PHOSPHATE UPTAKE AS RELATED TO EXTRACTABLE AND INORGANIC PHOSPHATE FRACTIONS IN SOME SAVANNA SOILS OF NIGERIA

BY

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A B S T R A C T

A study was carried out to investigate the amounts and forms of inorganic P fractions, and to determine the relationship of P fractions with selected soil tests and crop response in some savanna soils of Nigeria.

The average total P content in the soils varying in pH from 5.33 to 7.16 were 147.0 and 97.7 ppm for the surface (0-15 cm) and subsurface (15-30 cm) respectively. The average Al-P, Ca-P, Fe-P and occluded-P contents of the soils were 4.7, 4.9, 11.3 and 33.6 ppm in the surface layers and 2.4, 2.7, 9.3 and 30.0 ppm in the subsurface layer. The observed order of abundance of the inorganic P fractions were occluded-P $>>$ Fe-P $>>>$ Al-P $\simeq$ Ca-P, indicating that the soils are highly weathered.

Extractable P were generally low and Al-P accounted for much of the variation in extracted P and P uptake. The predictability of soil tests based on Al-P, Fe-P and Ca-P was lowest for the resin method (6.7%) and highest for the EDTA method (93.6%). Only 21% of P uptake was accounted for by the three active fractions. The resin methods was the only single measurement that was highly and significantly correlated with both uptake and yield, and it is here regarded as the most promising extractant for available P in the northern guinea, subsudan and plateau vegetation zones of Nigeria.

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CHAPTER ONE

INTRODUCTION

The role of phosphorus in plant nutrition, and their low content in the savanna soils of Nigeria, emphasize the need for a non-emphirical investigation into the problem associated with the phosphorus supply to plants in these soils.

Native soil phosphorus is solely derived from apatite inclusions in soil forming minerals. As weathering proceeds with the resultant decrease in soil pH, these mineral phosphorus forms get dissolved but eventually get refixed in sesquioxide complexes. These phosphorus compounds are largely unavailable to plants. In an attempt to calibrate the available soil phosphorus for fertilizer recommendations, the fraction which is thought to contribute to plant nutrition in the short run, described as the 'labil pool,' has been assessed by the use of extractants. These extractants are assumed to simulate the absorbing function of the plant root.

Chemical extractants (acides, bases, buffered salts and organic chelating compounds), ion exchangers, electrodialysis, isotopic dilution and exchangeability and sorption isotherms have been employed to assess the available soil phosphorus status the world over. Broad application of

these methods has not been extensively tested. In the savanna soils of Nigeria, chemical extractants, exchange resins and sorption isotherms have also been employed to evaluate the soil phosphorus status. These methods were empirical since the chemical nature of soil phosphorus utilized by plants is assumed to exist largely in combination with aluminium, iron and calcium. For best results, extracting solutions should remove phosphorus from different forms in proportion to those absorbed by plants. The contribution of aluminium phosphates to phosphorus uptake from soils of varied characteristics is well recognised. On the other hand, the availability of iron and calcium phosphates under different soil conditions is not certain. Information on the distribution of phosphorus forms in Nigerian Savanna soils is very scanty. This coupled with the need for a suitable soil test, selected on a non-empirical basis, requires an investigation into the different forms in which phosphorus exists in these soils. This study therefore has the following objectives:

1. To investigate the amount and distribution of the inorganic phosphate forms in some savanna soils of Nigeria.
2. To determine the relationship between the inorganic soil phosphorus fractions and the phosphorus extracted by some soil tests.
3 To determine the relationship between the inorganic soil phosphate fractions and phosphate uptake by an index plant.

CHAPTER TWO

REVIEW OF LITERATURE

SOURCES OF SOIL PHOSPHORUS AND ITS FIXATION BY SOIL

Sources

The bulk of phosphorus in nature occurs in minerals of the apatite group of which fluoroapatite, $Ca_{10}(PO_4)_6F_2$, is the most abundant and most soluble, although hydroxy-apatite, $Ca_{10}(PO_4)_6(OH)_2$, and chloro-apatite, $Ca_{10}(PO_4)_6CL_2$ are also known to be of wide spread occurence (Landergren, 1954). Phosphorus also occurs in less common minerals such as monazite, (Ce, La, Y, Th)PO_4. In soil studies, apatite is generally taken as the only primary sources of phosphorus present and it is consequently regarded as the starting point of all subsequent phosphorus transformations (Williams et al, 1969; Juo and Ellis, 1968).

Hsu and Jackson (1960) indicated that most parent materials were originally calcareous and that the phosphates were originally bonded to calcium with aluminium and iron phosphates existing in very small amounts. In support of this study is the work by Syers et al, (1967) who showed that almost all phosphorus in unweathered greywacke and mica-scist was in the form of apatite. Williams and

Walker (1969) also showed that almost 70% of the total phosphorus in the lowest horizon of a weakly weathered soil on basalt was acid extractable calcium phosphate. Hsu and Jackson (1960) went on further to discuss the transformation undergone by apatite during soil development. They showed that the total phosphorus within an individual profile, as well as among profiles varied less than calcium phosphate, indicating that the leaching losses and plant uptake were less significant than transformation in causing the decrease in calcium phosphate. As calcium phosphate was leached out and soil pH dropped to below 7 during pedogenesis, calcium phosphate decreased and aluminium and iron phosphates were found to correspondingly increase. Back transformation of aluminium and iron phosphates to calcium phosphate was found to occur to a certain extent when the pH of the soil was increased by $CaCO_3$ addition. These evidences allow the conclusion that inorganic soil phosphate transformation is controlled largely by pH, but that the rate is controlled by the slow rate of diffusion along moisture films adjoining particles of different crystal species. Aluminium and iron phoshpates were also observed to be of secondary origin, forming from the dissolution of calcium phosphate (Juo and Ellis, 1968b).

Fixation

Soils of the humid tropics are typically highly weathered, strongly acid in reaction and have high phosphate sorption capacities. However, some soils of the dry tropics have been noted to posses low phosphate sorption capacities (Mokwunye, 1977; Enwezor and Moore 1966).

The mechanism of phosphorus fixation by soil and transformation to forms that are unavailable to plants have been much studied. Two mechanisms have been considered to be responsible for soil phosphate fixation:

(a) Chemical adsorption

(b) Precipitation

Most workers have considered both mechanisms as resulting from a single chemical force (Kittrick and Jackson, 1956; Hsu, 1965). Black (1943), Williams et al. (1958), and Saunders (1965) as well as Bass and Sieling (1950), Russell and Low (1954), Coleman (1944), have shown that in soils, with emphases on acid soils, free iron and aluminium are the most important factors in the adsorption of phosphorus. Udo and Uzu (1972), working with some acid soils from Nigeria observed high sorption characteristics and attributed this to iron and aluminium oxides. Toth (1937) showed that the adsorption of phosphorus by soil was due to the displacement of silicates and hydroxyl ions from the soil colloids by the phosphate ion. This was supported by

Chatterjee and Datta (1951), who used this theory to explain the enormous decrease in phosphate fixation by kaolinite as pH increased. In a phosphate adsorption study by soil clays, Coleman (1944) postulated that the phosphate ions replace the hydroxyl ions from the free ion and aluminium hydroxides rather than from clay minerals. Dean and Reubins (1947), and Larson (1967) have also observed similar phenomenon. They showed that hydroxyl ions are quite effective in replacing adsorbed phosphate.

Precipitation of insoluble compounds of aluminium and iron was considered important by Ghani and Islam (1946) as a mechanism for phosphate reversion. Kittrick and Jackson (1956) have also reasoned on similar line and showed that greenalite and kaolinite react with phosphate by mechanism of chemical precipitation to form separate-phase phosphate crystals. It was suggested that the crystal species formed is dependent on the predominant cation and the solubility is regulated by the solubility product principle.

Hsu (1965) observed that the form of the Al and/or Fe present at the time of reaction of phosphate would determine whether the reaction is precipitation or adsorption. Many workers have also revealed the possible role of Al and/or Fe oxides and hydroxides in phosphate sorption in acid soils. Fried and Dean (1955) reported that the surface coatings of Fe and Al on the exchange material fixed a

large proportion of added phosphate. Udo (1977) observed that strongly weathered soils adsorb more phosphorus than weakly weathered soils which he attributed to the sesquioxides which are found in greater amounts in the more highly weathered soils.

Yuam et al. (1960), working on the transformation of newly added phosphate, observed percentage increase for the aluminium phosphate (Al-P) fraction on addition of soluble phosphorus to the soil. He went on further to demonstrate that with increase in drying temperatures and time of reaction there was a singificant shifting of P from Al-P to iron phosphate (Fe-P) fraction. This he explained as due to the lower solubility product of Fe-P. (Also supported by Hubbard and Walmsley, 1974).

Investigating the kinetics of P adsorption and desorption, Wilson (1968) showed that the only cations which enhance P adsorption were those, like Fe and Al, that can hydrolyse to produce hydrous oxide polymers which function as anion exchangers and reversibly adsorb the added phosphate.

Harter (1969) suggested the importance of organic matter in the initial bonding of phosphorus by soils and subsequent reversion to less soluble forms. Fox and Kamprath (1971) observed that soils in which colloids were organic had low capacity to adsorb P, and added P was more

soluble and moved freely to lower depths. Addition of exchangeable aluminium as $AlCl_3$ to the organic soil completely prevented P leaching. The work of Singh (1969a) also supported the fact that organic soils have low fixing capacities. In his study, he found that the free energies of adsorption on soil adsorping complexes indicated higher values for the B horizon with possibly Al and Fe adsorption complexes than those with A horizon suggesting lower energy of adsorption of P with organic matter.

FRACTIONATION OF INORGANIC PHOSPHORUS

Soil inorganic phosphorus has been fractionated by several workers (Dean, 1938; Ghani, 1943; Chang and Jackson, 1957; Williams et al, 1971). They have made use of the principle of differential solubilities of the different phosphate forms. The specificity of each of their methods in effectively separating the different chemical forms has been experimentally debated extensively and the use of certain extractants for some forms have met with much criticism. This complication is however due to the intricate nature of the numerous classes of the inorganic phosphorus forms in the soil.

Ghani (1943) used 0.2N acetic acid, cool 0.25N NaOH, and 2N H_2SO_4 for P fractionation. This method was modified by Williams (1950) who separated three fractions, viz:

(1) P extracted by 2.5% acetic acid - 1% 8-hydroxy quinoline, (2) P extracted by 0.1N NaOH and (3) insoluble in either extractants (composed mainly of flouro-and Chloro-apatites and resistant P minerals).

Chang and Jackson (1957) devised a fractionation scheme to separate discrete chemical forms of soil phosphorus. The order of extraction and fractions extracted are as follows:

Fraction No.	Extractants	Fractions
1	1N NH_4Cl	Water soluble P
2	0.5N NH_4F(pH7)	Aluminium phosphate
3	0.1N NaOH	Iron phosphate
4	0.5N N_2SO_4	Calcium phosphate
5	sodium dithionite-citrate	Reductant soluble iron phosphate (iron oxide occluded)
6	0.5N NH_4F(pH7)	occluded Al-P
7	0.1N NaOH	occluded Fe-P

The use of neutral NH_4F for the extraction of aluminium phosphate has been much criticised. It is argued that neutral NH_4F not only extracts aluminium phosphate but also removed some of the Fe-P as well. The fourth fraction was also found to include some occluded phosphates. To overcome these defects, Fife (1959) used 0.5N NH_4F solution adjusted to pH 8.2 and Glenn et al, (1959) suggested the use of 0.5N H_2SO_4 after the sodium dithionite critrate

treatment. For accurate distinction between Fe-P and Al-P in this procedure, Smith (1965) suggested the calculation of a separate factor for each level of standard P added to the first NH_4F extractant. In partially phosphated system, Bromfield (1967) found that NH_4F solution released most of the Al-P together with variable amounts of Fe-P and Ca-P. On this basis, he questioned the validity of equating NH_4F extractable P with aluminium - bound P content of soil.

Scharafat (1970) observed 20-50% dissolution of Ca-P by the NH_4F extractant and suggested the alimination of this reagent in the fractionation scheme. He extracted the soil four times with NaOH to obtain a combined Al-P and Fe-P fraction and arriving at a better definition of Ca-P present in the soil.

Williams et al, (1971) showed that NH_4F used in the extraction of Al-P react with calcareous materials forming CaF_2 which reabsorb the phosphate in solution presumably resulting in the formation of CaF_2 - orthophosphate complex. In the subsequent NaOH extraction of Fe-P, inorganic P is sorbed on CaF_2 and $CaCO_3$ which are eventually released in the dithionite-citrate extract. This results in the under-estimation of Al-P and Fe-P fractions and an overestimation of the occluded phosphate fraction. They then suggested the elimination of NH_4F extractant and proposed a single NaOH extraction before the dithionite-citrate extraction.

Despite these findings, Chang and Jackson's (1957) procedure has been most extensively used to characterise the distribution of soil inorganic phosphate forms.

AMOUNT AND DISTRIBUTION OF INORGANIC PHOSPHATE FORMS

Though much effort has been put to estimate the total phosphorus content of tropical soils, the characterization of the different forms has received less attention.

Most tropical soils are deficient in phosphorus (Bates and Baker, 1960; Udo and Ogunwale, 1977; Mokwunye, 1974). This has been attributed to the low apatite content of the soil forming minerals.

Nye and Bertheux (1957) fractionated the soils of the Gold Coast into three fractions according to Williams (1950) and found no special tropical peculiarity associated with the distribution of phosphorus, on comparism with neutral and acid soils in other parts of the world. They observed similar distribution of phosphorus in both acid and alkaline soils, although low values of acid extractable P were recorded for the basic soils.

Bates and Baker (1960) studied the distribution of P forms in a forest profile in Nigeria. They found high total P content through out the profile with considerably more accumulation in the top soil due to phosphorus recycling through litter. They demonstrated the greatest association

of P with the silt and clay fractions and less association with the sand fraction at all depths. The decrease in total P with depth was found to correspond to the higher percentage of the coarse and fine sand fractions relative to combined silt and clay at lower horizons.

Enwezor and Moore (1966) worked on some savanna and forest soils and provided the first phosphorus fractionation of Nigerian soils using Chang and Jackson's procedure, but without determining the occluded P. They found that over half of the extractable phosphorus was present as iron phosphate, the remainder being made up of approximately equal quantities of aluminium and calcium phosphates. The bulk of the total P was present in the residual fraction. There was a general decrease of all fractions with depth. They explained the higher Ca-P found on the top soil to be due to the release of metallic cations by decomposing litter. Westin and Britto (1969) observed similar finding and also showed that active P and organic P decline along with pH as weathering intensifies. This is in support of the agreed fact that the relative amounts of the discrete chemical forms is a reflection of the degree of weathering, with the shift in phosphate equilibra towards greater accumulation of occluded phosphates as weathering intensifies (Chang and Jackson 1957; Juo and Ellis, 1968; Hawkins and Kunze, 1965).

Pinto (1974) noted that the distribution of P was closely related to the pedogenetic evolution of soils with the more mature soils showing low P values. He observed that the distribution of the active fractions (Al-P, Fe-P and Ca-P) and their abundance in soils is dependent on pH, the solubility products of the different phosphates, the cations present and the degree of weathering. The influence of pH on P distribution was studied by Chu et al, (1962). They found that rock phosphate break-down into aluminium and iron phosphates decreased with increasing pH. While there was some significant influence of pH and Fe oxide content on the Fe-P fraction, the Al-P fraction was found to vary less with pH.

Rodes (1977) reported that the greatest variation in total P in some Sierra Leone soils is with respect to parent material. Ca-P tended to disappear in some highly weathered soils strongly acid in reaction. Lower phosphate values have been recorded for soils over sandstones as against soils that developed over igneous and metamorphic rocks (Uzu et al, 1975; Blasco and Bohorquez, 1967; Udo and Ogunwale, 1977; Udo, 1977; Enwezor, 1977). Generally, the relative distribution of P forms in some West African soils is in the order occluded - P $\geqslant$ Fe-P $>$ Al-P $>$ Ca-P, indicating that the soils are highly weathered.

CHEMICAL EVALUATION OF AVAILABLE PHOSPHORUS

Soil tests are designed to provide an index of availability of plant nutrients. According to Bray (1938), the available forms of a nutrient are those whose variations in amounts are responsible for significant variations in yield and response to applied fertilizers. Chemical extractants which include acids, bases and buffered salts, ion exchangers and chelating compounds have been used to extract available phosphorus from soils in an effort to calibrate the available phosphorus levels for fertilizer recommendations.

Bingham (1949) developed a method based on extraction of P with water and observed that the procedure was more satisfactorily used on sandy soils than on finer textured soils.

The suggestion that plant roots produce CO_2 provided the background for the use of CO_2 - saturated water as an extractant for available phosphorus. McGeorge (1939) observed that the solubility of P in alkaline soils increased with increasing concentration of CO_2 in water. Stanbery (1949) found CO_2 extraction method a satisfactory substitute for Neubauer method (Neubauer, 1932) in an alkaline soil.

Olsen et al, (1954) introduced the use of sodium bicarbonate as an extracting solution for calcareous soils. This was based on the principle that bicarbonate ions reduce calcium ion activity in calcareous soils. It was also observed that the solution extract portions of aluminium and iron phosphates, which makes it adaptable to acid soils. Das (1930) proposed the use of 1% K_2CO_3 as P extractant, 0.5N NaOH was recommended by Jones (1949), and Al-Abbas and Barber (1964) used 0.25N NaOH with 0.075N NaC_2O_4 to minimize readsorption of P in solution.

Bray and Dickman (1941) proposed using dilute acid and ammonium flouride solution. Bray and Kurtz (1945) used 0.025N HCl and 0.03N NH_4F (Bray No.1) reagent to extract adsorbed or available P, and 0.1N HCl and 0.03N NH_4F (Bray No.2 reagent) to extract reserve P from soils. The use of dilute acid and ammonium flouride solution is based on the assumption that the acid will extract a portion of all the forms of phosphorus in the soil, and the flouride will increase the amount of Al-P and Fe-P and mono and di-calcium phosphates extracted (Smith et al, 1957).

Organic acids have also been used as extracting solutions for soil P. This is based on the assumption that plants roots excrete organic acids. Dyer (1894) used 1% citric acid solution as P extractant. Egner (1941) developed a

procedure using calcium lactate and HCl at pH 3.5. Hibbard (1931) suggested the use of acetic acid.

Organic reagents, such as EDTA, that form water soluble chelates with metallic ions have been used by some workers to extract available P from soils (Viro, 1955; Alexander and Robertson, 1972; Nnadi et al, 1975). Sahrawat (1977) confirmed previous finding that EDTA binds all cations (Al, Fe and Ca) to release associated P.

Both cation and anion exchange resins have been employed to extract P from soils. Amer et al, (1955) used the Cl form of the strong basic anion exchange resin, Dowex -2, Using a 1 : 1 soil-resin ratio, they found that it was the rate of P release from the soil that governed the quantity of P adsorbed by the resin. The use of anion exchanger for P extraction is based on the assumption that, as the solution P is decreased to very low levels by the exchange machanism on the resin entity, which tends to imitate the physico-chemical absorbtive function of the plant root, a high percentage of the easily soluble P is released from the soil into solution. Barrow and Shaw (1977) noted that the amount of P extracted by anion exchange resin increased as volume of water and weight of resin increased.

On page 17 is summarized some of the major methods used for extracting available P.

	Method	Extractant	Reference
1.	Water	Distilled water	Wanatabe & Olsen, (1965)
2.	Resin	Distilled water plus anion exchange resin	Amer et al, (1955)
3.	HCl	0.3N HCl	Warren & Cooke, (1965)
4	HOAc	2.5% acetic acid (pH 2.6)	Williams and Stewart, (1941)
5.	Truog	0.002N H_2SO_4 (pH 3.0)	Truog, (1930)
6.	Citric	1% Citric acid (pH 2.2)	Dyer (1894)
7.	Bray No.1	0.03N NH_4F + 0.025N HCl	Bray & Kurtz (1945)
8.	Bray No.2	0.03N NH_4F + 0.1N HCl	Bray & Kurtz (1945)
9.	Morgan	10% NaOAc in 3% HOAc (pH 4.8)	Morgan, (1937)
10.	Lactate	0.02N Ca-Lactate in 0.01N HCl	Egner, (1941)
11.	Olsen	0.5M $NaHCO_3$ (pH 8.5)	Olsen et al, (1954)
12.	William	0.1N NaOH	Williams, (1950)
13.	EDTA	0.01N Na-EDTA	Sarhawat, (1977)

EXTRACTABLE PHOSPHORUS AS RELATED TO PHOSPHATE FRACTIONS

The low phosphorus levels of the savanna Soils of Nigeria, combined with their low capacity of absorb phosphorus (Mokwunye, 1977, Enwezor and Moore, 1966) as compared to other tropical soils with known sorption characteristics (Fox et al, 1968; Udo and Uzu, 1972) would invariably reflect on the amounts of phosphorus extracted by chemical soil tests.

Several investigators have compared the amounts of P removed by various extractants. Enwezor (1977a) compared various methods of determining available phosphorus. He observed that anion exchange resin and acetate solution (Morgan extractant) were least effective in extracting P of the methods used. This he attributed to the fact that because the soils were acid in reaction, soil P exists predominantly in the Al and Fe forms, which have low solubilities in water and dilute acids. Chang and Juo (1963), Enwezor and Moore (1966), Nye and Bertheux (1957) observed similar findings in previous works. Bray No.1 extractant (0.025N HCl + 0.03N NH_4F) was found to be more effective in extracting available P from Al and Fe phosphates (Swenson et al, 1949), and the Ca-P fraction is dissolved by the acid acomponent of the extractant.

Halm and Bampoe - Addo (1972) worked on some Ghana soils

Halm and Bampoe-Addo (1972) worked on some Ghana soils and noted that acid extractants removed more P than did alkaline solutions.

Oteng and Acquaye (1971) also compared the relative extracting power of some chemical soil tests. They found that Bray No.1 reagent extracted about 6% of total inorganic P, more than could be extracted by acetic acid, bicarbonate water, lactate and acetate methods. Water extractable P constituted only about 1% of total inorganic P and was found to be higher than the amount extracted by the acetate method. Oko and Agboola (1974) also recorded low values for water-extractable phosphorus.

Chelating compounds have been noted to extract appreciable amounts of soil phosphorus. Nnadi et al, (1975) indicated that at low concentrations (5 - 10 mM), chelating compounds, such as EDTA, exhibit a low buffering poise and have limited capacity for binding metal ions.

The amount of P removed by any extractant depends, to a large extent, on the kind and amounts of P compounds present in the soil (Breland and NeSmith, 1968). It has been suggested that the use of an extractant which removes Al, Fe and Ca phosphates in proportion to those absorbed by plants would provide a reliable index for available P in soils (Chang, 1965).

Several investigators have found high correlation between soil test methods and aluminium phosphate fraction (Susuki et al, 1963; Pratt and Garber, 1964; Juo and Ellis, 1968; Halm and Bampoe-Addo, 1972; Hawkins and Kunze, 1965; Choudhari et al, 1974; Hubbard and Walmsley, 1974). Maida (1978) observed that the major source of variation in Bray P_1 and resin extractable P was the Al-P fraction. He also noted that Fe-P fraction was the second most important inorganic phosphate form that contributed to the variation in resin extractable - P. This observation was in accordance with Enwezor (1977) and Kadeba and Boyle's (1978) findings. Calcium and organic phosphorus contributions were regarded as relatively unimportant.

Susuki et al (1963), and Pratt and Garber (1964) have demonstrated the high dependence of Bray P_1 on the Al-P fraction. The contribution of Al-P and Fe-P to Bray No.1 phosphorus was later demonstrated by Kanwer and Tripatti (1977). Payne and Hanna (1965) indicated positive correlation between Al -, Fe- and Ca-P fractions with Bray No.1 phosphorus. Choudhari, Sexana and Somani (1974) could not establish any relationship between Al-P and Bray No.1 phosphorus.

Susuki, Lawton and Doll (1963) obtained a high postive correlation between Al-P and resin - P. Kadeba and Boyle (1978) obtained a contrary result.

EDTA as an extractant has received limited study, and the P fractions extracted by this compound has not been fully characterized. Alexander and Robertson (1972) established that EDTA extractable P showed significant positive correlation with Al-P and Fe-P and did not exhibit any relationship with Ca-P. Sahrawat (1974) recorded significant positive correlation between EDTA-P and extractable - P according to Olsen, Morgan, Bray 1 and 2, and also with inorganic phosphate fractions associated with Al, Fe and Ca.

Ammonium flouride-soluble phosphorus has been related to water-soluble P (Chang and Jackson, 1957; Pratt and Carber, 1964). Water-soluble P has also been considered as the most important P fraction that control available P in acid soils. Clay content was negatively correlated with water - soluble P (Srivastava and Pathak, 1968). The effect of increasing clay content in decreasing the effectiveness of Bray's reagents to extract P from soil was related, by Pratt and Garber (1964), to exhaustion of the reagent.

Aside from the Al-P fraction, Fe-P has been correlated with available P (Al-Abbas and Barber, 1964). Payne and Hanna related Bray P1 with the Fe-P fraction, while Maida (1978) suggested that Bray P1 extractant may be a reliable index of P availability if Al-P and Ca-P are the major fractions that contribute to plant nutrition. Hawkins and Kunze (1965) related Ca-P with available P in a Texas Grumosol.

CROP RESPONSE AS RELATED TO INORGANIC PHOSPHATE FRACTIONS

Many studies have revealed the significant contribution of the Al-P fraction to available phosphorus in soils differing greatly in physical and chemical characteristics. In many cases, it has been found to dominate in this regard. It was shown to be more available to plants than either Fe-P or Ca-P fractions for barley in soils varying in pH from 4.8 to 7.8 (Susuki et al, 1963) for millet in soils of varied phosphate fertility levels (Payne and Hanna, 1964) and for maize and cowpea in alkaline soils (Choudhari et al, 1974). Aluminium phosphate was found to be the main source of P for wheat in untreated soils in the green house (Smith, 1965). Halstead (1967) and Rudd and French (1977) obtained high positive correlation between Al-P fraction and percentage yield. McKenzie (1962) concluded from his study that Al-P was most effective in controlling phosphate solution concentration. The availability of Al-P fraction to plants in typical and leached chernozems (black grassland soils), and also in podzolized and grey forest soils was observed by Ivanov (1975).

Choudhari et al, (1974) showed that Fe-P was the major fraction that contributed to the variation in yield for some local crops found in India (jowar and urd) as was observed earlier by Al-Abbas and Barber (1964) for millet,

but failed to relate plant uptake by maize, wheat and cowpea with iron - bound P.

Juo and Ellis (1968b) attributed the higher availability of Al-P and Fe-P fractions to their amorphous nature, which are largely associated with clay fraction of soils. Ca-P, due to its primary origin, may exist in forms of higher crystallized minerals through out the textural fractions of the soil. The consequence therefore is the very low availability of this phosphate fraction. Unlike the crystalline sesquioxides and apatites, the amorphorus compounds are available and are likely to play an important role in the P nutrition of plants. It was also suggested that crystallinity tends to reduce the availability of these phosphate fractions. The faster rate of crystallization of Fe-P in acidic aqueous medium over Al-P accounts for the greater availability of Al-P relative to Fe-P. McLachlan (1965) had earlier demonstrated the greater availability of the amorphous phosphates relative to the crystalline forms.

Kadeba and Boyle (1978) observed significant relationship between Al-P + Fe-P with P uptake by plantation seedlings in green house study.

Williams and Saunders (1956) pointed out that P in solution may be controlled by the clay fraction. This postulation was supported by Hanley and Murphy (1970) who

suggested that Al-P and Fe-P in the clay fraction may be important controlling factors in the availability of inorganic P to grasses. Singh, Martens and Obershain (1966) compared the inorganic P fractions in a clay loam soil before and after the growth of three crops of alfalfa. They observed that Al-P, Fe-P and Ca-P were sources of P to the first crop, and that Fe-P was the main source of P to the second and third crops. Enwezor (1977b) found significant positive correlation between percentage yield of maize and four soil phosphorus fractions. He observed that Al-P was most important and accounted for 31% of observed variation in yield. Iron phosphate was equally as important with 30% contribution to the observed variation. Calcium and organic phosphorus were associated with 24% and 20% of variation in yield respectively. Al-Abbas and Barber (1964) and Pinto, (1974), in additon to relating Fe-P with plant available P also obtained high relationship between water-soluble P and plant response.

The Ca-P fraction has also been found to contribute to available P. (Singh (1969b) found that Ca-P contributed more to phosphorus uptake by soyabean plant in acid soils and Al-P in alkaline soils. Ca-P has been correlated with P uptake by cowpea (Choudhari et al, 1974) and to rye-grass (Hernando and Diez, 1974) in calcareous soils. Calcium phosphate and aluminium phosphate combined was found to

contribute significantly to P available to barley (Susuki et al, 1963).

The near universal acceptance that Al-P, of all the soil inorganic phosphate fractions, is the one major fraction that contributes substantially to P uptake by plants is consistent with the observations by earlier workers on soils of tropical Africa.

Saunders (1954) working on Rhodesian soils, correlated P extracted by acid - flouride (Bray and Kurtz, 1945) with phosphate responses in the field. Though he failed to obtain any correlation between phosphate responses in the field and acid soluble phosphorus, the relationship with P extracted with hot O.1N NaOH was better than that obtained with P extracted with acid - flouride solution. No correlation was obtained with the organic phosphate fraction. Pigotte (1954) also found no correlation between the available P extracted by dilute acid (Truog method) and responses to superphosphate by swamp rice in Sierra Leone soils.

Nye and Bertheux (1957) concluded that the value for available phosphorus obtained with the acid fluoride reagent was more nearly proportional to the actual solubility of the soil phosphorus in the root environment. After the adoption of the schematic fractionation procedure of Chang and Jackson (1957), the nature of the various P fractions

in relation to their availability was studied. Though the Al-P fraction may not always be present in appreciable amounts, its significant contribution to P uptake from soils of widely varying characteristics cannot be contested. The contributions of Fe-P and Ca-P are uncertain and are known to be inconsistent.

CROP RESPONSE AS RELATED TO EXTRACTABLE PHOSPHORUS

Soil tests are designed to diagnose the fertilizer needs of plants under a given set of conditions. Bray (1948) postulated that a soil test for P should extract the total or a proportionate part of the available phosphorus from soils with variable properties.

The suitability of a soil test is usually judged on the basis of its correlation with absolute yield of unfertilized plots (Robertson, 1962), percent yield (Bray, 1948), nutrient uptake (Fitts and Nelson, 1956) and A value (Fried and Dean, 1952). Many of the soil tests are observed to be satisfactory only under limited range of conditions. Attempts to apply these to a wide range of conditions have met with little success (Nelson et al, 1953). Hubbard and Walmsley (1974) demonstrated the possibility of easily-utilizable phosphorus occupying sites of differing P affinity in two soils of similar mineralogy. Consequently, phosphorus in

one soil was more available than in the other. This may explain the varied results obtained by using the same extractant on similar soils in different environments. Oko and Agboola (1974) concluded that different groups of soils may require different extractants for a valid estimation of available soil P. Mater and Samman (1975) obtained better correlation between extractable phosphorus and relative yield when soils were grouped into different genetic horizons. It is an established fact that different extractants dissolve different phsophate compounds in soil, and the proportion of each specific phosphate compound in different soils is highly varied. Extractants for available phosphorus are evaluated here for their suitability under different soil and plant conditions as observed by different workers.

Oteng and Acquaye (1971) extracted soil P with ten different extractants (water; acetic acid; HCl; H_2SO_4 (Truog); citric acid; acid-flouride 1 and 2 (Bray Nos.1 and 2); bicarbonate (Olsen); acetate (Morgan); and lactate). Water, Bray No.2, Morgan and Olsen methods were significantly correlated with P uptake by millet. The ability to differentiate between P in liquid and solid phases and also the ability to extract easily exchangeable P sorbed on organic matter was said to explain the higher correlation value obtained for water P relative to other methods.

Water method was found to be unsuitable by Oko and Agboola (1974) on the basis of the low correlation value of 0.028 obtained with plant uptake.

Extractable phosphorus as a predictor of plant requirement for phosphorus has been studied by many workers. (Agboola and Corey, 1975; Kadeba and Boyle, 1978; Metwally et al, 1976; Beauchamp et al, 1976; Hislop and Cooke, 1960; Cajuste, 1972; Payne and Hanna, 1965; Dalal and Hallsworth, 1976; Choudhari, Sexane and Somani, 1974). Stamford and Bouldin (1960) reported that the extent of variation in plant uptake explained by extractable P was 40% with Bray No.1 reagent, 30% with anion exchange resin, and 14% with Olsen reagent. Oko and Agboola (1974) arrived at Bray No.1 reagent as a general purpose extractant and found it to be superior in assessing the available P status in paddy soils of Western Nigeria.

Susuki et al,(1963) reported that Bray P, and surface P did not correlate with P uptake in barley tops of the methods used to estimate available P. They obtained the highest correlation with dilute sulphuric-acid P and resin-P. Resin-extractable P was found to be superior to any other single measurement for predicting both uptake and yield for Rhodes grass (Bache and Rogers, 1970) and for plantation seedlings (Kadeba and Boyle, 1978). Enwezor (1977a) found that resin method was superior over dilute

acid in predicting yield. Bray No.1 and bicarbonate reagents were equally precise but less efficient in predicting yield. Bray No.2 reagent was selected as the most suitable P extractant for the south eastern soils of Nigeria on the basis of high correlation with yield.

Stephen and Lin (1974) determined available P using seven different extractants. They observed that soil P levels determined by Truog, Mehlich and anion exchange resin methods were significantly correlated with dry matter yield. Bray Nos.1 and 2 and Olsen P were not significantly related to phosphorus uptake.

CHAPTER THREE

MATERIALS AND METHODS

MATERIALS

Soil samples were collected from 16 locations in the northern guinea savanna, sub-sudan savanna and plateau vegetation zones of Nigeria at two depths, 0 - 15cm for the surface soil and from 15 - 30cm for the subsurface soil. The soils were regarded as virgin soils as there was no evidence of cultivation practice or other human activities on the sites for a period which may well have exceeded ten years. Care was taken to include major soil types, which was the criterion for the choice of locations.

The soils were divided into three broad groups: soils of north-western Nigeria which include samples numbers 1, 2 and 3. These are ferrisols and ferruginous tropical soils on sandstones, gneiss and schists as described by Valette (1973).

Soils in north-central Nigeria include sample numbers 4, 5, 6, 7, 8, 9, 11 and 12. These are ferruginous tropical soils on basement complex formed mainly from gneisses and igneous rocks (Klinkenberg and Higgins, 1968).

Lastly, soils of north-eastern Nigeria. These are more varied in origin and include sample numbers 10, 13, 14, 15 and 16. Sample number 13 is undifferentiated ferrisol formed

Table 1: Location, parent material and description of soils

Lab. No.	Location	Parent Material	Description of soils.
1.	Kaiama	Basement Complex	Ferruginous Tropical soil on crystalline acid rock.
2.	Luma	Sandstone	Undifferentiated Ferruginous Tropical soil.
3.	Kontagora	Sandstone	Ferruginous Tropical soil on crystalline acid rock.
4.	Samaru	Basement Complex	Ferruginous Tropical soil on sandy parent material and on crystalline acid rock.
5.	Funtua	Basement Complex	Ferruginous Tropical soil on sandy parent material and on crystalline acid rock.
6.	Makarfi	Basement Complex	Ferruginous Tropical soil on sandy parent material and on crystalline acid rock.
7.	Jaji	Basement Complex	Ferruginous Tropical soil on sandy parent material and on crystalline acid rock.
8.	Soba	Basement Complex	Ferruginous Tropical soil on sandy parent material and on crystalline acid rock.
9.	Saminaka	Basement Complex	Ferruginous Tropical on crystalline acid rock and Lithosol.
10.	Mubi	Basement Complex	Ferruginous Tropical on crystalline acid rock and Lithosol.
11.	Jos	Basement Complex	Ferruginous Tropical soil on crystalline acid rock and Undifferentiated Ferrisol.
12.	Bauchi	Basement Complex	Ferruginous Tropical soil on crystalline acid rock.
13.	Tubule	Sandstone	Undifferentiated Ferrisol.
14.	Gombe	Sandstone	Ferruginous Tropical soil on sandy parent material and Undifferentiated Lithosol.
15.	Deba-Habe	Sandstone and mud stone	Vertisol of Lithomorphic origin.
16.	Yadim	Basement Complex	Ferruginous Tropical soil on crystalline acid rock and on sandy parent materials.

KLINKENBERG & HIGGINS (1968).

on Kerri Kerri sandstone where-as sample number 14 is colluvial material on Gombe sandstone. Sample number 15 is lithomorphic vertisol derived from sandstone and mud-stone. Sample numbers 10 and 16 are tropical ferruginous soils on basement complex, (Klinkenberg and Higgins 1968). The names of locations, parent material and description of soils are given in Table 1.

The soils were air dried, crushed to pass through 2mm mesh screen and stored in polythene bags. For laboratory analysis, samples were crushed to pass through suitable sieves, and where specific analytical precedures demanded, recommended mesh screen sizes were used. They were then stored in glass bottles. For each soil scoop crushed for laboratory analysis, assurance was made that entire scoop passed through the mesh. It is well recognised that coarse particles, which are often discarded after adequate quantity of crushed samples must have been got, contribute more to the overall weight than nutrient status. This caution may erase unintended increase of values obtained in the laboratory, not reflected in green house study.

LABORATORY ANALYSIS

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.

Organic carbon

The organic carbon content of the soils was determined by dichromate oxidation method using the procedure described by Walkley and Black (1934).

Exchangeable cations

The exchangeable cations were determined by shaking 5gm of soil with three consecutive 30ml aliquots of 1N neutral NH4OAc on and end-to-end shaker, first for 2 hours and then twice for 30 minutes. Each shaking was followed by centrifugation and decantation into 100ml volumetric flasks. The flasks were made to mark and the potassium and sodium contents were determined by a flame photometer. The calcium and magnesium contents were determined by atomic absorption spectrophotometer.

Exchange acidity was determined by repeating the procedure for exchangeable cations using 1N KCl solution in place of NH_4OAc. The tritratable acidity was determined by titrating 50ml aliquot of the extract with 0.1N NaOH using phenolphthalein indicator. Effective cation-exchange capacity was obtained by summation.

Total phosphorus

Total phosphorus of the soils was determined by an alkaline oxidation method as described by Dick and Tabatabai (1977). 0.3gm of 100 mesh soil sample was oxidized with 3ml of sodium hypobromite on a sand bath at 270°C for one hour. Glass beads were added to the digesting system to eliminate bumping. The orthophosphate was dissolved with 1N H_2SO_4 and P determined colorimetrically by the modified molybdenum blue method of Murphy and Riley (1962).

Fractionation of soil phosphorus

The fractionation of the inorganic phosphate was performed according to the procedure of Chang and Jackson (1957) as modified by Peterson and Corey (1966). The inorganic fractions and their order of extraction were: aluminium phosphate (soluble in 0.5N NH_4F at pH 8.2), iron phosphate (soluble in 0.1N NaOH), reductant soluble iron phoshpate (soluble in 0.3M $Na_3C_6H_5O_7.2H\ O$ and $Na_2S_2O_4$) and calcium phosphate (soluble in 0.5N H_2SO_4). Phosphorus in the extracts were analysed colorimetrically using the procedure of Peterson and Corey (1966). The NH_4F extract was highly coloured. Decolorization was effected by filtering and aliquot through phosphorus free activated charcoal. The activated charcoal was dephosphorized by using a soxhlet extractor followed by repeated acidification, dilution and centrifugation. The charcoal was reactivated by drying in an oven at 150°C.

Extractable phosphorus

Available phosphorus was extracted by four chemical methods. These were: water, Bray No.1, EDTA and Resin.

Water method

5gms of soil were shaken with 50ml of distilled water for 1 hour on an end-to-end shaker. The suspension was acidified with one drop of concentrated HCl and centrifuged at 2000 rpm for 10 minutes. Phosphorus in solution was analysed by the molybdenum blue method of Murphy and Riley (1962).

Bray No.1 method

1gm of soil was shaken with 7ml of solution made up of 0.025N HCl and 0.03N NH_4F. Phosphorus in extract was determined colorimentrically (Olsen and Dean, 1965).

EDTA method

2gms of soil sample were shaken with 50ml of 0.01N EDTA solution for 1 hour on an end-to-end shaker (Sahrawat, 1977). The suspension was centrifuged at 2000 rpm for 15 minutes. 10ml aliquot was filtered through 0.5gm phosphorus free activated charcoal placed on a Whatman No.42 filter paper to decolorize the solution. Phosphorus in the extract was determined using ammonium molybdate stannous chloride blue colour method (Jackson 1957).

Resin method

2gms of 100-mesh soil sample and 2gms of Amberlite IRA-904 (Cl^- saturated) anion exchange resin which was retained by 30 mesh sieve were shaken with 100ml distilled water for 20 hours. The resin was separated from the soil using a 20-mesh screen by washing free of sand with a fine jet of water. Phosphorus adsorbed on the resin was extracted by leaching with 100ml of a mixture of 0.05N HCl and 0.025N H_2SO_4. A suction system was employed in the leaching process which was made to last about one hour. P in solution was determined by the Murphy and Riley (1962) modification of the ascorbic method.

Organic phosphorus

The organic phosphorus content of the soils was determined as outlined by Legg and Black (1955. One gram of soil, placed on a 50ml pyrex beaker was ignited in a muffle furace at 260°C for two hours. The ignited sample was then transfered to a 100ml centrifuge tube. A comparable 1gm sample of nonigigited soil was placed in a similar centrifuge tube. Ten milliliter of concentrated HCl was added to each tube and heated on a steam plate adjusted to 70°C for ten minutes. The tubes were removed, additonal 10ml of concentrated HCl was added to each tube and allowed to stand for one hour at room temperature. 50ml of distilled water was then added, mixed and centrifuged. P in the

extracts was determined immediately to prevent hydrolysis of organic phosphorus in the non-ignited extract. The extracts were decolorized as described by Legg and Black (1955). Phosphorus was determined by the Murphy and Riley (1962) method. An estimate of the organic phosphorus content was taken as the difference between the phosphorus found in the extracts of the ignited and unignited samples.

Phosphorus in plant material

1gm sample was digested with 15ml of 1:2:12 acid mixture of H_2SO_4, $HC1O_4$ and HNO_3 on a sand-bath. The extract was diluted, filtered through Whatman filter paper No.42, and made to 100ml volume. Phosphorus in the extract was determined by the molybdenum blue colour method of Murphy and Riley (1962).

Mechanical analysis

Particle size distribution was obtained by the standard hydrometer method. 50gm of 2-mm mesh soil was dispersed in 100ml of 5% calgon and 400ml distilled water for 5 minutes using a mechanical stirrer. The fractions were determined by the hydrometer method as described by Day (1965).

GREEN-HOUSE EXPERIMENT

The surface soils were cropped to maize in the green-house. Plastic planting pots of about 7 litters capacity

were filled with 4 kg of soil. In each pot, 16 maize seeds were planted and thinned to 12 stands per pot after six days when all seeds had germinated. Nutrients suspected to be critical in the savanna soils were applied in split doses:

These were:

100 ppm K supplied as KNO

200 ppm N supplied as KNO_3 and $Ca(NO_3)_2.4H_2O$

150 ppm Mg supplied as $MgSO_4.7H_2O$

35 ppm Zn supplied as $ZnSO_4.7H_2O$

S in nutrient solution was contained in Zn SO_4 and Mg SO_4.

Each soil was replicated four times and completely randomized in the greenhouse. Fir application of nutrient was at seeding. Second application was two weeks later. The soils were watered with distilled water as needed to keep the soil moist. The plants were harvested after 31 days, washed clean and dried at $60^{o}C$ for 7 days. Dry weight of plants per pot was recorded.

STATISTICAL ANALYSIS

Correlation and multiple regression analyses were performed using a C.D.C. Cyber 72 at the computer centre of Ahmadu Bello University, Zaria, Nigeria.

CHAPTER FOUR

RESULTS AND DISCUSSION

CHARACTERISTICS OF SOILS CHOSEN FOR STUDY

Locations from which samples were collected for this study are depicated in Fig.1. The soils were, at time of sampling under grassland or bush fallow. Information received from the inhabitants close to the sampling sites confirms the soils as virgin soils, as there was not knowledge of recent farming practice on the sites.

Soil Texture

Observation of soils during sampling showed that the soils were generally light textured. This was later certified in the laboratory. Particle size distribution of soils are given in Table 2. Soil texture varied from sand to clay loam for both depths. Clay content ranged from 2 to 29% in the surface soil (0 - 15cm) and 2 to 37% in the subsurface soil (15 - 30cm). Clay content increased with depth, though soils over sandstones tended to show an almost constant value for both depths. The silt content was generally low, with a minimum of 1% and never exceeded 13% in any soil. The sandy character of these soils is evident from the high percentage of sand recorded for all soils.

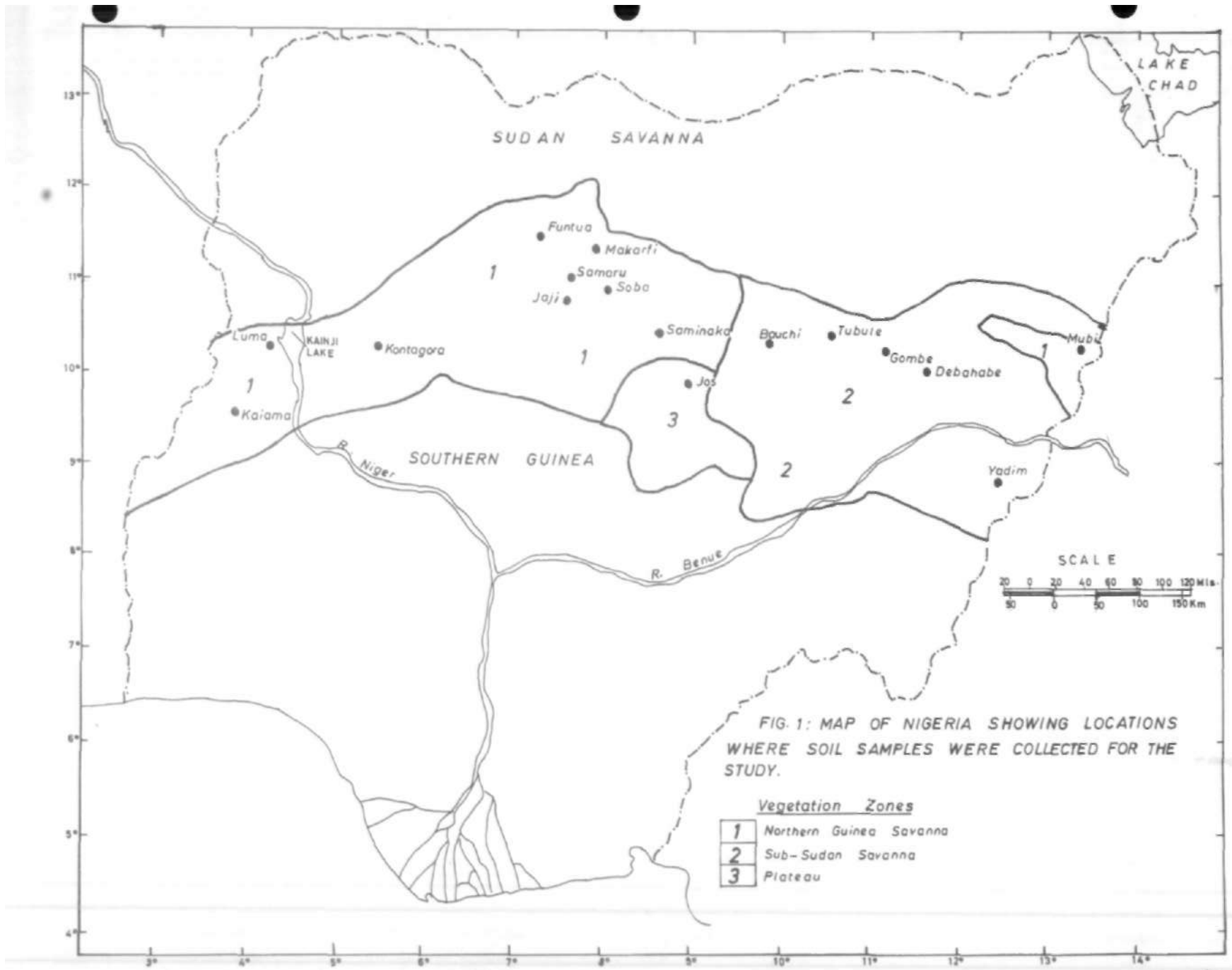


FIG. 1: MAP OF NIGERIA SHOWING LOCATIONS WHERE SOIL SAMPLES WERE COLLECTED FOR THE STUDY.

Table 2: Particle size distribution of soils

Lab.No	Location	Depth (cm)	Sand	Silt	Clay	*Textural Class
			-------- % -------			
1	Kaiama	0-15	85	7	8	Loamy Sand
		15-30	82	10	8	Loamy Sand
2	Luma	0-15	89	5	6	Loamy Sand
		15-30	89	6	5	Loamy Sand
3	Kontagora	0-15	90	5	5	Sand
		15-30	91	4	5	Sand
4	Samaru	0-15	84	6	10	Loamy Sand
		15-30	79	5	16	Sandy Loam
5	Funtua	0-15	86	5	9	Loamy Sand
		15-30	84	3	13	Sandy loam
6	Makarfi	0-15	75	12	13	Sandy loam
		15-30	66	12	23	Sandy Clay loam
7	Jaji	0-15	58	13	29	Clay loam
		15-30	50	13	37	Clay loam
8	Soba	0-15	81	7	12	Sandy loam
		15-30	70	7	23	Sandy Clay loam
9	Saminaka	0-15	72	11	17	Sandy loam
		15-30	55	12	33	Clay loam
10	Mubi	0-15	85	8	7	Loamy Sand
		15-30	83	9	8	Loamy Sand
11	Jos	0-15	66	10	24	Sandy Clay loam
		15-30	62	10	28	Sandy Clay loam
12	Bauchi	0-15	85	8	7	Loamy Sand
		15-30	80	5	15	Sandy loam
13	Tubule	0-15	93	1	6	Sand
		15-30	93	2	5	Sand
14	Gombe	0-15	96	2	2	Sand
		15-30	96	2	2	Sand
15	Daba-Habe	0-15	75	9	16	Sandy loam
		15-30	72	9	19	Sandy loam
16	Yadim	0-15	90	6	4	Sand
		15-30	90	5	5	Sand

*International system.

CHEMICAL PROPERTIES

pH

The chemical properties of the soils are listed in Table 3. Surface soils were slightly acid to slightly alkaline in reaction, with Jos recording the lowest pH and Luma the highest. Soil pH (water) ranged from 5.33 to 7.16 and were found to be consistently higher than pH ($CaCl_2$) in all soils by an average of about one unit. This difference indicates that the soils possess low buffering properties. The pH values in salt for the surface soils ranged from 4.60 to 6.78. The subsoils were generally more acidic and were 0.6 to 0.85 units lower than the corresponding surface soil, possibly due to the higher exchange cations present in the surface soils. The variation in pH in the subsurface soil was in line with the observed trend in the surface soil, save for the fact that Jaji tended to have the lowest pH ($CaCl_2$). The effect of parent material on soil pH was not pronounced, though the soils over sand stones were generally neutral to alkaline in reaction. The more acidic soils were those over basement complex.

Total carbon

Total carbon content of the soils ranged between a minimum of 0.40% and a maximum of 1.75% in Gombe and Jaji soils respectively. Values for most soils were within the

Table 3: Chemical properties of soils

Lab. No.	Location	Depth (cm)	Soil 1:1 H_2O	pH 1:1 $CaCl_2$	Total Carbon %	Exchangeable cations ---meq/100gm soil--- Na	K	Ca	Mg	Meg/ 100gm Effec- tive C.E.C.	+ C/P ratio
1	Kaiama	0-15	5.93	5.26	1.14	0.08	0.20	3.99	0.85	5.32	153.4
		15-30	5.94	4.82	0.89	0.10	0.21	2.68	0.48	3.77	148.0
2	Luma	0-15	7.16	6.78	0.68	0.06	0.17	5.37	0.37	5.97	97.2
		15-30	6.74	6.02	0.42	0.03	0.08	2.14	0.22	2.47	140.0
3	Kontagora	0-15	**6.44**	**5.74**	0.48	0.02	0.09	1.76	0.45	2.42	136.8
		15-30	**5.96**	**5.58**	0.26	0.03	0.10	1.17	0.30	1.80	325.0
4	Samaru	0-15	5.85	5.12	1.08	0.04	0.25	2.55	1.11	4.15	312.2
		15-30	5.14	4.44	0.46	0.05	0.14	1.37	0.57	2.73	174.0
5	Funtua	0-15	6.25	5.57	0.78	0.05	0.37	2.25	0.83	3.55	144.0
		15-30	6.23	5.39	0.63	0.05	0.27	2.13	0.65	3.15	149.0

vicinity of 0.75% which stood as an overall average for the surface soils of these ecological zones. There was a consistent decrease in the total carbon content with depth due to litter turn over and greater microbial activity in the surface soil.

Cation Exchange Capacity

Effective cation exchange capacity (CEC) was generally low with consistent relationship with mineralogy. Values ranged from 1.87 to 10.17 meq/100g soil in the surface soil, and 0.93 to 9.79 meq/100gm soil in the subsurface soil. The highest values were obtained from Deba-Habe, a vertisol with the swelling clays dorminating the clay fraction. This permitted the reasoning that the observed CEC was a function of amounts and kinds of clay that constituted the clay fraction, rather than just the amount of clay. Lower CEC values were recorded for the subsurface soils, though values tended to increase with depth in Soba, Mubi, Makarfi, Saminaka and Jos. The higher CEC of the surface soil suggest the contributary role of humic residues to overall CEC.

Calcium was the most abundant exchange cation in these soils and occupied an average of 75% of the exchange sites. Values for Na and K remained low for all soils. Mg content was also low but was significantly higher than Na and K contents.

Carbon: phosphorus ratio

Mean organic carbon: organic phosphorus ratio (C/P) was less than 200 for both depths, indicating the mineralization of organic P will readily occur (Tisdale and Nelson, 1956). The C/P values for the surface soils ranged between 69 and 312, with a mean of 165, and 54 to 325 in the subsurface soil, with a mean of 188.5. Values in the heavier textured soils tended to exceed 200, indicating that mineralization of organic P may not readily occur in these soils.

AMOUNT AND FORMS OF INORGANIC PHOSPHORUS

Total phosphorus

Table 4 shows the total phosphorus content of the soils and the distribution among the various chemical forms. Total phosphorus contents of the soils were generally low indicating the poor phosphorus fertility of these soils. In the surface soils, values ranged between 61.7 and 266.6 ppm with a mean of 147.0 ppm. Values were lower in the subsurface soils, varying between 44.0 and 203.0 ppm and a mean of 97.7 ppm. This obviously reflect surface accumulation of phosphorus through litter. The low phosphorus content of some tropical soils have been attributed to the low apatite content of the soil forming minerals.

Table 4: Soil phosphorus fractions and total phosphorus (ppm)

Lab. No.	Location	Depth	Al-P	Fe-P	Ca-P	Red-P*	Org-P	Resi-dual-P	Total
1	Kaiama	0-15	7.00	13.30	12.25	37.26	74.30	35.90	180.00
		15-30	2.50	13.00	6.80	33.0	60.00	11.40	126.70
2	Luma	0-15	11.25	11.40	3.25	29.60	70.00	36.20	161.70
		15-30	4.50	6.80	2.75	38.40	30.00	17.55	100.00
3	Kontagora	0-15	2.50	5.95	1.80	22.40	35.10	59.21	124.96
		15-30	trace	5.80	1.80	28.20	8.00	69.50	113.30
4	Samaru	0-15	4.40	11.40	1.80	37.34	34.60	57.11	146.70
		15-30	1.80	9.00	1.80	20.40	26.40	8.95	68.35
5	Funtua	0-15	2.50	13.40	5.10	36.80	54.20	36.40	148.40
		15-30	1.25	9.20	1.80	18.20	42.40	2.15	85.00
6	Makarfi	0-15	3.40	9.00	4.20	42.00	37.00	54.41	150.01
		15-30	4.50	8.00	1.50	30.00	26.00	0.00	70.00
7	Jaji	0-15	6.50	25.00	15.00	44.00	71.80	104.30	266.60
		15-30	4.50	19.00	6.50	38.40	51.20	83.40	203.00
8	Soba	0-15	2.25	7.14	2.50	31.40	37.60	9.11	90.00
		15-30	1.80	6.80	1.50	30.00	10.40	15.50	65.00
9	Saminaka	0-15	1.80	9.50	3.50	19.40	34.60	11.20	90.00
		15-30	1.80	10.00	1.50	25.20	20.00	29.90	88.35
10	Mubi	0-15	5.8	14.80	4.80	36.00	50.00	85.25	196.65
		15-30	1.00	9.00	3.80	19.40	35.50	34.65	113.35
11	Jos	0-15	4.80	19.85	7.20	33.70	67.00	60.75	193.30
		15-30	2.50	16.20	5.50	43.20	24.00	35.30	126.70
12	Bauchi	0-15	4.00	9.20	2.30	31.94	43.80	25.46	116.70
		15-30	0.70	7.30	2.00	28.20	21.60	40.20	100.00
13	Tubule	0-15	6.00	9.20	2.30	27.40	78.30	23.45	146.65
		15-30	2.50	9.50	1.50	30.00	44.20	0.00	87.70
14	Gombe	0-15	4.40	4.85	1.50	29.24	21.00	0.00	61.70
		15-30	2.00	3.80	0.75	25.00	12.00	0.00	44.00
15	Deba-Habe	0-15	2.80	9.20	5.50	32.40	62.00	41.45	153.35
		15-30	4.50	8.50	1.80	40.20	51.20	27.15	133.35
16	Yadim	0-15	5.80	10.00	5.00	36.80	61.00	4.75	121.35
		15-30	3.00	7.20	2.50	8.00	24.00	18.65	63.35
	Mean	0-15	4.70	11.50	4.90	33.61	52.02	40.31	147.00
		15-30	2.43	9.32	2.74	30.00	30.43	24.64	99.25

*Reductant soluble iron phosphate (Iron oxide occluded P).

Parent rocks of soils studied consists mainly of schists, grantitic gneiss and sandstones, all of which have low apatite inclusions.

As it is evident in Table 4, the variation in the total phosphorus content was significant, with peculiar relationship to clay content and organic matter. Phosphorus in soils have been more associated with the fine textured fractions (Bates and Baker, 1960). The high P content in Jaji and Jos may be explained as due to their high clay content. On the other hand, the very low clay content of Gombe may account for the low P content of the soil. The organic matter content was also observed to have an equal and sometimes superior influence on the amount of soil phosphorus as shown by the correlation coefficient of organic matter ($r = 0.79^{***}$) and clay ($r = 0.59^{*}$) with total phosphorus. This was the main variable that accounted for the observed difference between the surface soil and the subsurface soil. However, both factors seemed to have considerable influence as was demonstrated in Funtua and Makarfi soils. Both surface soils had comparable total P values (150 ppm) but varied in their clay content (Table 2) and organic carbon content (Table 3) in a reciprocal order, which defined the relationship between the two factors in accounting for the observed P values.

Harter, (1969) had earlier demonstrated the importance of organic matter in the initial bounding of P and subsequent reversion to less soluble forms.

Parent material may also offer an explanation for the observed differences in total P values between soils. The inherent fertility of the parent rocks has been used as a valid criterion for assessing the phosphorus fertility of broad regions. Variation in total P in respect to parent material has been demonstrated by Rodes (1977), Uzu et al (1975), and Enwezor (1977b). Pinto (1974) showed that the more mature soils possessed low P values. The low P content of these savannah soils may, in addition to the low apatite content, be due to their maturity. In this study, soils over basement complex were obsered to contain more P (with a range of 90 to 266.6 ppm and a mean of 154.5 ppm) than soils over sandstones (with values varying between 61.7 to 161.7 ppm and a mean value of 129.5 ppm) for the surface soils. The same relationship was also maintained in the subsurface soils. The high quartz content of sandstones may be responsible for the low P content of the soils over sandstones, considering the low nutrient content of quartz.

Inorganic phosphorus fractions

The results of the inorganic P fractions are given in Table 4. Data are reported on air-dry basis. The values of three active fractions (NH_4F - Soluble (Al-P), NaOH - Soluble (Fe-P) and H SO - Soluble (Ca-P), for all soils expressed

(Fe-P) and H SO - Soluble (Ca-P), for all soils expressed as percentages of total extractable inorganic P are shown in Table 5. Total active fractions, occluded-P (dithionite - citrate) and total extractable inorganic P expressed as percentage of total P are shown in Table 6.

The amount of Al-P varied from 1.8 to 11.25 ppm in the surface soil, and from trace amounts to 4.5 ppm in the subsurface soils. Average values of 4.7 ppm and 2.43 ppm were recorded for both surface and subsurface soils respectively. The contribution of this fraction to total extractable inorganic P ranged between 4.10 and 20.27% in the surface and near zero to 14.50% in the subsurface soil. Higher Al-P values were obtained for the more neutral to alkaline soils than for acid soils. There was a consistent decrease in the amount of Al-P with depth reflecting the observed decrease in total P with depth. Al-P was significantly correlated with total P ($r = 0.46$) at 5% probability level in the surface soil. The subsurface soil exhibited no such relationship.

The Fe-P content was higher than that of Al-P in all soils, with the exception of Luma and Gombe for which both values tended to be comparable. Amounts of Fe-P ranged from 4.85 to 25 ppm with an average of 11.5 ppm in the surface soils, and 3.80 to 19.00 ppm with an average of 9.32 ppm in the subsurface soil. Fe-P was found to

Table 5: Inorganic phosphorus fractions expressed as percentages of total inorganic phoshporus.

Lab. No.	Location	Depth (cm)	P fractions (%)				Total inorganic P (ppm)
			Al-P	Fe-P	Ca-P	Red-P*	
1	Kaiama	0-15	10.00	19.05	17.55	53.40	69.81
		15-30	4.52	23.30	12.30	59.67	55.30
2	Luma	0-15	20.27	20.54	5.90	53.29	55.50
		15-30	8.58	13.00	5.24	73.18	52.45
3	Kontagora	0-15	7.66	18.22	5.50	68.62	32.65
		15-30	trace	16.20	5.03	78.80	35.80
4	Samaru	0-15	8.00	10.80	3.20	70.00	55.00
		15-30	5.45	17.27	5.45	61.83	33.00
5	Funtua	0-15	4.33	23.18	8.82	63.67	57.80
		15-30	3.10	22.74	4.45	69.71	40.45
6	Makarfi	0-15	5.80	15.36	7.17	71.67	58.60
		15-30	10.23	18.20	3.41	68.16	44.00
7	Jaji	0-15	7.18	27.62	16.58	48.62	90.50
		15-30	6.58	27.80	9.50	56.12	68.40
8	Soba	0-15	5.20	16.50	5.80	72.50	43.30
		15-30	4.50	16.96	3.75	74.80	40.10
9	Saminaka	0-15	4.10	21.50	8.00	66.40	44.20
		15-30	4.68	26.00	3.90	65.42	38.50
10	Mubi	0-15	9.50	24.10	7.82	58.58	61.40
		15-30	2.32	20.83	8.80	68.05	43.20
11	Jos	0-15	7.32	30.28	11.00	51.40	65.60
		15-30	3.71	24.11	8.16	64.02	67.40
12	Bauchi	0-15	8.42	19.37	4.85	67.36	47.50
		15-30	1.83	19.11	5.53	73.53	38.20
13	Tubule	0-15	13.36	20.50	5.12	61.02	50.00
		15-30	5.75	21.84	3.45	68.96	43.50
14	Gombe	0-15	11.00	12.12	3.75	73.18	40.00
		15-30	6.34	12.04	2.38	79.24	31.55
15	Deba-Habe	0-15	5.60	18.40	11.00	65.00	50.00
		15-30	8.18	15.46	3.27	73.09	55.00
16	Yadim	0-15	10.10	17.36	8.70	63.84	57.60
		15-30	14.50	34.78	12.07	38.65	20.70
	Mean	0-15	8.62	20.30	8.17	63.08	55.00
		15-30	5.64	21.24	6.04	67.08	44.22

Table 6: Total active P, total inorganic P and occluded P expressed as percentages of total P.

Lab. No.	Location	Depth (cm)	% Active-P	% Inorganic-P	% Occluded-P
1	Kaiama	0-15	18.10	38.80	20.70
		15-30	18.10	38.80	26.00
2	Luma	0-15	16.01	34.32	18.30
		15-30	14.05	52.48	38.40
3	Kontagora	0-15	8.20	21.60	18.00
		15-30	6.71	31.60	25.00
4	Samaru	0-15	12.00	37.50	25.50
		15-30	18.43	48.30	30.00
5	Funtua	0-15	14.15	39.00	24.80
		15-30	14.40	47.60	33.20
6	Makarfi	0-15	11.00	39.00	28.00
		15-30	20.00	62.90	42.90
7	Jaji	0-15	17.50	34.00	16.50
		15-30	14.80	33.70	19.00
8	Soba	0-15	13.20	48.11	35.00
		15-30	15.54	61.60	46.20
9	Saminaka	0-15	16.50	49.11	32.70
		15-30	15.05	43.60	28.00
10	Mubi	0-15	13.00	31.40	18.31
		15-30	12.20	38.10	26.00
11	Jos	0-15	16.50	34.00	17.40
		15-30	19.10	53.20	34.10
12	Bauchi	0-15	13.28	40.70	27.40
		15-30	10.00	38.20	28.20
13	Tubule	0-15	12.00	34.10	18.70
		15-30	15.40	49.60	34.20
14	Gombe	0-15	17.40	64.80	47.40
		15-30	15.00	71.70	57.00
15	Deba-Habe	0-15	11.40	32.60	20.80
		15-30	11.10	41.20	30.20
16	Yadim	0-15	17.14	41.50	30.30
		15-30	20.00	32.70	12.60
	Mean	0-15	14.21	38.80	25
		15-30	15.00	46.90	28

constitute between 12.12 to 30.28%, with a mean of 20.30% of total inorganic P, and 12.04 to 34.78 with a mean of 21.24% in the surface and subsurface soils respectively. The higher amounts of Fe-P over other active fractions is expected since the soils were essentially slightly acid to neutral in reaction. Soils with the lower pH values (Jos and Jaji) recorded the highest percentage Fe-P values, suggesting preferential formation of Fe-P in the more acid soils as reported by Chang and Jackson, (1958) and Hus (1964). There was a tendency for greater accumulation of Fe-P in the more acid soils than in the more neutral soils, as shown by the computed means of 21.8% of total inorganic P for the surface soils with pH less than 6, and 18.8% for surface soils above pH 6. The proportion of Fe-P was higher in the sub-surface soils than in the surface soils, still reflecting the lower pH values of the sub-surface soils. Fe-P was significantly correlated with total P in both surface soil ($r = 0.89$) and sub-surface soil ($r = 0.75$).

Amounts of Ca-P were generally low as would be expected in the slightly acid soils of the savanna regions. Amounts were comparable to the amounts of Al-P in both depths. Ca-P in the surface soils ranged from 1.5 to 15 ppm and from trace values to 6.8 ppm in the sub-surface soils. Mean values were 4.9 ppm and 2.74 ppm in the surface and sub-surface soils respectively.

The low amounts of Ca-P found in these soils may be due to possible conversion of Al-P and Fe-P in the acid to neutral soils of these ecological zones. Percentage contribution of this fraction to total extractable inorganic P ranged between 3.2 to 17.55% and from 2.38 to 12.30% in the surface and subsurface soils respectively, with corresponding mean values of 8.17 and 6.04%. The preferential formation of Ca-P relative to Al-P in near neutral soils has been reported by Lindsay and Moreno (1960). Calcium phosphate was significantly correlated with total P in the surface soil ($r = 0.78$) and subsurface soil ($r = 0.72$) as was observed with Fe-P.

The reductant soluble fraction (iron-oxide occluded P) was the most abundant of the extractable inorganic P in these soils. Amounts varied from 22.4 to 44 ppm and 8 to 43.2 ppm in the surface and subsurface soils respectively. Mean contribution to total extractable inorganic P was 63.03% in the surface soil, and slightly higher value of 67.08% in the subsurface soil. Comparable results have been reported by other workers on savanna soils (Uzu et al, 1975; Udo and Ogunwale, 1977). These values exceed the contribution of the active fractions combined, as shown in Table 6. The occluded P was observed to constitute between 16.5 to 47.6% of total P in the surface soils and 12.6 to 57.0% in the subsurface soils.

The active fractions constituted 11 to 18.1% of total P and 10 to 20% in the corresponding depths.

The relative amounts of inorganic P fractions have been used to assess the extent of pedogenetic processess. On the Chang and Jackson scale, the observed distribution of the inorganic P forms indicate that all the soils were highly weathered, and are capable of fixing reasonable proportions of the existing small amounts of the native soil phosphorus in relatively unavailable forms. Occluded phosphate was about three times more in amount than Fe-P, which in turn was three times greater than the amounts of Al-P and Ca-P. The relationship could be simply stated thus: Occluded-P>>>Fe-P>>>Al-P $\approx$ Ca-P. This sequence of abundance of the inorganic fractions was also observed by Uzu et al, (1975).

The amounts of Al-P were significantly correlated with Ca-P ($r = 0.65$) in the more acid soils, but exhibited no relationship with others on general consideration. Generally, Ca-P was highly related to Fe-P ($r = 0.80$) while both fractions showed very low correlation coefficients with Al-P. This indicates the transitory role of Al-P, and in these mature soils, Fe-P has assumed a near primary role like Ca-P.

EXTRACTABLE PHOSPHORUS AS INDICES OF AVAILABLE PHOSPHORUS

Soil P was extracted with four extractants described in Chapter 3. The correlation coefficients between the methods are given in Table 7. Mean values of P extracted by the four extractants under varied conditions are given in Table 8. Table 9 shows the amount of P extracted from all soils by the extractants.

The amount of P extracted by EDTA was significantly correlated with all the other methods and was the only method that was related to the resin method. The most highly related were EDTA and Water with a correlation coefficient of 0.77**. Resin extractable-P was non-si significantly correlated with water (r = 0.27) and Bray No.1 (r = 0.14). The degree of interrelationship was higher in all cases for soils with pH above 6, except for resin and EDTA methods which were more related in the more acid soils, though r value was non-significant. The differing degress of interrelationship among methods demonstrate the relative similarities between the methods in extracting soil P. The high r value obtained between water-P and EDTA-P suggests that these two extractants may have derived their P from the same chemical forms of soil P, and to a large extent would substitute for one another. No two methods were significantly correlated in the acid soils.

Table 7: Correlation between amounts of P removed by different methods from surface soils.

Method	Soil pH group	Number of samples (n)	Methods		
			EDTA	Resin	Bray No.1
Water	pH > 6	8	0.91***	0.28	0.91***
	pH < 6	8	-0.56	-0.54	-0.72
	all	16	0.77**	0.26	0.45*
Bray No.1	pH > 6	8	0.85**	0.23	
	pH < 6	8	0.32	0.08	
	all	16	0.54*	0.14	
Basin	pH > 6	8	0.37		
	pH < 6	8	0.49		
	all	16	0.46		

* Significant at 5% level of probability
** Significant at 1% level of probability
*** Significant at 0.1½ level of probability

Table 8: Mean values of P removed from soils as influenced by pH and varied parent materials.

Soil group	Depth (cm)	Phosphorus (ppm) extracted with			
		Water	Bray No.1	Resin	EDTA
pH ≥ 6	0-15	2.01	2.36	8.12	4.00
	15-30	0.55	1.12	5.08	1.09
pH < 6	0-15	0.64	2.43	6.82	1.75
	15-30	0.41	1.79	5.44	0.86
Sandstone	0-15	1.97	3.16	7.66	4.60
	15-30	0.32	1.62	6.21	1.67
Basement Complex	0-15	1.04	2.05	7.31	2.09
	15-30	0.50	1.62	5.00	0.58

Table 9: Amounts of phosphorus removed from soil by different extractants.

Lab. No.	Location	Depth (cm)	Phosphorus (ppm) extracted with			
			Water	Bray No.1	Resin	EDTA
1	Kaiama	0-15	0.41	2.10	10.63	1.25
		15-30	0.54	1.40	12.81	1.25
2	Luma	0-15	5.30	4.32	6.90	10.50
		15-30	0.24	1.40	6.25	1.25
3	Kontagora	0-15	0.29	1.68	7.50	2.75
		15-30	0.00	0.42	3.75	0.50
4	Samaru	0-15	0.77	1.05	6.90	1.35
		15-30	0.00	0.42	3.75	0.50
5	Funtua	0-15	1.51	1.54	6.90	1.25
		15-30	0.88	0.77	4.38	0.50
6	Makarfi	0-15	0.52	3.92	3.13	trace
		15-30	0.68	1.40	2.19	trace
7	Jaji	0-15	0.88	1.58	5.63	0.86
		15-30	1.04	0.72	3.75	1.25
8	Soba	0-15	0.00	1.40	5.94	0.00
		15-30	0.00	0.56	0.94	0.00
9	Saminaka	0-15	0.87	1.19	3.75	0.50
		15-30	0.54	0.56	3.75	0.25
10	Mubi	0-15	2.10	2.10	13.44	6.00
		15-30	0.67	1.26	4.38	0.86
11	Jos	0-15	0.80	2.24	7.50	0.25
		15-30	0.27	1.40	4.38	trace
12	Bauchi	0-15	0.43	2.94	8.44	6.50
		15-30	0.47	1.96	8.44	1.00
13	Tubule	0-15	0.43	4.32	8.56	3.25
		15-30	0.27	2.66	3.75	3.00
14	Gombe	0-15	3.12	3.64	10.63	4.50
		15-30	0.67	1.96	10.31	1.50
15	Deba-Habe	0-15	0.69	1.82	4.70	2.00
		15-30	0.43	1.05	5.31	1.75
16	Yadim	0-15	3.12	2.38	8.13	5.00
		15-30	0.43	7.42	6.25	0.75
	Mean	0-15	1.33	2.40	7.42	2.90
		15-30	0.45	1.60	5.35	0.92

The amounts of P removed by the four extractants used were low for the soils studied. This is a direct consequence of the sandy texture of these soils. The slightly acid reaction of the soils ensured fixation in unavailable forms and extraction of P by the reagents was difficult, due to the fact that all soils were highly weathered, with the greatest proportion of P existing in the occluded and Fe-P forms, both of which have very low solubilities in water, and the reagents in general.

Anion exchange resin extracted more P than any other method. EDTA and Bray No.1 reagents removed comparable amounts but were significantly lower than amounts extracted by resin. The lowest results were obtained with water as was observed by Oteng and Acquaye (1971) and Oko and Agboola (1974).

Amounts of P extracted by anion exchange resin varied from 0.94 ppm in Soba subsurface soil, to 13.44 ppm in Mubi surface soil, with mean amounts of 7.42 and 5.35 ppm for the surface and subsurface soils respectively. These amounts represent 13.50 and 12.10 mean percent of total extractable inorganic P for the respective depths. The relatively higher amounts of P extracted by resin, may be due to the fact that the rate of diffusion from soil to solution did not pose any limitation, since solution P was constantly being reduced by the chemical exchange on

the resin, therefore encouraging further diffusion. Barrow and Shaw (1977) showed that there was no definite value for for resin P since higher values were always obtained when extraction times were increased. As indicated by Enwezor (1977b) anion exchange resin in soil-water system essentially measures water soluble-P. The result demonstrate that high solubilization power of water if solution phosphors is reduced to very low amounts, as it is the case in soil-water-root system.

Phosphorus extracted by EDTA varied from zero ppm in the surface and subsurface soils of Soba and Makarfi, to 10.50 ppm in Luma surface soil. Mean values were 2.90 and 0.92 ppm, constituting 5.27 and 2.10 mean percent of total extractable inorganic P in the surface and subsurface soils respectively. Though the chelating compound was found to be relatively effective in removing P in some soils such as Luma, Bauchi and Mubi surface soils, its generally low extracting power may be attributed to the weak chelating property of the reagent, ascribable to the low concentration of EDTA used. Its activity must have been weak relative to the stronger phosphate bonds that exists in these soils.

Amounts extracted by Bray No.1 reagent varied from 1.05 to 4.32 ppm with a mean of 2.32 ppm in the surface soils, and 0.42 to 7.42 ppm with a mean of 1.12 ppm in the

subsurface soil. These values constituted 4.36 and 3.62 mean percent of total extractable inorganic P for the respective depths. The low clay contents of these soils, on general consideration, invalidates the explanation that the small amounts of P removed by the reagent may be due to exhaustion of the reagent (Pratt and Garber, 1964). P in these soils were largely unavailable for extraction by this reagent due to the fact that the larger proportion of inorganic P existed in the occluded and Fe-P forms, which have very low solubility in dilute acids (Enwezor, 1977b). The low Al-P amount found in these soils may also explain the relative ineffectiveness of the flouride component of the reagent in extracting soil P.

Water extracted the least amount of P in these soils. Amounts varied from zero ppm in some subsurfaces soils to 5.30 ppm in Luma surface soil. Mean values were 1.33 and 0.45 ppm in the surface and subsurface soils respectively. The low amounts of P extracted by water has been explained as due to low solubility of Al-P and Fe-P in acid soils (Enwezor 1977b). These fractions constitute the major bulk of the active P fractions in the soils studied. Water extracted the highest amount from the slightly alkaline soil of Luma. Despite the high total P content of Jaji and Jos, the most acidic soils, very low amounts

of P were extracted. This suggests possible refixation of P during extraction, as well as the high degree of unavailability of phosphorus in these soils.

The influence of soil pH on P extracted by the reagents is shown in Table 8. All extractants, with the exception of Bray No.1 reagent, removed more P from soils of higher pH. The higher efficiency of Bray No.1 reagent in the more acid soils is expected. The flouride ion displaces phosphates from iron and aluminium phosphate compounds to release P. The lower activity of Fe and Al in the more neutral to alkaline soils may account for the higher amounts of P extracted by the other three extractants.

The influence of parent material was more general and all extractants removed more P from soils over sandstones. The suitability of water, as an extractant, on sandy soils was pointed out by Bingham (1949). Aside from the fact that soils over sandstones tended to be more alkaline, the more sandy nature of these soils may have been responsible for thelower retention and refixation properties that possibly might have been possessed by these soils, therefore making it easier to remove P.

Amounts of P removed by all extractants decreased consistently with depth. This was more evident in amounts extracted by EDTA, reflecting lower content of exchangeable

cations in the subsurface soil. Bonding of P by organic matter may be responsible for the greater P values obtained for the surface soils. Velcher et al, (1975); and Singh (1969a) have found lower P fixing properties of soils with increase in organic matter content.

CORRELATION AND MULTIPLE REGRESSION OF P EXTRACTED BY THE EXTRACTANTS ON PHOSPHORUS FRACTIONS

Phosphorus extracted by the four extractants were correlated with soil P fractions, and the correlation coefficient (r) are reported in Table 10. The Al-P fraction correlated highly with P extracted by all methods and it was the only fraction that was significantly correlated. Higher correlation coefficients were obtained with Al-P for the more neutral to alkaline soils. The only disparity was with resin-P which was significantly correlated with Al-P in acid soils only. Water-P and EDTA-P were significantly correlated at the 1% cofidence limit when all soils were considered together, and at 0.1% confidence limit in soils with pH above 6. The most highly correlated methods with Al-P were EDTA (r = 0.97***) and water (r = 0.92***) for soils above pH 6. The relationship between Al-P and EDTA-P and water-P were non-significant in acid soils, signifying low contribution of this fraction to P extracted by these methods in acid soils.

Table 10: Correlation of soil test values with inorganic P fractions (surface soils).

Phosphorus fractions	Sample (n)	Soil pH group	Correlation coefficients (r) with P extracted by			
			Water	Bray No.1	Resin	EDTA
Al - P	8	pH ≥ 6	.92***	.84**	.22	.97***
	8	pH < 6	-.30	.14	.70	.07
	16	all	.66**	.53*	.36	.66**
Fe - P	8	pH ≥ 6	.26	-.08	.26	.30
	8	pH < 6	.57	-.38	.04	-.36
	16	all	-.04	-.24	+.02	-.18
Ca - P	8	pH ≥ 6	.01	-.30	-.10	-.02
	8	pH < 6	.21	-.28	.18	-.37
	16	all	-.14	-.23	.01	-.30

* Significant at 5% level of probability
** Significant at 1% level of probability
*** Significant at 0.1% level of probability

Bray-P was significantly correlated with Al-P at the 5% confidence limit when all soils were considered together, and at 1% confidence limit in the more neutral to alkaline soils. Resin-P was significantly correlated with Al-P in acid soils only ($r = 0.70^{*}$)

Iron phosphate and calcium phosphate were non-significantly correlated with P extracted by all extractants. Amounts extracted by Bray and EDTA methods were essentially negatively correlated with Fe-P and Ca-P considered separately for both pH groups. All methods were negatively correlated with both fractions, except resin method which showed positive but very low r values with both fractions. These results indicate greater availability of Al-P to the extractants, and the contributions of Fe-P and Ca-P to P extracted by the methods were very negligible. Numerous investigators have also reported high dependence of extractants procedures on the Al-P fraction (Maida, 1978; Susuki et al, 1963; Pratt and Garber, 1964). Others include Hawkins and Kunze, (1965); Halm and Bampoe-Addo (1972); Juo and Ellis, (1968). None of the P forms correlated significantly with P extracted by any of the methods in the subsurface soil. Fe-P and Ca-P were mostly involved in negative correlation with Bray- and EDTA-P.

Multiple regression analysis was carried out to investigate the relationship between extraction methods

and the three P fractions for the surface soil only. The regression equations and the coefficient of multiple determination (R^2) for the extraction methods are given in Table 11.

When all soils were considered together, Fe-P and Ca-P were both involved in a negative relationship with low coefficients, suggesting their low contribution to P extracted by the methods. Al-P was always involved in a positive relationship indicating greater dependence of the soil test methods on this fraction.

The coefficient of multiple determination represents the variation of extracted P accounted for by Al-P, Fe-P and Ca-P. The higher the R value, the greater the predictability of the extracted P based on the three fractions. This index varied from 14.3% for resin, to 70% for EDTA methods. When soils were considered on the basis of pH, the dependence of extracted P on P fractions was as high as 93.6% for EDTA in soils above pH 6.

Table 11 also shows the percentage of R^2 explained by a single variable. Al-P accounted for most of the R^2 value with the lowest percentage contribution of 13 for resin and the highest of 44 for water when all soils were considered together. Water and Bray No.1 methods were more associated with Fe-P which accounted for much of their R^2 in acid soils. In the more alkaline soils, Al-P was the major fraction that

Table 11: Multiple regression of soil tests on phosphorus fractions and coefficients of multiple determination (R^2)

Dependent variable y (P in ppm)	Sample (n)	Soil pH group	Prediction equation	R^2	R explained by single variable
Water - P	8	pH $\geq$ 6	$Y = -.304 + .568X_1 - .076X_2 + .109X_3$	.850	.843 (X_1)
	8	pH < 6	$Y = 0.600 - .087X_1 + .038x_2 - .008X_3$	.788	.321 (X_2)
	16	all	$Y = -.134 + .461X_1 - .421X_2 - .135X_3$	.566	.439 (X_1)
Bray No.1 - P	8	pH $\geq$ 6	$Y = 1.975 + .337X_1 - .112X_2 - .234X_3$	.848	.697 (X_1)
	8	pH < 6	$Y = 2.177 + .376X_1 - .082X_2 - .072X_3$	.310	.145 (X_2)
	16	all	$Y = 1.958 + .322X_1 - .073X_2 - .495X_3$	.493	.283 (X_1)
Resin - P	8	pH $\geq$ 6	$Y = 6.593 - .462X_1 + .666X_2 - 1.289X_3$	.285	.067 (X_2)
	8	pH < 6	$Y = 2.040 + 1.479X_1 - .102X_2 - .144X_3$	.645	.497 (X_1)
	16	all	$Y = 5.947 + .445X_1 - .372X_2 - .401X_3$	.143	.129 (X_1)
EDTA - P	8	pH $\geq$ 6	$Y = -.590 + 1.046X_1 + 2.238X_2 - .139X_3$	.939	.936 (X_1)
	8	pH < 6	$Y = .926 + .656X_1 - .057X_2 - .251X_3$	.307	.137 (X_3)
	16	all	$Y = .429 + 1.022X_1 - .463X_2 - .376X_3$	.705	.431 (X_1)

X_1 = Al-P, X_2 = Fe-P, X_3 = Ca-P.

contributed to P removed by the methods as it is evidence by the R values. However, resin-P was more related to Fe-P. The very low R^2 values obtained in this study for resin-P, suggests that sources other than the three active fractions contributed to the P extracted by this method.

The relative contribution of the various P fractions to the P extracted by the soil test methods was assessed by carrying out a linear stepwise regression analysis. Results of the analysis, as well as the R^2 values for all soils are given in Table 12a. The step numbers indicate the order of relative importance of the P fractions in contributing to extracted P, step number 1 being the most important. From the rank order of the P fractions, it is evident that the major fraction that contributed to the observed variation in the regression of extracted P was the Al-P fraction. Addition of Ca-P to Al-P improved the R^2 values for water and EDTA methods. Addition of Fe-P to the two fractions did not improve the relationship. This suggests that water and EDTA must have extracted P associated with Al and Ca, and not with Fe. Bray No.1 reagent removed much of its P from Al-P and Fe-P fractions. Addition of Ca-P to the regression equation did not improve the relationship. The major source of variation in the resin methods was the Al-P fraction.

Table 12a: Stepwise regression analysis for the regression of soil P test on P fractions and coefficients of multiple determination for all 16 soils (N = 16)

Soil test method	P fraction	R^2	R^2
Water	Al	.4391**	
	Al-P + Ca-P	.5651	.1260**
	Al-P + Ca-P + Fe-P	.5651	.0009
Bray No.1	Al-P	.2825*	
	Al-P + Fe-P	.4823	.1998*
	Al-P + Fe-P + Ca-P	.4926	.0103
Resin	Al-P	.1292	
	Al-P + Fe-P	.1414	.0122
	Al-P + Fe-P + Ca-P	.1426	.0012
EDTA	Al-P	.4306**	
	Al-P + Ca-P	.7031	.2725***
	Al-P + Ca-P + Fe-P	.7053	.0022

* Significant at 5% level of probability
** Significant at 1% level of probability
*** Significant at 0.1% level of probability

Results of the stepwise regression analysis for both pH groups are given in Tables 12 (b and c). In acid soils Fe-P was the major fraction that contributed to variation in water and Bray phosphorus. Addition of Al-P to Fe-P greatly improved the relationship, and was significantly correlated at the 5% level of probability ($r = 0.88$). In the more neutral soils, Al-P was the major fraction that contributed to the variation in water, Bray and EDTA-P. Addition of Fe-P to Al-P improved the relationship with Bray P_1.

The standard partial regression coefficients (SPRC), a measure of the relative importance in predicting soil test P are summarized in Table 13. As the table shows, Al-P was the most important fraction that contributed to P extracted by the reagents. Extraction of this fraction by the extractants was in the order of EDTA > water > Bray > resin. When all soils were considered together, Fe-P and Ca-P were mostly involved in negative relationship.

The insignificant contribution of Fe-P to extracted P values, explain the small amounts of P extracted by the reagents. The values may be too low to represent the available P fraction in the soil for one growing season. The generally higher amounts extracted by resin indicate that this extractant may be capable of removing more

Table 12b: Stepwise regression analysis for the regression of extracted P on P fractions in soils of pH $\geq$ 6 (n = 8)

Extraction Proc.	P Fraction	R^2	R^2
Water	Al-P	.8426**	
	Al-P + Fe-P	.8464	.0038
	Al-P + Fe-P + Ca-P	.8499	.0035
Bray No.1	Al-P	0.6969**	
	Al-P + Fe-P	0.8468	.1499**
	Al-P + Fe-P + Ca-P	0.8475	.0007
Resin	Fe-P	.0665	
	Fe-P + Ca-P	.2807	.2142
	Fe-P + Ca-P + Al-P	.2826	.0019
EDTA	Al-P	.9362***	
	Al-P + Ca-P	.9386	.0024
	Al-P + Ca-P + Fe-P	.9388	.0002

* Significant at 5% level of probability
** Significant at 1% level of probability
*** Significant at 0.1% level of probability

Table 12c: Stepwise regression analysis for the regression of extracted P on P fraction in soils of pH < 6 (n = 8)

Extraction Proc.	P Fractions	R^2	R^2
Water	Fe-P	.3207	
	Al-P + Fe-P	.7772	.4565*
	Al-P + Fe-P + Ca-P	.7876	.0104
Bray No.1	Fe-P	.1406	
	Al-P + Fe-P	.2857	0.1451
	Al-P + Fe + Ca-P	.3101	0.0244
Resin	Al-P	.4916	
	Al-P + Ca-P	.6251	.2335
	Al-P + Ca-P + Fe-P	.6452	.0201
EDTA	Ca-P	.1365	
	Al-P + Ca-P	.2979	.1614
	Al-P + Fe + Ca-P	.3067	.0088

* Significant at 5% level of probability
** Significant at 1% level of probability
*** Significant at 0.1% level of probability

Table 13: Coefficients of multiple determination (R^2) and standard partial regression coefficients (SPRC) for the regression of soil test - P on P fractions

Extractable-P	Soil group	Sample (n)	SPRC Al-P	SPRC Fe-P	SPRC Ca-P	R^2
Water - P	pH ≥ 6	8	.967	-.143	.099	.850
	pH < 6	8	-.719	1.086	.196	.788
	all	16	.777	-.030	-.359	.566
Bray - P	pH ≥ 6	8	.965	-.374	-.045	.848
	pH < 6	8	.538	-.406	-.298	.310
	all	16	.701	-.340	-.171	.493
Resin - P	pH ≥ 6	8	-.051	.845	-.746	.283
	pH < 6	8	1.005	-.239	-.098	.645
	all	16	.402	-.072	.058	.143
EDTA - P	pH ≥ 6	8	.961	.254	-.068	.939
	pH < 6	8	.523	-.158	-.581	.307
	all	16	.830	-.085	-.486	.705

strongly held P from soils, which may very well represent plant uptake of P from soils. The zero values obtained with water and EDTA methods in some soil show that the methods are unsuitable.

GREEN HOUSE STUDY

Phosphate values as indices of P supply:

The surface soils were cropped to maize in the green house for 31 days. Dry matter weights per pot, P content and P uptake are given in Table 14. Dry matter yield varied from 8.50g to 13.17g, with an average of 10.37g per pot. The phosphorus content of the maize plant varied from 0.038% to 0.063% with an average of 0.05%. The average P content of maize in the acid soils was not different from that in soils above pH 6. Phosphorus uptake values were correspondingly low, ranging from 0.90 to 1.88 mg P/Kg soil. Phosphorus uptake was highly correlated with dry matter yield ($r = 0.72^{**}$). P content was also significantly correlated with P uptake ($r = 0.54^{*}$) but was insignificantly related with yield. The low yield obtained is evidence of the poor P fertility of these soils and indicates the low levels of easily utilizable phosphates.

Table 14: Dry matter yield, P content and uptake from soils by the maize plant

Lab. No.	Location	Texture	Dry matter yield g/pot	% P	P uptake mg/kg
1	Kaiama	ls	11.740	0.040	1.174
2	Luma	ls	11.350	0.040	1.250
3	Kontagora	s	11.050	0.043	1.880
4	Samaru	ls	9.130	0.057	1.300
5	Funtua	ls	9.600	0.049	1.180
6	Makarfi	sl	9.400	0.055	1.290
7	Jaji	cl	9.120	0.043	0.980
8	Sabo	sl	9.220	0.049	1.130
9	Saminaka	sl	8.500	0.045	0.960
10	Mubi	ls	12.120	0.057	1.730
11	Jos	scl	9.560	0.063	1.500
12	Bauchi	ls	10.280	0.046	1.180
13	Tubule	s	10.730	0.051	1.370
14	Gombe	s	13.170	0.057	1.880
15	Deba-Habe	sl	9.460	0.038	0.900
16	Yadim	s	11.550	0.051	1.470
	pH $\geq$ 6		10.940	0.049	1.430
	pH $<$ 6		9.810	0.050	1.220
	all		10.370	0.050	1.320

The lowest P-uptake value was recorded for Jaji soil, in contrast to its high total-P content, whereas relatively high uptake value was obtained from Gombe soil, which is least with respect to total phosphorus. This observation supports and clarifies the fact that other factors, besides the amount of total P in soils, are definitely involved in the supply of soil phosphorus to plants.

Generally, four factors are considered to be involved in defining the supply of phosphorus to plants: (1) the intensity fractor, which defines the ease or difficulty of withdrawal; (2) the quantity factor which indicates the amounts of available P; (3) the capacity factor which defines the relationship between intensity and quantity during uptake; and (4) the kinetic factor which describes the rate at which the solution P is replenished from the solid phase and transported from solution to root, (Williams, 1967). The intensity factor was measured by the use of extractants. The kinetic factor, which is largely influenced by soil parameters seem to be the main factor that could define the uptake of P from the soils. Positive correlation coefficient was obtained between % sand and P uptake ($r = 0.73^{**}$). This, compared with the negative relationships with clay content, demonstrates the greater release potential associated with the lighter textured soils. The three soils with the highest uptake values

were essentially light textured, and they include Gombe, Kontagora and Mubi. All have pH above 6. P uptake from the more neutral soils (1.43 mg P/Kg soil) was more than that removed from the acid soils (1.22 mg P/Kg). Juo (1958) had observed greater association of the sesquioxides with the clay fraction. The high phosphate reversion capacities of sesquioxides have been much demonstrated (Udo and Uzu, 1972; Bass and Sieling, 1950; Williams et al, 1958; Saunders 1965).

Crop parameters as related to phosphate fractions:

Correlation of soil P fractions with dry matter yield, P uptake and P content are given in Table 15. Ca-P and Fe-P were mostly involved in negative relationship with yield and uptake. Only the aluminium phosphate fraction exhibited any relationship with any crop parameter. Al-P was significantly correlated with yield at the 5% level of probability in acid soils and also when all soils were considered together. Al-P was also involved in positive but non-significant correlation with P uptake.

Multiple regression analysis of crop phosphate values on P fractions showed that Fe-P contributed mostly to P uptake in soils above pH 6. In the more acid soils, Al-P explained most of the variation (Table 16). With all soils combined, the SPRC for Al-P (0.32) was higher than that for Fe-P (0.19). SPRC for Ca-P was negative (-0.55) indicating

Table 15: Correlation of dry matter yield, P content and P uptake with inorganic P fractions

P fractions	Soil group	Sample (n)	Correlation coefficient (r)		
			Yield	P uptake	% P
Al-P	pH ⩾ 6	8	.458	.342	-.032
	pH < 6	8	.677*	.158	-.214
	all	16	.459*	.287	-.097
Fe-P	pH ⩾ 6	8	-.122	.002	-.532
	pH < 6	8	-.168	-.129	.149
	all	16	-.277	-.298	.011
Ca-P	pH ⩾ 6	8	-.358	-.298	-.542
	pH < 6	8	.198	-.338	-.046
	all	16	-.121	-.304	-.07

Table 16: Standard partial regression coefficients (SPRC) and coefficients of multiple determination for the regression of crop response values on P fractions

Crop values	Soil group	Sample (n)	S P R C			
			Al-P	Fe-P	Ca-P	R^2
Yield	pH ≥ 6	8	.468	.001	-.372	.348
	pH < 6	8	.919	-.903	.327	.844
	all	16	.643	-.704	..255	.454
% P	pH ≥ 6	8	.100	-.360	-.270	.335
	pH < 6	8	-.302	.513	-.264	.153
	all	16	-.109	.215	-.218	.029
P uptake	pH ≥ 6	8	.145	.368	-.571	.194
	pH < 6	8	.687	.503	-.600	.475
	all	16	.322	.188	-.546	.208

that Ca-P was least important in contributing to P uptake. The fractionation data explained only 21% of the variation in P uptake. In the acid soils, the contribution of the three active fractions (Al-P, Fe-P and Ca-P) to uptake was 47.5%, much higher than for soils with pH 6 and above which was 19.5%.

All soils were fractionated after cropping to find out the contribution of three active P fractions to P uptake. The initial amounts of P present, and the reduction in the amount by cropping are given in Table 17. Although the total reduction in P did not closely correspond to uptake in most cases, a trend was observed in the change in fractions after cropping. The average reductions in Al-P, Fe-P and Ca-P fractions were 1.72, 0.28 and -0.04 ppm respectively. These represent 36.60, 2.43 and -0.82% of the initial amounts of the respective fractions. The result show that Ca-P did not contribute to P uptake, and that Al-P had comparatively higher availability. This supports the interpretation of the SPRC (Table 16). Transformation of soluble phosphates to Ca-P may have occurred during the cropping period, due to possible increase in pH as a result of the influence of the applied nutrient elements, which were mainly alkaline inducing.

Many workers have also observed high contribution of Al-P to plant uptake (Susuki et al, 1963; Payne and Hanna, 1964; Smith, 1965; and Ivanov, 1975). Kadeba and Boyle (1978) observed high dependence of plant uptake on the sum of the Al-P and Fe-P fractions.

In four soils, namely Kontagora, Samaru, Soba and Deba-Habe, the index plant used up appreciable amounts of Fe-P as shown by the reduction in the amounts of P fractions after cropping (Table 17). Al-Abbas and Barber (1964) and Choudhari et al, (1974), have earlier observed similar results on some index plants.

Crop parameters as related to soil tests:

The correlation of soil tests with crop P values are shown in Table 18. Dry matter yield was significantly correlated with all soil test phosphorus. The highest correlation coefficient was obtained with resin-P at 0.1% probability level. EDTA-P was also highly correlated at the 1% level, while water and acid fluoride-P (Bray P_1) were related to yield at the 5% level. Phosphorus uptake was also significantly correlated with all soil tests except EDTA-P. The relationship was at 0.1% confidence limit with resin, and at 5% confidence limit with water and Bray P1. Phosphorus content was non-significantly correlated with any soil test method.

Table 17: Contributions of active forms to P uptake

Lab. No.	Location	Contributions of P fractions(ppm) Al-P initial	Al-P reduction	Fe-P initial	Fe-P reduction	Ca-P initial	Ca-P reduction	Total reduction (ppm)	Uptake (ppm)
1.	Kaiama	7.00	2.92	13.30	-0.04	12.25	-0.18	2.70	1.17
2	Luma	11.25	3.00	11.40	0.55	3.25	0.43	3.98	1.25
3.	Kontagora	2.50	0.32	5.95	0.41	1.80	0.04	0.92	1.88
4.	Samaru	4.40	1.90	11.40	1.45	1.80	-0.07	3.28	1.30
5.	Funtua	2.50	1.22	13.40	-0.15	5.10	-0.25	1.00	1.18
6.	Makarfi	3.40	1.90	9.00	-0.20	4.20	-0.07	1.63	1.29
7.	Jaji	6.50	3.38	25.00	-0.07	15.00	-0.80	2.51	0.98
8.	Soba	2.25	0.75	7.14	1.45	2.50	0.26	2.46	1.13
9.	Saminaka	1.80	0.90	9.5	-0.72	3.50	0.41	0.59	0.96
10.	Mubi	5.80	0.95	14.80	0.82	4.80	0.50	2.27	1.73
11	Jos	4.80	2.40	19.85	-0.50	7.20	-0.24	1.66	1.50
12.	Bauchi	4.00	1.30	9.20	0.28	2.30	-0.32	1.26	1.18
13.	Tubule	6.00	0.38	9.20	0.12	2.30	-0.14	0.36	1.37
14.	Gombe	4.40	1.65	4.85	0.28	1.50	-0.03	1.90	1.88
15.	Deba-Habe	2.80	0.93	9.20	0.41	5.50	-0.26	1.08	0.90
16.	Yadim	5.80	3.68	10.00	0.36	5.00	0.05	4.09	1.47
	Mean	4.70	1.72	11.50	0.28	4.90	-0.04	1.98	1.32

Table 18: Correlation of soil tests with crop response value

Crop response values	Soil group	Sample (*n*)	Correlation coefficients with P extracted by: Water	Bray No.1	Resin	EDTA
Yield	pH ≥ 6	8	.597	.654*	.793*	.618*
	pH < 6	8	-.833	.436	.852**	.394
	all	16	.545*	.472	.813**	.622**
% P	pH ≥ 6	8	.254	.484	.402	.064
	pH < 6	8	.095	.300	-.328	-.455
	all	16	.051	.371	-.042	-.220
P uptake	pH ≥ 6	8	.510	.514	.894***	.458
	pH < 6	8	-.290	.443	.317	-.012
	all	16	.480*	.442*	.696***	.393

* Significant at 5% level of probability
** Significant at 1% level of probability
*** Significant at 0.1% level of probability

For soils above pH 6, the soil test method that best predicted uptake was the resin method. In the more acid soils, Bray No.1 method best predicted uptake, though it was non significant. The data showed that water and EDTA phosphorus were not suitable as indices of P uptake for acid soils. For predicting yield, the resin method ranked best for both pH groups and was the only method that was significantly correlated in the acid soils.

The cropping study showed that the resin method was the most suitable among the methods studied for the extraction of available P from soils. It proved to be superior to any other single measurement in predicting P uptake by the index plant when all soils were considered together and in particular for soils above pH 6. In the more acid soils, Bray No.1 method slightly superseded it. These results correspond to some earlier works by Bache and Rogers (1970), who showed that the resin method was superior to any other single measurement in predicting available P in soils. This was supported by Kadeba and Boyle (1978). Enwezor (1977a) had earlier recommended Brays reagent No.2 as a general purpose extractant for available P in the more acid soils of south eastern Nigeria.

Considering the low predictability of uptake (20.8%) and resin-P (14%) on the basis of Al-P, Fe-P and Ca-P, it could be suggested that sources other than these three

active fractions contributed to P uptake by the index plant. Workers had earlier indicated the importance of organic P as a potential sink of available-P (Acquaye, 1963; Enwezor, 1977b). It has also been suggested that the predominance of organic P in most soils may explain the relatively low precision with which crop response could be predicted by phosphorus extracted by chemical means (Enwezor, 1977b).

With the 20-hour extraction period used for the resin method in this study, the kinetic exchange of P by the resin may be reasoned to be from soil solution as well as from readily exchangeable P from mineral surfaces. It then implies that resin-P is a composite parameter that reflects both intensity and quantity factors involved in P uptake by the plant. The high dependence of resin-P on the sum of Al-P and Fe-P fractions as against any one lone fraction emphasizes further the fact that resin P is a composite parameter. This agress with other findings by Bache and Rogers (1970); Gunary and Suttons (1967);and Kadeba and Boyle (1978).

CHAPTER FIVE

SUMMARY AND CONCLUSION

Though much effort has been invested in the assessment of plant response to applied phosphorus in the savanna soils of Nigeria, the characterization of the amounts and forms of phosphorus in these soils have not been given appropriate consideration. Soil phosphorus which is utilized by plants is thought to exist in combinations with aluminium, iron and calcium. A successful soil test should therefore extract these forms in proportions similar to those absorded by plants. Numerous soil tests have been employed, with limited success, to calibrate the available soil phosphorus for crop management in the savanna soils, but the forms of P extracted by these extractants are still a matter of conjecture. This study was therefore designed to investigate the amounts and forms of soil phosphorus, to determine the relationship of phpsohorus fractions with some soil tests and with crop response in three savanna soils.

Soil samples were collected from 16 locations in the northern guinea savanna, subsudan savanna and plateau vegetation zones at two depths; (0-15cm) and subsurface (15-30cm). Phosphorus was fractionated into four fractions: aluminium, iron, calcium and reductant soluble iron

phosphates following Chang and Jackson's procedure as modified by Peterson and Corey (1966). The four extractants used to estimate available P included: anion exchange resion, 0.01N Na-EDTA, distilled water and 0.03N NH_4F + 0.025N HCl. Surface soils were cropped to maize. Phosphorus in plant samples was measured. The major conclusions that can be drawn from this study are:

1. Total phosphorus content of soils were low with average values of 147.0 and 97.7 ppm in the surface and subsurface soils respectively.

2. Soils over basement complex were more fertile than soils over sandstones with respect to phosphorus, with average values of 154.5 and 129.5 ppm in the surface soils respectively.

3. The mean amounts of Al-P, Ca-P, Fe-P and occluded-P were 4.7, 4.9, 11,3 and 33.6 ppm, representing 8.6, 8.2, 20.3 and 63.0 percent of inorganic P respectively in the surface soils. Amount in the subsoils were lower and in the same order were: 2.4, 2.4, 9.3 and 30.0 ppm, representing 5.6, 6.0, 21.2 and 64.1 percent of inorganic P respectively.

4. The order of abundance of P fractions was: occluded-P > Fe-P > Ca-P ≫ Al-P, indicating that the soils are highly weathered.

5. Average amounts of P extracted by the extractants f from the surface soils were: water- 1.32 ppm, Bray No.1- 2.40 ppm, resin- 7.42 ppm and EDTA- 2.90 ppm. Amounts extracted by the extractants from the sub-surface soils were 0.45, 1.62, 5.35 and 0.92 ppm respectively. The generally small amounts of P extracted suggest that P in these soils are highly unavailable.

6. Amounts of P extracted by the extractants decreased consistently with depth, reflecting lower P fixation properties with the more organic surface soils.

7. The Al-P fraction was significantly correlated with all soil tests particularly in the more neutral soils. Fe-P and Ca-P were mostly involved in negative relationships with soil tests. This suggests that the bulk of available P so determined was aluminium phosphate.

8. The predictability of soil tests on the basis of Al-P, Fe-P and Ca-P was maximum for the EDTA method (93.6%) and minimum for the resin method (6.7%), with Al-P accounting for much of the variation in acid soils.

9. The Al-P fraction was significantly correlated with phosphorus uptake while Fe-P and Ca-P were involved in negative relationships suggesting the unavailability of Fe-P and Ca-P to the index plant.

10. The Al-P, Fe-P and Ca-P fractions accounted for only 21% of the variation in P-uptake implying that sources other than the three active fractions contributed to P-uptake.

11. The method that best predicted uptake in the more neutral soils and also for all soils was the resin method. Bray No.1 method best predicted uptake in the more acid soils.

12. Water and EDTA methods were unsuitable as extractants for available-P.

13. The predictability of resin-P was nearest in similarity to that of uptake based on Al-P, Fe-P and Ca-P, which makes the resin method the most promising soil test for soils of the northern guinea, subsudan and plateau vegetation zones of Nigeria. It was the only single measurement that was highly correlated with both uptake and yield.

LITERATURE CITED

1. Acquaye, D.K. 1963. Some significance of soil organic phosphorus mineralization in the phosphorus nutrition of cocoa in Ghana. Plant Soil 19: 65-80.

2. Agboola, A.A. and Corey, R.B. 1975. Correlations of Bray P, soil test values with maize yield in areas of soils derived from metamorphic and igneous rocks of western Nigeria. Nigerian J. of Sci. 9: 369-375.

3. Al-Abbas, A.H. and Barber, S.A. 1964. A soil test for phosphorus based upon fractionation of soil phosphorus: 1. Correlation of soil phosphorus with plant available phosphorus. Soil Sci. Soc. Am. Proc. 28: 218-221.

4. Alexander, T.G. and Robertson, J.A. 1972. EDTA extractable phosphorus in relation to available and inorganic phosphate forms in soils. Soil Sci. 114: 69-72.

5. Amer, F., Bouldin, D.R., Black, C.A. and Duke, F.E. 1955. Characterization of soil phosphorus by anion exchange resin adsorption and P equlibration. Plant Soil, 6: 391-408.

6. Baeche, B.W. and Rogers, N.E. 1970. Soil phosphate values in relation to phosphate supply to plants from some Nigerian soils. J. Agric. Sci. Camb. 74: 383-390.

7. Barrow, N.J. and Shaw, T.C. 1977. Factors affecting the amount of phosphate extracted from soil by anion exchange resin. Geoderma. 18: 309-323.

8. Bass, G.B., and Sieling, D.H. 1950. Methods for determining relative phosphate fixing capacity of acid soils. Soil Sci. 69: 269-280.

9. Bates, J.A.R. and Baker, T.C.N. 1960. Studies on Nigerian forest soils. II. Distribution of P in soil profiles and in various soil fractions of a Nigerian soil. J. Soil Sci. 2: 257-260.

10. Beauchamp, E.G., MacMillian, K. and Hamilton, H.A. 1976. Extractable phosphorus in the surface and subsurface layers of St. Rosalie and St. Blaise soil series in Quebec. Canadian J. of Soil Sci. 56: 345-356.

11. Bingham, F.T. 1949. Soil test for phosphate. Calif. Agr. 3(8): 11, 14.

12. Black, C.A. 1943. Phosphate fixation by kaolinite and other clays as affected by pH, phosphate concentration, and time of contract. Soil Sci. Soc. of Amer. Proc. 7: 123-133.

13. Blacso, M.L. and Bohorquez, N.A. 1968. Fractionation of phosphorus in tropical soils of Colombia. Agrochimica 12: 173-178.

14. Bray, R.H. 1938. New concept of the chemistry of soil fertility. Soil Sci. Soc. Amer. Proc. 2: 175-179.

15. Bray, R.H. 1948. Requirements for successful soil tests. Soil Sci. 66: 83-89.

16. Bray, R.H. and Dickman, S.R. 1941. Adsorbed phosphates in soils and their relationship to crop response. Soil Sci. Soc. Amer. Proc. 6: 312-320.

17. Bray, R.H. and Knrtz, L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

18. Breland, H.L. and NeSmith, J. 1968. Comparison of several soil test procedures on different soils. Proc. Soil Crop Sci. Soc. Fal. 27: 49-67.

19. Roomfield, S.M. 1967. An examination of the use of ammonium flouride as a selective extractant for aluminium-bond phosphate in partially phosphated systems. Aust. J. Soil Res. 5: 225-234.

20. Cajuste, J.L. 1972. Factors regulating plant availability of P applied to Brazilian soils. Ph.D. Thesis, University of Wisconsin.

21. Chang, S.C. 1965. Application of phosphorus fractionation to the study of the chemistry of available phosphorus. Soil Fertil. Taiwan 1965: 1-15.

22. Chang, S.C. and Jackson, M.L. 1957. Fractionation of soil phosphorus. Soil Sci. 84: 133-144.

23. Chang, S.C. and Jackson, M.L. 1958. Soil phosphorus fractions in some representative soils. J. Soil Sci. 9: 109-119.

24. Chang, S.C. and Juo, S.R. 1963. Available phosphorus in relation to forms of phosphates in soils. Soil Sci. 95: 91-96.

25. Chatterjee, B. and Datta, S. 1951. Phosphate fixation by clay mineral montmorillomite and kaolinite. J. Soil Sci. 2: 224-233.

26. Choudhari, J.S., Sexana, S.N. and Somani, L.L. 1974. Studies on chemical availability of inorganic phosphate fractions and their utilization by crops in some soils of Rajasthan. J. of the Indian Soc. of Soil Sci. 22: 258-261.

27. Chu, C.R.W.W. Moschler, and G.W. Thomas. 1962. Rock phosphate transformation in acid soils. Soil Sci. Soc. Amer. Proc. 26: 476-478.

28. Coleman, R. 1944. Phosphorus fixation by the coarse and fine clay fractions of kaolinite and montmorillonite clays. Soil Sci. 58: 71-77.

29. Dalal, R.C., and Hallsworth, E.G. 1976. Evaluation of the parameters of soil phosphorus availability factors in predicting yield responses and phosphate uptake. Soil Sci. Soc. Amr. Jour. 40: 541-546.

30. Das, S. 1930. An improved method for the determination of phosphoric acid in soils. Soil Sci. 30: 33-49.

31. Day, P.R. 1965. Hydrometer method of particle-size analysis. In Methods of Soil Analysis (Agron. No.1 Part 1) Ed. C.A. Black et al. pp.562-567.

32. Dean, L.A. 1938. An attempted fractionation of the soil phosphorus. J. Agr. Sci. 28: 234-246.

33. Dean, L.A., and Reubins, E.J. 1947. Anion exchange in soils: 1. exchangeable phosphorus and anion exchange capacity. Soil Sci. 63: 377-387.

34. Dick, W.A., and Tabatabai, M.A. 1977. Determination of orthophosphate in aquaous solutions containing labile organic and inorganic phosphorus compounds. Jour. of Environ. Quality. 6: 82-85.

35. Dyer, B. 1894. On the analytical determination of probably available "mineral" plant food in soils. J. Chem. Soc. 65: 115-167.

36. Egner, H. 1941. The Egner lactate method for phosphate determination. Amer.Fertilizer 94: 5-7, 22-26.

37. Enwezor, W.O. 1977a. Soil testing for phosphorus in some Nigerian soils: 1. Comparism of methods of determining available phosphorus in soils of S.E. Nigeria. Soil Sci. 123: 48-53.

38. Enwezor, W.O. 1977b. Soil testing for phosphorus in some Nigerian soils: 3. Forms of phosphorus in soils of southeastern Nigeria and their relationship to plant available phosphorus. Soil Sci. 124: 27-33.

39. Enwezor, W.O. and A.W. Moore 1966. Phosphorus status of some Nigerian soils. Soil Sci. 102: 322-328.

40. Fife, C.V. 1959. An evaluation of ammonium fluoride as a selective extractant for aluminium bound soil phosphate. II. Preliminary studies on soils. Soil Sci. 87: 83-88.

41. Fitts, J.W. and Nelson, W.L. 1956. The determination of lime and fertilizer requirements of soils through chemical tests. Adv. Agronomy. 8: 241-282.

42. Fox, R.L., and Kamprath, E.J. 1971. Adsorption and leaching of P in acid organic soils and high organic matter sand. Soil Sci. Soc. Amer. Proc. 35: 154-156.

43. Fox, R.L., Plucknett, D.L. and Whitney, A.S. 1968. Phosphate requirements of Hawairan Latosols and residual effects of fertilizer phosphorus. Trans. 9th Inter. Congr. Soil Sci. 2: 301-310.

44. Fried, M., and Dean, L.A. 1955. Phosphate retention by iron and aluminium in cation exchange systems. Soil Sci. Soc. Amer. Proc. 19: 143-147.

45. Ghani, M.O. 1943. Fractionation of soil phosphorus. Indian J. of Agric. Sci. 13: 29-45.

46. Ghani, M.O., and Islam M.A. 1946. Phosphate fixation in acid soils and its mechanism. Soil Sci. 62: 293-306.

47. Glenn, R.C., Hsu, P.H., Jackson, M.L., and Corey, R.B. 1959. Agron. Abstract 81: 9.

48. Gunary, D. and Sutton, C.D. 1967. Soil factors affecting plant uptake of phosphate. J. Soil Sci. 18: 167-173.

49. Halm, A.T. and Bampoe-Addo, A. 1972. Available phosphorus as related in some Ghana soil series. Ghana J. Agric. Sci. 5(2): 89-94.

50. Halstead, R.L. 1967. Chemical availability of native and applied P in soils and their textural fractions. Soil Sci. Soc. Amer. Proc. 31: 414-418.

51. Hanley, P.K., and Murphy, M.D. 1970. Phosphate forms in particle size separates of Irish soils in relation to drainage and parent materials. Soil Sci. Soc. Amer. Proc. 34: 587-590.

52. Harter, R.D. 1969. Phpsphorus adsorption sites in soils. Soil Sci. Soc. Amer. Proc. 33: 630-632.

53. Hawkins, R.H. and Kunze, G.W. 1965. Phosphate fractions in some Texas Grumosols and their relation to soil weathering and available P. Soil Sci. Soc. Amer. Proc. 29: 650-656.

54. Hernando, V. and Diez, J.A. 1974. Relationship between various fractions of phosphorus in soil and their uptake by rye grass. Agrobiologica. 33: 109-118.

55. Hibbard, P.L. 1931. Chemical methods for estimating the availability of soil phosphate. Soil Sci. 31: 437-466.

56. Hislop, J. and Cooke, I.J. 1960. Anion exchange resin as a means of assessing soil phosphate status. A laboratory technique. Soil Sci. 105: 8-11.

57. Hubbard, E.A. and Walmsley, D. 1974. Studies on the phosphate fixation and release on the banxite soils of Jamaica. 1. The fate of added phosphate. Trop. Agric. 51: 361-369.

58. Hsu, P.H. 1965. Fixation of phosphate by aluminium and iron in acidic soils. Soil Sci. 99: 398-402.

59. Hsu, P.H., and Jackson, M.L. 1960. Inorganic phosphate transformations by chemical weathering in soils as influenced by pH. Soil Sci. 90: 16-24.

60. Ivanvo, P. 1975. Phosphate uptake by plants in relation to form and isotope exchangability of inorganic soil phosphates. Soil and Fert. 38: 314.

61. Jones, G.H.G. 1949. Discussion on soil fertility problems. Proceedings of the first commonwealth Bur. Tech. Commun. 46: 180.

62. Juo, A.S.R., and Ellis, B.G. 1968a. Chemical and physical properties of Al and Fe phosphates and their relationship to availability. Soil Sci. Soc. Am. Proc. 32: 216-221.

63. Juo, A.S.R., and Ellis, B.G. 1968b. Particle size distribution of Al, Fe, and Ca phosphates in the profiles. Soil Sci. 106: 374-380.

64. Kadeba, O. and Boyle, J.R. 1978. Phosphorus in forest soils. Plant and soil 49: 288-297.

65. Kanwer, B.B. and Tripathi, B.R. 1977. Evaluation of P fractions contributing to available P extracted by some common soil test methods. Jour. of the Indian Soc. Soil Sci. 25: 150-154.

66. Kittrick, J.A. and Jackson, M.L. 1956. Election microscope observation of reactions of phosphates with minerals leading to a unified theory of phosphate fixation in soils. J. Soil Sci. 7: 81-89.

67. Klinkenberg, K. and Higgins, G.M. 1968. Outline of Northern Nigeria Soils. Niger. J. Sci. 2: 91-115.

68. Landergren, S. 1954. Geochemistry. V.N. Goldsmidt, ed. by A. Muir, 454, Clarendon Press.

69. Larsen, S. 1967. Soil phosphorus. Adv. Agron. 19: 151-210.

70. Legg, J.O. and Black, C.A. 1955. Determination of organic phosphorus in soils: II. Ignition method. Soil Sci. Soc. Am. Proc. 19: 139-142.

71. Lindsay, W.L. and Moreno, E.C. 1960. Phosphate phase equilibra in soils. Soil Sci. Soc. Amer. Proc. 24: 177-182.

72. Maida, J.H.A. 1978. Phosphate availability indices related to phosphate fractions in selected Malawi soils. J. Sci. Food and Agric. 29: 421-428.

73. Mater, A.E. and Samman, M. 1975. Corrleation between $NaHCO_3$ extractable P and response to plant fertilization in pot tests. Agron. Jour. 67: 616-618.

74. Metwally, A.I., Hamdy, H. and El-Baz, S. 1976. Evaluation of various parameters for available phosphorus in aluvial and calcarcous soils of Egypt. Soil and Fert. 39, 3819.

75. McGeorge, T.W. 1939. Studies on plant food availability in alkaline calcareous soils: seedling tests and soil analysis. Arizona Agri. Exp. Sta. Tech. Bull. 82: 295-331.

76. MacKenzie, A.P. 1962. Inorganic soil phosphorus fractions of some Ontario soils as studied using isotopic exchange and solubility criteria. Can. J. Soil Sci. 42: 150-156.

77. McLachlan, K.D. 1965. The nature of available phosphorus in some acid pasture soils and a comparison of estimating procedures. Aust. J. Exp. Anim. Husb. 5: 125-132.

78. Mokwunye, U. 1974. Some reflections on the problems of available phosphorus in soils of tropical Africa. Samaru Conf. Paper No.3.

79. Mokwunye, U. 1977. Phosphorus fertilizers in Nigerian Savanna soils. 1-Use of phosphorus sorption isotherms to estimate the phosphorus requirement of maize at Samaru. Trop. Agric. (Trinidad) 54: 265-271.

80. Morgan, M.F. 1937. The universal soil testing system. Conn. Agric. Exp. Stn. Bull. 392.

81. Murphy, J. and Riley, J.P. 1962. A modified single solution for the determination of phosphate in natural waters. Anal. Chem. Acta. 27: 31-36.

82. Nelson, N.L.A., Mehlich, A. and Winters, E. 1953. The development, evaluation and use of soil tests for phosphorus availability. Agron. 4: 153-188) (Soil and test P. Ed. by Pierre W.H. and Norman A.G.).

83. Nnadi, L.A., Tabatabai, M.A. and Hanway, J.J. 1975. Determination of phosphate extracted from soils by EDTA and NTA. Soil Sci. 119: 203-209.

84. Nye, P.H. and Bertheux, M.H. 1957. Distribution of phosphorus in forest and savanna soils of the Gold Coast and its agricultural significance. J. Agric. Sci. 49: 141-154.

85. Oko, B.F.D. and Agboola, A.A. 1974. Comparism of different phosphorus extractants in soils of the western state of Nigeria. Agron. Jour. 66: 639-642.

86. Olsen, S.R., Cole, C.V., Wanatabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dept. Agr. Circ. 939, 19p.

87. Olsen, S.R. and Dean, L.A. 1965. Phosphorus. In C.A. Black (ed.). Method of soil analysis II. Agronomy 9: 1035-1049.

88. Oteng, J.W. and Acquaye, D.K. 1971. Studies on the availability of phosphorus in representative soils of Ghana. 1. Availability tests by conventional methods. Ghana J. Agric. 4: 171-183.

89. Payne, H. and Hanna, W.J. 1965. Correlation among soil phosphorus fractions, extrable phosphorus and plant content of phosphorus. J. Agric. Food Chem. 13: 322-326.

90. Peterson, G.W. and Corey, R.B. 1966. A modified Chang and Jackson procedure for routine fractionation of inorganic phosphorus fractions. Proc. Soil Sci. Soc. Am. 30: 563-565.

91. Pigotte, C.J. 1954. The use of phosphate fertilisers in Sierra Leone. Proc. 2nd Inter-African Soils Conf. Leopoldville 2: 803-813.

92. Pinto, R. 1974. Forms of soil phosphorus and their availability to plants. Trop. Agric. (Trinidad), 51: 179-188.

93. Pratt, P.F. and Garber, M.J. 1964. Correlation of phosphorus availability by chemical tests with inorganic P fractions. Soil Sci. Soc. Am. Proc. 28: 23-26.

94. Robertson, J.A. 1962. Comparison of an acid and alkaline extracting solutions for measuring available phosphorus in Alberta soils 42: 115-121.

95. Rodes, E.R. 1977. Phosphorus in Sierra Leone soils. Tropical Agr. (Trinidad) 54: 77-85.

96. Rudd, C.L. and French, R.J. 1977. Comparison of extraction methods for the determination of available soil phosphorus. Soil and Fer. 40: 415.

97. Russell, G.C. and Low, P.F. 1954. Reaction of phosphate with kaolinite in dilute solutions. Soil Sci. Soc. Am. Proc. 18: 22-25.

98. Sahrawat, K.L. 1977. EDTA extractable phosphorus in soils as related to available and inorganic phosphate fractions. Communications in Soil Sci. and Plant Analysis 8: 281-287.

99. Saunders, W.M.H. 1965. Phosphate retention by New Zealand soils and its relationship to free sesquioxides, organic matter and other soils properties. New Zealand J. Agric. Res. 8: 30-57.

100. Saunders, D.H. 1954. Assessment of soil fertility for advisory purposes in S.Rhodesia. Trans. 5th Int. Congr. Soil Sci. 3, 171, Leopoldville.

101. Scharafat, I. 1970. Recommendation for an improved method for the fractionation of soil phosphorus. Phosphorsaure 28: 272-286.

102. Singh, D. 1969a. Equilibrium concentrations of inorganic P and adsorbed phosphorus in soils. Diss. Abstract.. International 31/03, pp.1011.

103. Singh, L. 1969b. Inorganic soil phosphate fractions in relation to plant availability and improved soil test methods. Ph.D. Thesis, University of Mississipi.

104. Singh, R.N., Martous, C.D. and Obenshain, S.A. 1966. Plant availability and forms of residual phosphorus in Davidson clay loam. Soil Sci. Soc. Am. Proc. 32: 91-94.

105. Smith, A.N. 1965. Distinction between iron and aluminium phosphate in Chang and Jackson's procedure for fractionation of inorganic soil phosphorus, Agrochemica 9: 162-168.

106. Smith, F.W., Ellis, B.G. and Grava, J. 1957. Use of acid fluoride solutions for the extraction of available P phosphorus in calcareous soils and in soils of which rock phosphate has been added. Soil Sci. Soc. Am. Proc. 26: 563-566.

107. Srivastava, O.P. and Pathak, A.N. 1968. Available phosphorus in relation to forms of soil phosphorus. J. Indian Soc. Soil Sci. 16: 103-109.

108. Stamford, C. and Boulding, D.R. 1960. Biological and chemical availability of phosphate-soil reaction products. Int. Congr. Soil Sci., Trans. 7th Madison Wis.). III. 60-71.

109. Stanbery, C.O. 1949. The behaviour of phosphorus in an alkaline irrigated soils in Washington. Soil Sci. Soc. Amer. Proc. 13: 205-212.

110. Stephen, R.C. and Lin, Y.C. 1974. Chemical determination of soil phosphorus levels and the relationship of these with plant response. *Agriclture Hong Kong.*

111. Susuki, A., Lawton, K. and Doll, C.E. 1963. Phosphorus uptake and soil tests as related to forms of P in some Michigan soils. Soil Sci. Soc. Amer. Proc. 27: 401-403.

112. Swenson, R.M., Cole, C.V. and Seiling, D.H. 1949. Fixation of phosphate by iron and aluminium and replacement by organic and inorganic ions. Soil Sci. 67: 3-22.

113. Syers, J.K., Williams, J.D.H., Tyner, E.H. and Walker, T.W. 1969. Primary and secondary origin of "Non-extractable" soil inorganic phosphorus. Soil Sci. Soc. Amer. Proc. 33: 635-636.

114. Tisdale, S.L. and Nelson, W.L. 1956. "Soil fertility and fertilizers". p.74. The MacMillan Co., Co., New York.

115. Toth, S.G. 1937. Anion exchange by soil colloids. Soil Sci. 44: 299-314.

116. Truog, E. 1930. Determination of the readily available phosphorus of soils. J. Amer. Soc. Agron. 22: 874-882.

117. Udo, E.J. 1977. Forms and distribution of phosphorus in three Nigerian soil profiles along a toposequence. Trop. Agr. (Trinidad) 54: 149-156.

118. Udo, E.J. and Ogunwale, J.A. 1977. Phosphorus fractions in selected Nigerian soils. Soil Sci. Soc. Am. J. 41: 1141-1146.

119. Udo, E.J. and Uzu, F.O. 1972. The determination of total phpsphorus in some Nigerian soils. Nig. J. Sci. 5: 127-131.

120. Uzu, F.O., Juo, A.S.R. and Fayemi, A.A.A. 1975. Forms of P in some important agricultural soils of Nigeria. Soil Sci. 120: 212-218.

121. Valette, J. 1973. The reconaisance soil survey of the Mokwa - Kontagora - Kainji areas, North Western and Kwara States, Nigeria. Soil Survey Bull. No.44 (I.A.R., A.B.U., Zaria).

122. Velcher, V., Shrov, D and K.R. "Ster, S. 1975. The effect of farm yard manure on the phosphate sorption capacity and mineral phosphates forms in soils. Agrokhimiya 10: 70-77.

123. Viro, P.J. 1955. Use of ethylenediaminetetraacetic acid in soil analysis: I: 79: 459-465, II: Soil Sci. 80: 69-71.

124. Walkley, A. and Black, C.A. 1934. An examination of Degtjareff method for determining soil organic matter, and a proposed mordification of the chromic acid titration method. Soil Science, 29-38.

LIBRARY

125. Wanatabe, F.S. and Olsen, S.R. 1965. Test of an ascorpic acid method for determining phosphorus in water and NaHCO extracts from soils. Soil Sci. Soc. Amer. Proc. 29: 677-678.

126. Warren, R.G. and Cooke, G.W. 1965. Comparisms between methods of measuring soluble phosphorus and potassium in soils used for fertilizer experiments on sugar beet, in "Soil phosphorus" (Bull. Minist. Agric. Fish. Fd. Lond. 13), pp.75-83.

127. Westin, F.C. and De Britto, J.G. 1969. Phosphorus fractions in some Venezuelan soils as related to their stage of weathering. Soil Sci. 107: 194-202.

128. Williams, C.H. 1950. Studies on soil phosphorus. III. Phosphorus fractionation as a fertility index in South Australian. Soils. J. Afri. Sci. 40: 233-242.

129. Williams, J.D.H., Syers, J.K., Harris, R.F. and Armstrong, D.E. 1971. Fractionation of inorganic phosphates in calcareous lake sediments. Soil Sci. Soc. Am. Proc. 35: 250-255.

130. Williams, J.D.H. and Walker, T.W. 1969. Fractionation of phosphate in a maturity sequence of New Zealand basaltic soil profiles: 1. Soil Sci. 107: 22-30.

131. Williams, J.D.H., Syers, J.K., Walker, T.W. and Shaha, R. 1969. Apatite transformations during soil development. Agrochimica 13: 491-501.

132. Williams, E.G., Scott, N.M. and McDonald, M.J. 1958. Soil properties and phosphate sorption. J. Sci. Food Agr. 9: 551-559.

133. Williams, E.G. and Stewart, A.B. 1941. The colorimetric determination of readily soluble phosphate in soils. J. Sco. Chem. Ind., Lond. 60: 291-297.

134. Williams, J.D.H. and Saunders, W.M.H. 1956. Distribution of phosphorus in profiles and particle size fractions of some Scottish soils. J. Soil Sci. 7: 90-108.

135. Williams, E.G. 1967. The intensity and quantity aspects of soil phosphorus status and laboratory extraction values. An Edafol. Agrobiol. 26: 525-546.

136. Wilson, A.T. 1968. The chemistry underlying the phosphate problem in agriculture. Aust. J. Sci. 31: 55-67.

137. Yuan, T.L., Robertson, W.K. and Neller, J.R. 1960. Forms of newly fixed phosphorus in three acid sandy soils. Soil Sci. Soc. Amer. Proc. 24: 447-450.