in water were 5.69 and 7.11, respectively. Organic C as well as the total N for most of the soils were generally low. Organic C values for most of the soils were around 0.3% and total N values ranged from 0.005 to 0.082%. Effective cation exchange capacity of the soils was between 3.20 me/100g and 34.47 me/100g. Many of the soils had relatively low values of total P. "Fadama" soils had higher phosphorus values than the upland soils with average values of 276 ppm and 123 ppm P, respectively. The exchange complext of these soils was highly saturated with bases on effective CEC basis. Most of the soils had values above 90%.

The mean values of N uptake from the first, second and third crops of wheat were 27, 16 and 12 mg/pot, respectively for upland soils. The average values from first, second and third crops for "fadama" soils were 28, 15 and 13 mg/pot, respectively. The N-supplying power of these soils therefore tended to decrease from the first to the third crop of wheat, and did not significantly differ between upland and "fadama" soils. With the 24 soils put together the correlation coefficients between $NH_4$-N extractable by acid $KMnO_4$ and N uptake and dry matter were positive but insignificant, the maximum value of 0.33 was obtained with the total dry matter.

When the soils were separated on basis of their parent material, relatively high positive but non-significant correlation coefficients were noted between this acid $KMnO_4$ extraction method and soils derived from both Chad Lagoonal deposits and aeolian sand deposits. Significant correlation coefficients were, however, observed between this chemical index and N uptake from first and third crops of wheat for soils derived from alluvial sand deposits, (r = 0.81* and 0.85*, respectively). When the soils were grouped on basis of position (upland and "fadama") good correlation were also noted between this extraction procedure and N uptake from the first crop and total dry matter for "fadama" soils (r = 0.60* and 0.52*, respectively). The correlation relationships between the soil-N availability index and yield were not significant for upland soils.

The correlation coefficients between alkaline $KMnO_4$ extraction procedure and yield though positive were generally poor no matter how the soils were grouped. The relationships between the incubation technique and yield were not only very poor but very erratic, generally. Organic C showed very good relation with acid $KMnO_4$ extraction method for soils derived from Chad Lagoonal deposits, alluvial sand deposits, aeolian sand deposits, upland soils and "fadama" soils (r = 0.87**, 0.96**, 0.98**, 0.90** and 0.97**, respectively). The relationship when the 24 soils were taken together was positive and general.

Alkaline $KMnO_4$ procedure and incubation method had low correlation coefficients with organic C and total N for all the six groupings of the soils. Organic C had good relationship with N uptake (1st crop) and total dry matter for "fadama" soils 0.60* and 0.52*, respectively. Similarly total N related well with the N uptake (first crop) and total dry matter for "fadama" soils (r = 0.60* and 0.52*, respectively).

The conclusions that could be arrived at from the study are:

(i) The soils studied had relatively low power of supplying N to the growing crop possibly due to the low native N content and hence would require N-fertilizer application for effective and sustained yield.

(ii) Possibly due to heterogeneity of the soils, none of the chemical N-availability indices was very good in predicting the N-supplying power of these soils when soils were not separated into groups.

(iii) When the soils were separated on basis of their parent materials or position ("fadama" or upland), the two chemical N indices seemed superior to the incubation technique. Apart from being more rapid in operation (each required about 1 hour of extraction as against 14 days incubation) most of the correlation coefficients between each of the chemical procedures and yields were positive.

However, the acid $KMnO_4$ extraction method had better correlation with yield than the alkaline $KMnO_4$ procedure and therefore appeared more promising as an index of the N-supplying potentials of soils from Lake Chad Basin.

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# APPENDIX

## REGRESSION EQUATIONS AND CORRELATION COEFFICIENTS FOR PAIRS OF VARIABLES THAT SHOWED SIGNIFICANT CORRELATIONS.

Ai: N uptake

(a) N uptake (1st crop) on $NH_4$-N released by acidified $KMnO_4$ (for soils derived from alluvial sand deposits)

$$Y = 18.250 + 0.0570x$$

$$r = 0.81^{*}$$

(b) N uptake (3rd crop) on $NH_4$-N released by acid KMnO (soils derived from alluvial sand deposits)

$$Y = 9.024 + 0.0172x$$

$$r = 0\ 85^{*}$$

(c) N uptake (1st crop)on $NH_4$-N released by acidified $KMnO_4$ (for "fadama" soils).

$$Y = 11.943 + 0.0531x$$

$$r = 0.060^{*}$$

(d) Dry matter (total) on $NH_4$-N released by acidified $KMnO_4$ (for "fadama" soils)

$$Y = 2.150 + 0.0035x$$

$$r = 0.52^{*}$$

Aii:

Aii: Organic Carbon Vs $NH_4$-N

(a) Organic C on $NH_4$-N released by acid $KMnO_4$ (soils derived from Chad Lagoonal deposits)

$$Y = 0.084 + 0.0008x$$

$$r = 0.87^{**}$$

(b) Organic C on acid $KMnO_4$, $NH_4$-N (soils derived from alluvial sand deposits)

$$Y = 0.014 + 0.0010x$$

$$r = 0.96^{**}$$

(c) Organic C on acid $KMnO_4$, $NH_4$-N (soils derived from aeolian sand deposits)

$$Y = 0.012 + 0.0011x$$

$$r = 0.98^{**}$$

(d) Organic C on acid $KMnO_4$, $NH_4$-N ("fadama" soils)

$$Y = 0.036 + 0.0009x$$

$$r = 0.90^{**}$$

(e) Organic C on acid $KMnO_4$, $NH_4$-N (upland soils)

$$Y = 0.008 + 0.0011x$$

$$r = 0.97^{**}$$

Aiii: Total N Vs $NH_4$-N

(a) Total N on $NH_4$-N released by acidified $KMnO_4$ (soils derived from Chad Lagoonal deposits)

$$Y = 0.0004 + 0.0001x$$

$$r = 0.93^{**}$$

(b) Total N on $NH_4$-N released by acid $KMnO_4$ (soils derived from alluvial sand deposits)

$$Y = 0.001 + 0.0001x$$

$$r = 0.99^{**}$$

(c) Total N on $NH_4$-N released by acid $KMnO_4$ (soils derived from aeolian sand deposits)

$$Y = 0.005 + 0.0001x$$

$$r = 0.98^{**}$$

(d) Total N on $NH_4$-N released by acid $KMnO_4$ ("fadama" soils)

$$Y = 0.002 + 0.0012x$$

$$r = 0.96^{**}$$

(e) Total N on $NH_4$-N released by acid $KMnO_4$ (upland soils)

$$Y = 0.002 + 0.0001x$$

$$r = 0.96^{**}$$