# THE POTASSIUM STATUS AND THE EFFECT OP LIME ON THE AVAILABILITY OF NATIVE SOIL POTASSIUM IN SOME SUDAN SAVANNA SOILS OF NIGERIA

BY

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A Dissertation
Submitted to the
Faculty of Agriculture, Ahmadu Bello University,
Zaria in partial fulfilment of the requirements
for the Degree of Master of Science in the
Department of Soil Science.

February, 1979;

Dedicated to my younger Brother
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ABSTRACT

Laboratory and Greenhouse experiments were carried out with soil samples from the Sudan savanna zone of Nigeria to investigate the K status of the soils. The aspects studied were fractionation and fixation of K, the best method for available K determination for routine soil analysis, the effect of lime on the availability of native soil K and the recuperative abilities of some of the soils for exchangeable K after cropping.

The soils used are characterised by very low effective CEC (mean, 2.14 meq/100 g) and organic matter (mean, 0.43%). They have high percentage base saturation and are slightly acidic with average pH $5.8_{(H_2O)}$. They are mostly sandy to sandy loam in texture and contain low amounts of exchangeable bases.

The fractionation study showed that these soils are low in exchangeable K with a mean value of 0.17 meq/100 g. The difficultly exchangeable K and non-exchangeable K were low in some soils (derived from aeolian sand) and high in others (derived from basement complex/alluvium parent material). The mean values in meq/100 g are 0.49 and 1.05 respectively. Total K content varied widely according to parent material being higher in soils over basement complex/Alluvium parent material. All fractions correlated significantly at 5% with $pH_{(H_2O)}$ while only exchangeable K fraction and total K correlated significantly with silt. The correlations between CEC and difficultly exchangeable K and non-exchangeable K

were highly significant (r= 0.7073*** and 0.7287***), respectively.

Potassium fixation generally increased with concentration of added K, greater amount being fixed by the dry method than the wet method. These soils have very low K fixing capacity. Average percentage K fixed on addition of 5.00 meq K/100 g were only 3.53% and 5.64% for the wet and dry methods, respectively. K fixation correlated significantly with silt and highly significantly with exchangeable K (r = 0.654*** and 0.8380*** by the wet and dry methods, respectively).

The available K values obtained by the mineral acid extraction methods - estraction with 0.5 N HCl (IV); extraction with 1.0 N HCl (V) and extraction with dilute cold $H_2SO_4$ were higher than those obtained by the neutral normal $NH_4OAC$ extraction methods shaking for 2 hrs in 1:6 soil/solution ratio (I); leaching procedure (II) and shaking for 30 mins in 1:10 soil/solution ratio (III). For routine soil test for available K, the 0.5 N HCl extraction (IV), neutral N $NH_4OAC$ extraction by leaching (II) and by shaking for 30 min (III) have been recommended for ease of operation and reproducibility. The available K determined by single extraction with neutral N $NH_4OAC$ by leaching practically represents the total exchangeable K. The available K values obtained by the six methods correlated highly significantly among themselves and with K-uptake at 0.1%.

Results of the effect of lime on the availability of native soil K showed that lime did not enhance K release and uptake. About the same average values were obtained for zero and other lime rates and from the analysis of variance, the differences between rates were non-significant. The cropped soils subjected to a series of wetting and drying cycles showed a recovery of some levels of exchangeable K.

The practical implication of low K status and K fixation capacity on K fertilization of crops in the Sudan zone has been discussed. Many Sudan savanna will respond to applied K after a few years of intensive cultivation. Potassium leaching rather than K fixation is a problem in the Sudan savanna soils.

# INTRODUCTION

Potassium is one of the major plant nutrients which is needed in relatively large amounts for proper growth of crops. Adequate supply of K to crops ensures quality produce and increases the crop - resistance to pests and diseases. Crop response to applied K in terms of final yield is highly variable depending on the quantity of soil available K, plant requirement, moisture supply, etc. Plants go for luxury consumption if excess K is available in the soil. Thus K supply should be properly regulated in order to obtain optimum yield with minimum expenditure on fertilizer. Excess K application also leads to cation imbalance.

Potassium occurs in the soil as primary and secondary minerals such as feldspars, micas, illite and vermiculite. On weathering, primary minerals are transformed into secondary minerals which carry K as exchangeable or interlayer cations. Thus, weathering increases the availability of mineral K. There is an equilibrium among different forms of K in the soil:-

Non-exchangeable K $\rightleftharpoons$ Exchangeable K $\rightleftharpoons$ water-soluble or solution K.

Savanna soils are poor in native fertility and low in CEC, exchangeable cations, and inorganic and organic colloids. Exchangeable K content of savanna soils is highly variable depending on the clay content and the type of parent material from which the

soil is formed. Sudan savanna soils developed from sandy parent material are low in K and hence may respond well to K application provided the supply of other nutrients are adequate.

The objectives of the present study are:-

(1) to investigate the distribution of K fractions and total K in soils and possibly explain the lack of crop response to K fertilization in some of the soils.

(2) to study the K fixation capacity of the soils.

(3) to evaluate some methods of available K determination and recommend some methods for routine soil test and

(4) to study the effect of lime on the availability of native soil K and the recuperation of exchangeable K after cropping.

# LITERATURE REVIEW

Comprehensive reviews of the early studies on soil K have been given by Reitemeier (1951). More recent works on the behaviour of K in savanna soils of Nigeria include those of Wild (1971) and Heathcote (1972h).

In this paper, I do not intend giving extensive reviews of the K relationships in soils and plants per se but aspects relevant to the present studies will be reviewed.

## Occurence of K in Soils.

It is frequently reported that K contained in soils originates from the disintegration and decomposition of rocks containing K - bearing minerals. The most important of these minerals are:- Potash feldspars, ($KAlSi_3O_8$), - Orthoclase and Microcline; Micas - Muscocite, ($H_2KAl_3(SiO_4)_3$) and Biotite, $(HK)_2(MgFe)_2Al_2(SiO)_3$). Potassium also occurs in soils in the form of clay minerals like illite, vermiculite, chlorite and interstratified minerals.

The distribution of K in soils on a world wide basis follows a definite geomorphologic pattern and it varies widely according to parent material. The K content of the Lithosphere is estimated at 2.40%. In northern Nigeria, surface soils over basement complex have a mean K content of 2.2% while the mean content over sandstones was only 0.08% (Wild 1971). For Ghanaian soils Acquaye et. al., (1967 reported a mean value of 0.70%. Nye and Stephens (1962) reported a range of 0.14 - 1.05%. Wild (1971) and Acquaye et. al., (1967) reported

that most of the K in these soils are associated with the sand and silt fractions.

Forms of K in Soils and their Equilibrium Relationship

Several workers have frequently reported either four or three forms of K in soils. Reitemeter (1951), McLean and Simon (1958) and Munson and Nelson (1963) recognised four forms of K in soils. These are classified as water-soluble or soil-solution, exchangeable, non-exchangeable and mineral forms. Black (1967) stated that from the chemical standpoint, soil K is often divided into three categories, viz., water-soluble, exchangeable and non-exchangeable. He went further to state that sometimes the non-exchangeable is divided into two fractions on the basis of the K extracted by an acid, a cation exchange resin or a K - precipitating agent. Peech and Bradfield (1949) and Kee (1966) also recognised three forms of K in soils, viz., water soluble, exchangeable and non-exchangeable forms. Basically there are three forms of K in soils since all the 'not-immediately' available K are called non-exchangeable. These forms of K are always in equilibrium.

Water - Soluble Form: This is defined as the quantity of K existing at any one time, dissolved in water of a soil under normal field moisture conditions and relatively unbound by cation exchange forces. It is therefore immediately available to plants and also

subject to leaching. Application of soluble K fertilizers result in marked increases of this form of K. It however does not remain in this form for an extended period of time because it reverts to exchangeable as well as other forms of K. In relative terms, the amounts of water soluble K in the soil is small (except in saline soils); as a result it is not always determined separately in soil analysis; instead it is extracted along with the exchangeable form using neutral normal salts. Brady (1972) reported that this form of K is only 10% of the exchangeable form. It is frequently reported that the distinction between this form and others, both in quantitative terms and by the method of determination is arbitrary since different values are bound to be obtained depending on soil: water ratio as well as the state of equilibrium between this form and exchangeable form at any particular instance. By mere dlution with water, the water soluble K will increase because of hydrolysis of exchangeable K, further replacement of exchangeable K by divalent ions or dissolution of K-bearing minerals.

Exchangeable Form: This is defined as the K adsorbed on the surface of colloids or on exchange complex of clay minerals and organic matter and held electrostatically by the negatively charged colloidal particles. Blanchet and Bosc (1968) defined exchangeable K as the K that we cannot consider as a food reserve definite in

amount. It represents rather a sort of level, a 'manometer reading', reflecting the particular state, often a transitory state of the $K^+$ ions poised between the two opposed tendencies towards fixation and release.

This form of K is always subject to ionic exchange reactions hence the name exchangeable K. It is taken up by plants either as a result of direct root contact, or indirectly through transfer by the soil solution (Thompson, 1957). It exists in a dynamic equilibrium with the water soluble form.

Exchangeable K in soils can be extracted using different kinds of extractants. Acid extractants have been employed by several workers and exchangeable K values determined by such extractants are always higher than that determined by the neutral salt methods (Attoe and Truog, 1945; Ekpete, 1972; and Sobulo, 1973). By varying the concentration of the extractants and the duration and method of extraction, different values of exchangeable K can be got for the same soil. As a result, Garman (1957) and Scheffer and Schachschabel (1967) have stated that exchangeable K may not always be regarded as a diagnostic entity of a soil. Consequently, Garman (1957) broadly defined exchangeable K as "the quantity removed with a definite extractant of specific concentration and dilution ratio". Earlier work by Ayres (1949) and Hoagland and Martin (1933) and a recent one by Udechukwu (1975) showed that the amount of exchangeable K extracted

using neutral normal $NH_4OAC$ represents the exact amount in a soil since subsequent extractions yielded negligible amounts. Hence the use of neutral normal $NH_4OAC$ solution as an extractant in determining exchangeable K is universally accepted though some good correlations have been obtained between the high values got by the acid extractants and the neutral normal $NH_4OAC$ extracts (Unamba - Opara, 1972; Acquaye, 1973; Hanway and Scott, 1959).

Like the water soluble form, exchangeable K is readily available (Brady 1972).

Amounts of exchangeable K tend to be low in most savanna soils (Dupont and de Dinechin, (1967), reported by Wild and Jones, 1972; and Wild, 1971). A mean value of 0.25 meq/100 g was given for 41 soils from Upper Volta (Dupont and de Dinechin, (1967), reported by Wild and Jones, 1972). In northern Nigeria a mean value of 0.18 meq/100 g was recorded by (Wild, 1971). Acid sand soils of southern Nigeria also have very low exchangeable K contents (Tinker and Ziboh, 1959b; Udechukwu, 1975). A mean value of 0.99 meq/100 g was reported for the acid sand soils of eastern Nigeria (Udechukwu, 1975). These values for the savanna and acid sand soils of southern Nigeria are really low when compared with the exchangeable K values of other tropical soils. For instance, Hawaiian sugar cane soils have value ranging from 0.19 - 3.3.39 meq/100 g (Ayres, 1949).

Non-Exchangeable Form: This is the form that is not amenable to cation exchange reactions and, as a result, it is not easily available to plants. Barbier (1962) reported by Duthion (1968) recognises two forms of non-exchangeable K :- (1) that which is definitely (permanently) fixed; included, for example, within the crystal structure of primary minerals like feldspars, muscovite and biotite (mica). This form is definitely witheld from the feeding action of plants and therefore have been regarded by Attoe and Truog (1945) and Duthion (1968) as difficultly available. This fraction represents about 95% of the total K. This is the form that has been regarded as mineral form (Reitemeier, 1951; McLean and Simon, 1965; Munson and Nelson, 1963).

A second form is regarded as 'fixed K' also called reverted (retrograded) K. It occurs between the expanding lattice sheets of 2:1 clay minerals. It does after a time make up a mobile reserve because slow exchanges between this form of K and the exchangeable K will occur under certain conditions. Because of this it is rated as moderately or slowly available K and constitutes about 2% of the total soil K (Attoe and Truog, 1945). Other workers like Addiscott and Talibudeen (1969) and Arnold and Close (1961 a & b) have also stated that there could be two forms of non-exchangeable K based on rate of release. Arnold and Close (1961 a & b) have described two forms namely, loosely-held non-exchangeable K and mineral native K.

The former one corresponds to Barbier's second form (i.e. fixed K) and also to the 'step K' described by Haylock (1956) while the later one corresponds to Barbier's first form (i.e. K within the crystal structure of primary minerals) and also to Haylock's 'constant rate K'.

Plants can take up non-exchangeable K (Bray and De Turk, 1939; and Arnold and Close, 1961). But the relative availability or availability coefficient according to Schachtschabel (1937) and Pratt (1951) of non-exchangeable K is lower than that of exchangeable K; yet it is the reservoir from which available K is replenished continuously.

Applications of soluble K fertilizers result in marked increases of K in the water soluble form. The K does not remain in this form for a long period of time but reverts to the exchangeable, then to the non-exchangeable form as fixed K. Duthion (1968) reported the fixation of 250-300 kg K/ha, resulting from generous and repeated K fertilization over a two year period. The non-exchangeable K may be taken up by plants either directly or after it has been converted to exchangeable K (Chandler, Jr.; Ayres, 1949; Salmon, 1945; Acquaye, 1973; and Islam and Bolton, 1971).

As the supply of the water soluble and exchangeable forms (i.e. readily available K) become deplected either as a result of leaching losses or crop removal, there is a gradual release of non-exchangeable K for plant use (Hoagland and Martin, 1933; Abel and

Magistand, 1935; Bray and DeTurk, 1938; Sen, Deb and Bosc, 1949; and Foster 1972).

Non-exchangeable K is usually determined chemically with strong reagents like mineral acids of varying concentrations and also biologically by continuous cropping either in the green house or in the field.

Soil-K Equilibrium: Several studies suggest that a dynamic equilibrium, a time dependent reaction exists among the various forms of K in soils.

According to Garman (1958), Hissink in 1925 first proposed the idea of a basic equilibrium existing among the various forms of soil K.

Bray and DeTurk (1938), Wood and DeTurk (1940) and Malcom and Kennedy (1969) indicated that equilibrium is rapidly established between the water soluble and exchangeable forms suggesting that reaction between the two occurs instantaneously. In contrast the transformation between exchangeable and non-exchangeable forms is slow and strongly affected by prevailing soil conditions (Wood and DeTurk, 1940; and McLean and Simon, 1958).

Since after Hissink's report on soil K equilibrium many modifications have emerged. According to Duthion (1960), Barbier, (1962) gave the following modification:-

K in solution ⇌ Exchangeable K ⇌ fixed or ⇌ K definitely fixed
reverted K(?)

1 1
1 1
1 1
1 1

rapid and continuous exchanges — slow and contingent exchanges

More recently Acquaye (1973) suggested the following modification.

K in soil solution ⇌ K in soil surface ⇌ non-exchangeable K.

Garman (1957) suggested the following scheme which allows for a more exact interpretation of the K behaviour in soil.

Exchangeable K

K water soluble ⇌ adsorbed K ⇌ structural K

non-exchangeable K

These equilibrium conditions are useful and meaningful only when there is agreement between the definition of the various terms used (Garman 1957).

The 'adsorbed K' in Garman's Scheme has been defined as that fraction which is held electrostatically by excess negative charges on the surface of clay minerals and organic matter and it could be

replaced by other cations without altering the nature of the exchange material. Garman (1957) states that the form of soil K refered to as non-exchangeable in his scheme may include both strongly 'adsorbed K' and 'structural K' but because of the differences in their ease of replacement, for a more realistic soil K equilibrium condition, they should not be considered in the same category.

The 'structural K' has been defined as that portion of the soil K which is combined in the crystal structure of both the primary and secondary minerals. This is not readily replaced by other cations in most extracting solutions. The significance of this K in the equilibrium equation is that it serves as a reserve or pool supply for maintaining constancy of K relationships in the soil. When a soluble K fertilizer is added to the soil it may become fixed as structural K either in the secondary or primary mineral form. When water-soluble and exchangeable K are depleted in the soil either by crop removal or leaching and erosion losses there is release from non-exchangeable K as a result the equilibrium is restored. This process is very important in K equilibrium in the soil.

The Roles of K in Plants.

Unlike the other essential plant nutrient elements, K does not form an integral part of any plant tissue. Therefore, its function in plants is purely regulatory.

Since K is the most abundant cation in the sap of plant cells, it is important as a natural osmotic regulator. K ions have been found

to activate a number of enzymes in vitro. These include pyruvic transphosphorylase (pyruvic kinase), fructokinase, Bacterial hexokinase, Galactose ATP. Evans (1963) studied the effect of K and other univalent cations on the activity of pyruvic transphosphorilase from peas. The enzyme was less active in extracts from K deficient plants and addition of KCl to the reaction mixture reactivated the enzyme.

K improves the general tone and vigour of plants. It also increases crop resistance to certain disease and encourages strong root system. It therefore prevents undesirable lodging of plants. It is important in all cell metabolic processes in the synthesis of carbohydrate, proteins, fats and oils, development of chlorophyll and translocation in plants. Because of its role in carbohydrate synthesis it is particularly important in root crops and also increases the plumpness of grains. When, for instance, plants are deficient in K, carbohydrate production is reduced due to a decrease in carbon dioxide assimilation, therefore, ears of corn become chaffy and the kernels are loose on the cob because they are not well filled with starch. Yield of root crops is also low. Infact the percentage K is usually comparatively high in mixed fertilizers recommended for potatoes and other root crops.

K is essential as an activator for enzymes involved in the synthesis of certain peptide bonds. When it is deficient, soluble nitrogen compounds accumulate in the tissues due to a decrease in

protein formation from amino acids (Black 1957). Other effects of K deficiency are poor keeping quality of fruits - they crack, especially citrus, banana fruits and sugar cane; increase in disease susceptibility, increase in incidence of low temperature damage and retardation of maturity. Deficiency of K in plant is known to disturb the Kreb cycle in roots (Vyskrebentenseva (1963) cited by Hesse, 1971).

When K is too high in the soil, iron chlorosis is induced (Walsh and Clarke (1942), cited by Hesse, 1971) and Mg deficiency becomes prominent (Boynton and Burell, 1944).

The most recently assigned role of K in plants is that concerned with stomatal opening. K uptake increases osmotic pressure since plants' absorptive capacity increase. This causes the guard cells to swell up and keep the stomata open. Only K should be taken up by guard cells for this purpose. This reaction occurs only in the light. The reverse is the case in the dark, K is lost, turgor pressure is decreased and the stomata close. This might explain the luxury consumption of K during the day and why deficiency of K causes a reduction in photosynthesis.

Factors Affecting K Availability.

There are many factors which operate in the soil that affect the availability of K to plants. Most important among these are the

physico-chemical processes like the solubility of the minerals containing K, leaching and erosion losses and fixation. Other factors include pH, moisture content, liming, presence and amounts of other ions.

The chief sources of soil K are of course the primary and secondary minerals - feldspars, micas, illite and vermiculite. If these K bearing minerals are absent in the parent material or if present but not easily weathered and solubilized, low amounts of the element in the soil can be anticipated.

Leaching and Erosion Processes: These contribute significantly to K losses from root zones. This is more so in humid regions. Vidal and Fauche (1962) and Tonrte et.al. (1964) as cited by Wild and Jones (1972) reported that at Bambay, Senegal, leaching losses account for 3 - 12 kg K/ha/annum. At 2Kg K/ha/annum such soils might suffer sever K deficiency since this amount represents 15% of the exchangeable K in top soil (0 - 15 cm) having 0.10 meq/100g exchangeable K. According to Wild and Jones (1972), Moureaux and Fauck (1967) carried out leaching studies and found that an amount of water equivalent to 4000 mm of rain reduced exchangeable K in a brown sub-arid, a ferruginous and a slightly ferrallitic soils to 55, 35 and 35% of their respective original values. The overall effect of such leaching losses is that the readily available K, i.e. water-soluble and exchangeable K is made unavailable to plants.

*Moisture Content and K Concentration in Soil:* Several studies have suggested that the most important mechanism of K supply to plant roots appears to be diffusion (Oliver et. al., 1966; Drew et. al., 1969 a, b; Farr et. al., 1969 and Grimme et. al., 1971) It, therefore, means that factors that affect K diffusion in soils indirectly affect K availability to plants.

As K diffusion takes place in the soil solution (Barber et. al., 1963; and Vaidyanathan et. al., 1968) soil moisture and K concentration in the soil solution appear to be of prime importance in this respect. Grimme et. al. (1971) showed that there was a decrease in diffusive flux when the water content in the soil was lowered. This result finds support by the work of (Graham - Bryce, 1963; and Rowell et. al., 1967). They observed lower diffusion coefficients at reduced water content. Oliver and Barbier (1966) showed that availability of K measured as K uptake is reduced by 15 to 40% if the moisture content is lowered from field capacity (40% water) to pF 2.4 (30% water). A further reduction in soil water tension to pF 2.7 (22% water) brings about a decrease in K availability of about 40 to 70%. This decrease in availability is caused by restricted diffusive flux at low water content.

The importance of K concentration in soil solution on the availability of K to plants stems from the fact that diffusive flux depends on concentration gradient that builds up towards the absorbing

surface. It is therefore not surprising that a good correlation exists between K concentration of the saturation extract and diffusive flux (Grimme et. al., 1971). Sand culture experiments have shown that the rate of K uptake by roots depends on the K concentration and it is not very sensitive to quite large changes in the concentration of other cations as $Ca^{2+}$ $Mg^{2+}$ and $Na^{+}$ in the solution (Wild et. al., 1969). Asher and Ozanne (1967) indicated that the minimum K concentration for active growth of many crops including most of the valuable grasses is about $5 \times 10^{-5}$M. Nemeth and Harrach, (1974) cited by Mengel, (1975) reported that the yield of wheat rose significantly with increasing K concentration in the soil solution. Grain yields of 7 tons/ha were attained only when the soil solution contained about 40 mg K/litre.

The amounts and types of clay minerals present in the soil indirectly affects K availability by affecting K concentration in soil solution. Nemeth et. al. (1969) indicated that the higher the amount of clay, the more K is bound to it and hence taken out of the soil solution.

Liming, Presence and Amounts of Other Ions in the Soil: Peech and Bradfield (1933) and Pierre and Bower (1943) reviewed extensively the influence of other cations especially $Ca^{2+}$ on soil K availability and absorption by plants. Pierre and Bower (1943) summarising numerous investigations concluded that K absorption by plants is usually decreased by the presence of high concentrations of cations in solution and that

however under certain conditions it may be increased.

Many investigators have always come up with conflicting results on the effect of liming on the availability of soil K. For instance Jenny and Shade (1939) cited by York and Rogers (1946) indicated that the addition of $CaCO_3$ liberated large amounts of K on every soil studied. Whereas according to York and Rogers (1946), Dean (1936) gave the opposite view that lime did not liberate soil K and that $Ca^{2+}$ may be so active in depressing the solubility of K that in time the soil may become deficient in available K. Peech and Bradfield (1943) found no evidence of K fixation by lime while Volk (1941) and Harris (1937) indicated that lime increased K fixation hence making it unavailable to plant. Khomvilai and Blue (1977) found that for some of their soils, K retention, i.e., fixation was increased by the first lime increment but retention later decreased with increasing rates of $CaCO_3$. Dolomite lime had less adverse effect on K retention than calcite.

York and Rogers (1946) found that additions of Ca through liming resulted in an increased release of non-exchangeable K on every soil studied though this release was smallest in coarse textured soils with low total K content. They also found that lime increased K fixation. They concluded that the addition of lime to a soil could result in an increase or decrease in available K, depending on the ability of the soil to fix applied K and on the kind, amount

and solubility of K - bearing minerals in the soil.

Higher Ca:Mg/K ratio in the soil solution induces low availability of K in soils (Pierre and Bower, 1943). High $NO_3^-$ content and high pH value in soils increase the depressive effect of Ca and Mg on K availability (Pierre and Bower, 1943). According to Pierre and Bower (1943), Barbier (1936) reported that $NH_4^+$ and $Ca^{2+}$ have great depressive effect on K availability at high than at low pH value and that this explains why plants are deficient in K when grown on high lime soils having high ratios of Ca to K.

K Fixation: K fixation is believed to account significantly for the unavailability of applied K.

Several workers have studied K fixation in soils (Kaila, 1966; Tincknell and Lopez Ritas, 1962; Kee, 1965; Ahmed, 1963; Weir, 1966; Scheffer and Schachtschabel, 1967; Van der Marel et. al., 1956; and Udechukwu, 1975). Udechukwu (1975) studied K fixation in acid sand of eastern Nigeria under three moisture conditions, - wet, dry and moist storage conditions.

Many factors are known to affect K fixation in the soil. These are:- pH, K concentration in soil solution, humus content, type and content of clay mineral; presence of other cations and presence of blocking substances like sesquioxides.

K fixation increases with rising concentration of added K (Scheffer and Schachtschabel, 1967; Kee, 1965; Udechukwu, 1975;

Godefroy and Muller, 1966). Kee (1965) and Udechukwu (1975) reported that on percentage bases fixation decreases with increasing amount of K added.

Kee (1965), Kaila (1966), Weir (1966), Schuffelen and Van der Marel (1955), Scheffer and Schachtschabel (1967), and Udechukwu (1975), showed that K fixation tend to increase with increase in amount of K - fixing clay in the soil. Kee (1965) reported that low fixation is associated with Kaolinitic clays while higher fixation is associated with 2:1 clays. Kaila (1966) found that both in the surface and subsurface samples, the mean values for K fixation tend to increase from the group of the fine sand soils to that of heavy clay. Clays like vermiculite, montmorillonite and illite are responsible for most K fixation in the soil (Scheffer and Schachtschabel, 1967). Duthion (1968) classified the extent of K fixation by the different clay minerals. He considers K fixation in kaolinite, chlorite and mica as nil; slight with montmorillonite; variable with illite and strong with vermiculite depending on their initial K content. Acid sand soils of south eastern Nigeria have low K fixation capacity (Forde 1969 cited by Udechukwu 1975). This is due to the predominance of kaolinite clays in the soils (Tinker and Ziboh, 1959).

Kaila (1966), Scheffer and Schachtschabel (1967) and Weir (1966) noted that blocking substances like organic compounds of all types and sesquioxides (Al and Fe oxides) inhibit K fixation in the soil. Rich (1964) reported that K fixation is favoured in high pH. The

effect of other cations like $Ca^{2+}$ on K fixation has been discussed under liming. The effect of organic components on K fixation is not pronounced (Badiger et. al., 1969).

Release of Non-Exchangeable K in Soils.

Non-exchangeable K has been defined previously in this review as that K that is not amenable to cation exchange reactions. As a result it is not easily available to plants. But under certain conditions there could be continuous release of non-exchangeable K to exchangeable form. Peech and Bradfield (1943) suggested a widely used soil K equilibrium:

$$\text{non-exchangeable K} \rightleftharpoons \text{exchangeable K} \rightleftharpoons \text{water-soluble K.}$$

As the water-soluble and exchangeable K are used up by growing crops or lost through leaching, there is replenishment through release from the non-exchangeable K until equilibrium is re-established.

This release from the non-exchangeable K is very important in K nutrition in the soil and the extent of this release is related to the K supplying power of soils. It is a common observation that some previously uncultivated soils in the Sudan zone showed little or no crop response to K fertilization. This is also true under non-intensive cropping as is the present general practice in this zone (Watson 1964). This lack of crop response could continue for several years before yields decline. These observations may be due to significant K

release from non-exchangeable K sources during the growth period of crops. It, therefore, means that it would be very uneconomical to apply K fertilizers to soils without previously evaluating the non-exchangeable K reserves of such soils. This evaluation is also important since soils differ in their capacity to release K from non-exchangeable forms.

Stewart and Volk (1946) and Arnold and Close (1961) have shown that soils of identical total K status can vary greatly in their ability to release K from non-exchangeable sources. As discussed by Reitemeier (1951), the proportional release of non-exchangeable K from sand, silt and clay fractions probably varies greatly in different soil types.

Chemical and biological methods are normally employed in the study of the release of non-exchangeable K in soils. Biological method is normally carried out either in the green house or in the field. The practice of studying the release characteristics by continuous field cropping is tedious and the results are not normally easily available as a result the continuous or exhaustive cropping in the green house has overtaken the field cropping as a biological means.

Most chemical methods used in the laboratory involve the use of strong acids like HCl and $HNO_3$. Udechukwu (1975) used Hot N HCl and boiling $HNO_3$. Pope and Cheney (1957), Pratt (1951), Maclean (1961), Haylock (1956), Yuan et. al. (1976), and Moss and Colter (1964) used boiling N $HNO_3$. Continuous leaching with 0.1 N HCl was employed by

Garman (1957) and Maelean (1961). Electrodialysis was used by Ayres (1949). McEwen and Matthews (1958) employed the continuous percolation procedure through a resin column with $CO_2$-saturated water. This method was proposed first by Matthews and Smith (1957). Cation exchange resin extraction methcd was used by Pratt (1951), Maclean, (1961); and Salmon (1965).

Most of these chemical methods have been found to correlate significantly among themselves and with the continuous cropping method (McEwen and Matthews, 1958; Maclean, 1961; Pratt, 1951; Garman, 1957; and Pope and Cheney, 1957). Pratt (1951) and McEwen and Matthews (1958) indicated that the chemical method is faster and less tedious than the biological method. McEwen and Matthews (1958) concluded that the percolation method is much more rapid than the continuous cropping technique and not as rigorous as the acid digestion which may cause breakdown of soil minerals.

According to Udechukwu (1975) the percolation method was tried with success at Nigerian Institute for Oil Palm Research (NIFOR) main station near Benin, Bendel State of Nigeria. Forde (1969) cited by Udechukwu (1975) pointed out that one advantage of the chemical method of measuring release of non-exchangeable K is in cases where plant uptake of a specific nutrient may be limited by such factors as poor soil structure or root restriction.

Soil Test for Available K.

In this review available K is taken as exchangeable K though there has been arguments in literature on whether exchangeable K should be regarded as 'available K' or index to K availability. Some workers put forward that available K mean more than exchangeable K or are by no means identical since some fractions of non-exchangeable K can also be available to plants (Fraps (1929) reported by Black, (1957); Bray and DeTurk (1939); and Arnold and close, (1961). Pope and Cheney (1957) Maclean (1961) found a significant correlation between exchangeable K and K uptake by plants. Kee (1965), Salmon (1965); Abel and Magisted (1935); and Rose and Bertramson (1949) have found that exchangeable K is not an accurate index to K-uptake by plants and also to K release from non-exchangeable form during cropping. However, exchangeable K has been used as an index to K availability (Hoagland and Martin 1933).

A wide range of extractants and extracting procedures have been employed by various workers to extract available K in soils with varying degrees of success. The common procedure usually employed involves shaking or leaching a known weight of soil with a known volume of the extracting solution usually buffered or unbuffered salt solution or dilute solutions of mineral or organic acids. These methods are called empirical methods. The use of buffered salt solution has so far gained grounds over the unbuffered solution.

According to Hesse (1971), Warre and Cooke (1962) compared water, citric and acetic acids and HCl as extractants of available K and found citric acid to be best for their soils. Normal $NH_4OAC$ solution at pH 7.0 (neutrality) has been used widely (Ekpete, 1972; Unamba-Opara, 1972; Udechukwu, 1975, and Hanway and Scott, 1959). Leaf (1957) used normal $NH_4OAC$ at pH 6.9 and 4.6 and also normal $NH_4NO_3$ at pH 6.9 and 4.0. Beneth and Reed (1965) employed sodium acetate and $NaNO_3$ solutions at three concentrations (0.1, 0.5, and 3.0 N) and three extractant/soil ratio. Suitable extractant was 0.1 N $NaNO_3$ at extractant/soil ratio of 5:1

The use of various dilutions of mineral acids have been extensively practised (Pratt, 1951; Hunter and Pratt, 1957; Baumgardner and Barber, 1956; Attoe and Truog, 1945, Ekpete, 1972, Unamba-Opara, 1972, Udechukwu, 1975; Hanway and Scott, 1959; and Leaf, 1957). Hunter and Pratt (1957) used phenol disulphuric acid and sulphuric acid as extractants. The values of exchangeable K got by some of these acid extractants correlate significantly among themselves and also with neutral normal $NH_4OAC$ extractable K (Unamba-Opara, 1972; Hanway and Scott, 1959; Udechukwu, 1975).

Woodruff (1955) introduced a method utilizing the concept of standard free energies to determine whether a soil has sufficient available K to support a crop. Beckett (1964 a & b) and Beckett and Craig (1964) have proposed the Q/I relationship (i.e. Quantity:

Intensity relationship) for assessment of available K. Their method have been employed by various workers on different soils (Wild, 1971; Acquaye and Maclean, 1966; Zandstra and MacKenzie, 1968). This method proposed by Beckett (1964) is regarded as a fundamental technique.

Extraction of K from Plant Materials.

A wide range of methods have been employed by various workers to extract K from dried plant samples. Acquaye (1973) employed wet ashing with a mixture of $HNO_3$, $H_2SO_4$ and $HClO_4$ acids, Sobulo (1969), Wild (1971) and Udechukwu (1975) soaked the sample over night in 0.5 N HCl while Salmon (1965) soaked over night in M HCl. Weber and Caldwell (1965) used 0.1575 N acetic acid. Doll et. al. (1965) used 0.1 N HCl while Islam and Bolton (1971) employed dry ashing followed by wet digestion with HCl. Maclean (1961) employed dry ashing at 500°C and Wild et. al., (1969) dry ashed at 450°C.

Determination of K in Soil and Plant Extracts.

When K has been extracted from soil and plant, it can be determined either spectrographically, volumetrically, colorimetrically or gravimetrically. Flame photometric and absorption spectrophotometric methods are also employed.

A turbidimetric method depending upon suspension of K cobaltinitrite can be used where great accuracy is not required (Olson, 1953; and Peech and English, 1943). Olson (1953) reported that this method can be used in rapid testing of soils.

Gravimetrically, K can be determined as the cobaltinitrite, the chloroplatinate or the tetraphenylborate. The cobaltinitrite method is rapid, economical and adaptable to semi-micro technique (Jackson 1958). The method involves several stages of evaporation, precipitation and filtration and errors are likely to occur during these stages. Because of this, flame photometry and tetraphenylborate procedure are preferred. As an alternative to the gravimetric method, precipitate of K cobaltinitrite can be determined volumetrically by titration with citrate or permanganate (Jackson, 1958).

Colorimetrically K can be determined as the dipicrylaminate, a salt of di-2, 4, 6-trinitrophenylamine (Williams, 1941).

Eiseman et. al., (1957) and Portnoy et. al., (1962) reported by Hesse (1971) described the use of glass electrode responsive to K ions.

Though all the above methods could be employed with some degrees of success, the flame photometric and atomic absorption spectrophotometric methods of determining K in soil and plant extracts have superceded them because of convenience and speed.

# MATERIALS AMD METHODS

## Soil Sampling and Handling.

Sample Location: Soil samples used in this study were collected from twenty sites all in Sudan savanna zone of Nigeria. In all the sites, samples were taken at 0 - 15 cm depth only. As much as possible samples were taken from fallow plots where no cultivation has been carried out for some years. Fig 1. and Table 1 show the location of the sampling sites and the description of the soils, respectively.

Soil Handling: Composite samples were taken from different points about five meters apart and latter bulked and put into new, clean, labelled polythene bags. These were thoroughly mixed and spread out on clean plastic sheets in the green house. After two days of air drying they were thoroughly hand mixed again and sieved with a 2 mm sieve. Subsamples were taken and bottled for all laboratory analysis.

## Characterization of the Soils.

The chemical and physical properties of the soils determined are :- pH, organic matter, exchangeable bases, exchange acidity, effective cation exchange capacity, particle size analysis and percent base saturation.

pH: The soil pH was determined in water at 1:1 soil/water ratio and also in 0.01 M $CaCl_2$ solution at 1:2.5 soil/solution ratio using Kent pH meter model 7060.

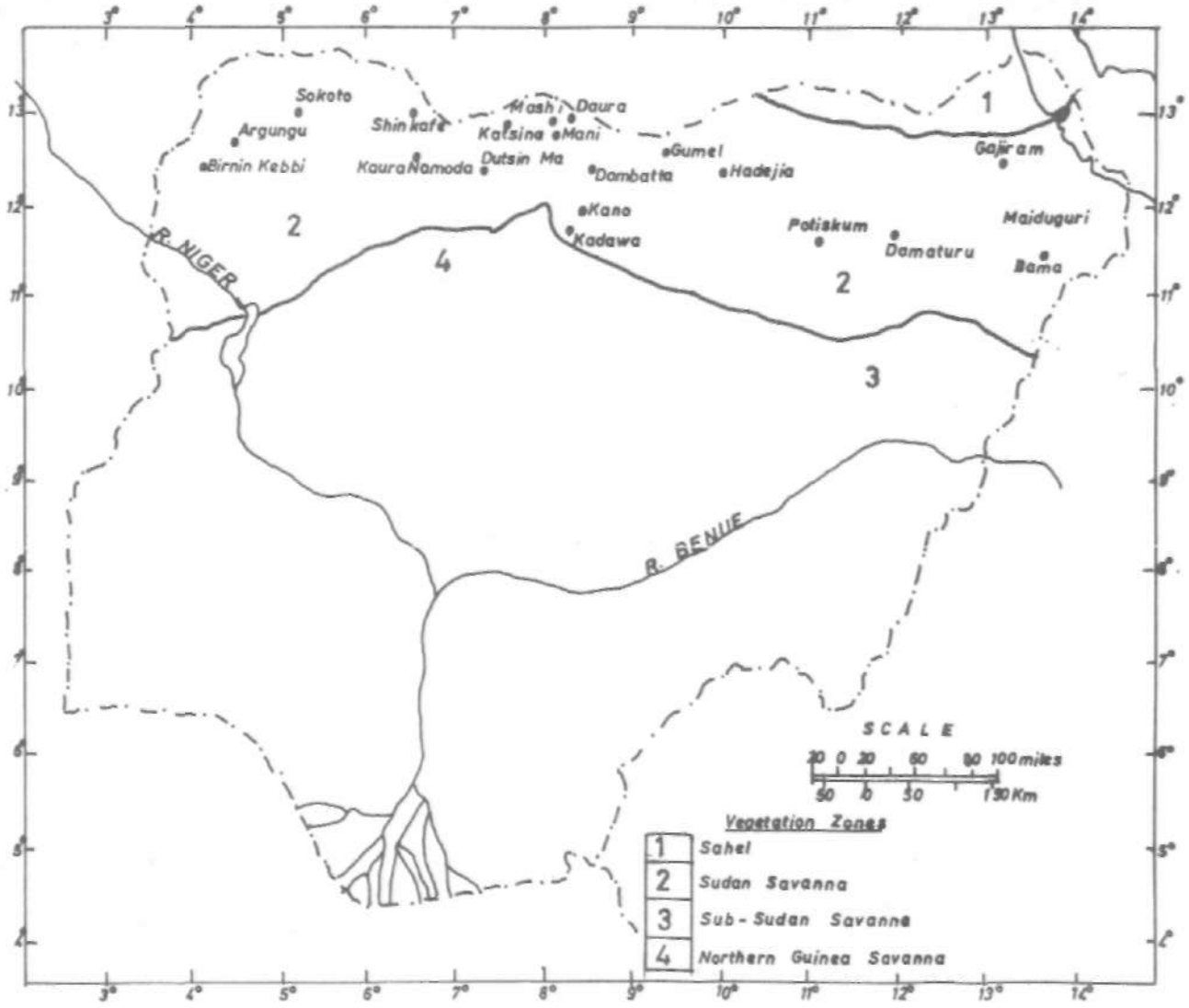



FIG 1: MAP OF NIGERIA SHOWING LOCATIONS WHERE SOIL SAMPLES WERE COLLECTED FOR THE STUDY

Table 1: The locations, State, parent materials, and ecological zone of the areas sampled.

| Soil No. | Location | State | Parent Material | Ecological Zone |
|---|---|---|---|---|
| 1. | Kaura Namoda | Sokoto | Aeolian sand/Alluvium | Sudan |
| 2. | Shinkafe | Sokoto | Aeolian sand/Alluvium | Sudan |
| 3. | Sokoto | Sokoto | Aeolian sand | Sudan |
| 4. | Argungu | Sokoto | Aeolian sand | Sudan |
| 5. | Birnin Kebbi | Sokoto | Aeolian sand | Sudan |
| 6. | Dutsunma | Kaduna | Aeolian sand/Basement Complex | Sudan |
| 7. | Katsina | Kaduna | Aeolian sand | Sudan |
| 8. | Mani | Kaduna | Aeolian sand | Sudan |
| 9. | Mashi | Kaduna | Aeolian sand | Sudan |
| 10. | Daura | Kaduna | Aeolian sand | Sudan |
| 11. | Kadawa | Kano | Aeolian sand/Basement Complex | Sudan |
| 12. | Kano | Kano | Aeolian sand | Sudan |
| 13. | Dambatta | Kano | Aeolian sand | Sudan |
| 14. | Gumel | Kano | Aeolian sand | Sudan |
| 15. | Hadejia | Kano | Aeolian sand | Sudan |
| 16. | Potiskum | Borno | Sand Stone Keri Keri Formation | Sudan |
| 17. | Damaturu | Borno | Aeolian sand/Alluvium | Sudan |
| 18. | Maiduguri | Borno | Alluvium | Sudan |
| 19. | Bama | Borno | Alluvium/Basement Complex | Sudan |
| 20. | Gajiram | Borno | Aeolian sand (dune) | Sudan Sahel |

Organic Matter: The soil organic carbon was first determined by the short Walkley - Black method (Jackson 1958) using finely ground samples. The organic matter was calculated by multiplying the organic carbon values by a factor of 1.724.

Exchangeable Bases: Five g of each soil was first shaken with 30 ml of neutral normal $NH_4OAC$ solution for 2hrs (i.e., 1:6 soil/ solution ratio), centrifuged for 10 min and the clear supernatant solution was decanted into a 100 ml volumetric flask. Another 30 ml of the $NH_4OAC$ solution was added to the same sample, shaken for 30 min, centrifuged for 10 min and the solution was decanted into the appropriate volumetric flask. This process was repeated again and the solution made to mark with the $NH_4OAC$ solution. Na and K were determined in a Gallenkamp flame photometer while Ca and Mg were determined in a Perkin - Elmer Model 403 atomic absorption spectrophotometer after lithium chloride had been added to prevent deionization.

Exchange Acidity: Ten g of each soil in a leaching tube was leached with 1 N KCl solution. Twenty ml portions of the KCl solution were used. The leacheate was collected in 100 ml volumetric flask and made up to mark with the N KCl solution. The exchange acidity was determined by titration with 0.05 N NaOH (McLean, 1965).

Effective Cation Exchange Capacity: This was determined by summing up the values of the $NH_4OAC$ extractable bases and the exchange acidity.

Particle Size Analysis: This was determined by the hydrometer method as described by Day (1965).

Percentage Base Saturation: This was calculated by dividing the sum of the exchangeable bases by the effective cation exchange capacity values and multiplying by 100.

Fractionation of Soil K.

Exchangeable K Fraction: This was determined as described for the determination of exchangeable bases on page 34 and designated hereafter as $^{K}NH_4OAC$.

Difficultly Exchangeable K Fraction: This was determined by the boiling N $HNO_3$ extraction method. To 2.5 g of each finely ground soil contained in 125 ml flask was added 25 ml of N $HNO_3$. After careful mixing, the suspension was boiled for exactly 10 min on a hot plate, the flask being rotated intermittently. After cooling, the suspension was filtered into 100 ml volumetric flask using whatman No. 42 filter paper. The soil was washed with four 15 ml portions of 0.1 N $HNO_3$ and made up to mark. The K in the filtrate was determined in a flame photometer. The K thus determined less the exchangeable K was taken as the difficultly exchangeable K designated hereafter as $^{K}HNO_3$.

Non-Exchangeable K Fraction: This was determined by the extraction with hot N HCl. To 5 g of each finely ground soil contained in a 125 ml flask was added 50 ml of 1 N HCl and after mixing, the suspension was heated for 1 hr on a hot plate. After

cooling, the suspension was filtered using whatman No. 42 filter paper. The soil was washed with 25 ml portions of 0.5 N HCl and made up to mark. The K in the filtrate was determined in a flame photometer. The K thus determined less exchangeable K was taken as the non-exchangeable K designated hereafter as $^{K}HCl$.

Total K Determination: The method in Black (1965) was employed. To 0.1 g of each finely ground soil contained in a platinum crucible few drops of water, 5 ml of HF and 0.5 ml of $HClO_4$ were added in that order and heated on a sand bath at 200 - 225°C. The crucibles were covered with their lids and heated to evaporate the content to dryness. After cooling, 2 ml of water and few drops of $HClO_4$ were added and heated again to dryness after which 5 ml each of 6 N HCl and water were added and heated on a hot plate until the solution just boiled. The solution was filtered into a 100 ml volumetric flask using whatman No. 42 filter paper. The filter paper was washed with distilled water and the volume made to mark. Potassium in the filtrate was determined in a flame photometer.

Repeated Extraction with Hot N $HNO_3$: The method described for difficulty exchangeable K determination on page 35 was employed here. After the first extraction, five more extractions were carried out with the same sample. K in each extract was determined in flame photometer. The K thus determined less the exchangeable K gave the non-exchangeable K extracted each time.

The K in the filtrate was determined in a flame photometer. The amount of K fixed and the percentage K fixation were calculated.

Dry Fixation: The method described by Scheffer and Schachtschabel (1967) was employed. The procedure carried out in the wet fixation was repeated here with few exceptions. One of such exceptions is that after equilibrating by shaking for one hour with the KCl solutions, the suspension was dried in the oven at 80°C for 24 hours after which 50 ml of the $NH_4OAC$ solution was added and shaken for another one hour.

Methods of Available K Determination.

The methods employed are:-

A Extraction with neutral N $NH_4OAC$ by

I Shaking for 2 hrs in 1:6 soil/solution ratio

II Leaching procedure

III Shaking for 30 mins in 1:10 soil/solution ratio

IV Extraction with 0.5 N HCl

V Extraction with 1.0 N HCl

VI Extraction with dilute cold $H_2SO_4$.

A.I This is as described for the exchangeable bases on page 34

A.II Ten g of each soil in a leaching tube was leached with 100 ml of neutral normal $NH_4OAC$ solution using 20 ml portion at a time. The leacheate was received in 100 ml volumetric flask and latter made up to mark. K in the leacheate was determined in a flame photometer.

A.III The K determined by this method is called equilibrium exchangeable K. Five g of each soil was shaken with 50 ml of neutral normal $NH_4OAC$ solution (i.e. 1:10 soil solution ratio) for 30 min (Sobulo, 1969) and filtered through Whatman No. 42 filter paper. The filtrate was collected in 100 ml volumetric flask and K in the filtrate was determined in a flame photometer.

A.IV and V. Ten g of each soil was leached as described for A:II using 0.5 N and 1.0 N HCl, respectively. K in the leacheate was determined in a flame photometer.

A.VI To 10 g of each soil contained in 100 ml beaker were added 25 ml of distilled water and 1 ml of concentrated $H_2SO_4$. It was stired and left to stand for 30 min after which it was filtered into 100 ml volumetric flask using Whatman No.42 filter paper. The soil was washed with 15 ml portions of 0.1 N $H_2SO_4$ until the filtrate was brought to mark. K in the filtrate was determined in a flame photometer.

*Repeated Extraction With Neutral Normal* $NH_4OAC$ *by the Leaching* Method: Ten g of each soil was leached with neutral, normal $NH_4OAC$ solution as described for A.II above.

After this initial leaching, seven successive leachings were made on the same samples. K in all leacheates was determined in a flame photometer.

Effect of Lime on the Availability of Native Soil K.

Kadawa, Kano and Dambatta soils were used for this study in the green house. A total of 72 pots (of about 7 litres capacity) were arranged in randomised complete block design (R.C.B.D). Six rates of lime, 0 to five tonnes/ha were applied and replicated four times. Four kg soil that had been thoroughly mixed with the right lime rate was poured into each appropriate pot placed on plastic containers to receive excess water that may drain out. Before planting, enough distilled water was added (on gravimetric basis) so as to bring the soil to field capacity. This was maintained at field capacity for three weeks by applying appropriate amount of water daily. At the end of this period eight maize seeds (Zea Mays (L), variety, Samaru 123) were selected and placed evenly on the pots. Little quantity of soil was scooped out and the seeds were placed in each hole and later covered with the scooped out soil. The following nutrients - 200 ppm N as $NH_4NO_3$, 60 ppm P as $NaH_2PO_4 . 2H_2O$ and 50 ppm Mg as $MgSO_4$ were applied in solution at planting.

After germination, the seedlings were thinned down to 5. During the growth period water was added once a day during the morning hours so as to bring the weight of the soil to the initial watering weight. The weight of the plant at a later growth period was taken into consideration in watering the pots.

After seven weeks of growth the plants were harvested by cutting them at the soil level with a sharp clean razor blade. The soil in each pot was turned out and the roots picked out, washed and rinsed twice in distilled water. Both the shoots and roots were bagged in clean paper bags and dried for 10 days in an electric oven at $70^{\circ}C$.

After drying, the samples were weighed and the dry matter yield calculated.

The dried samples were ground by passing them through a grinder with a glass cup receiver. Subsamples were dried again and 0.5 g taken for the determination of amount of K taken up by the plant.

All the procedure in the first green house study above were repeated in the second one with few exceptions. One of such exceptions is that 12 maize seeds were planted and thinned down to eight and the plants grew for only 33 days.

Recovery of Exchangeable K on Wetting and Drying Cropped Soils.

Three of the cropped soils - Kadawa, Kano and Dambatta were used for this study. The procedure of Wild (1971) was employed. Duplicate 100 g of the sieved cropped soil were taken to the laboratory in small plastic plates. The soils were brought to field capacity by applying appropriate amount of distilled water. One set of the soils was kept at field capacity continously by applying appropriate amount of water daily. The other set also at field capacity was dried in the laboratory over a period of three days. This cycle of wetting and drying for three days was repeated twenty times and after the 1st, 5th and the 20th cycles the exchangeable K was determined by extraction with neutral normal $NH_4OAC$ solution at a 1:6 soil/solution ratio. After 60 days the first set of soils kept wet continously were sampled and exchangeable K determined with neutral normal $NH_4OAC$ solution. K in the extracts was determined with a flame photometer.

Extraction of K from Plant Samples.

Half g plant sample was digested with 15 ml of an acid mixture (prepared by mixing 20 ml $H_2SO_4$, 80 ml $HClO_4$ and 650 ml $HNO_3$) on a digesting plant. The digest was cooled and diluted with small quantity of distilled water and filtered with Whatman No.42 filter paper into 100 ml volumetric flask and made to mark. K in the filterate was determined in a flame photometer.

Statistical Analysis.

Where necessary all data obtained in this study were subjected to two types of statistical analysis thus:-

(1) Correlation and regression analysis

(2) Analysis of variance.

# RESULTS AND DISCUSSIONS

## General Soil Properties.

The data on the physical and chemical properties of the soils presented in Table 2 indicate that the soils are characterised by very low effective CEC, organic matter content and high percentage base saturation. The soil pH was generally on the slightly acid side. The range and mean values of the exchangeable bases given at the bottom of Table 2 show that these are generally low.

The particle size analysis put the textural class of the soil between sand to sandy loam. This is not unexpected since most of the soils are derived from aeolian deposits (Table 1).

## Fractionation of Soil K.

The absolute and relative values of K fractions and total K are presented in Table 3.

Exchangeable K - $K_{NH_4OAC}$: With a range of 0.10-38 meq/100 g and a mean value of 0.17 meq/100 g, the exchangeable K content of the Sudan savanna soils tend to be low. A mean value of 0.18 meq/100 g was obtained for some northern Nigerian soils and was regarded as low by Wild (1971). Dupont de Dinechin (1967) reported by Wild and Jones (1972) gave a mean value of 0.25 meq/100 g for 41 soils from Upper Volta. Acquaye (1973) reported a mean value of 0.19 meq/100 g for some Ghanaian soils. West Indian volcanic soils

have ranges of 0.07 to 1.58 meq/100 g (Moss and Coulter, 1964).

The low exchangeable K content of these soils is not unexpected since most of the soils are derived from aeolian deposits. The negative correlation between exchangeable K and sand in Table 5 confirm this.

On an average, this fraction constituted 1.79% of total K and it falls within the range of 1-2% reported by Brady (1972).

Difficultly Exchangeable K - $^{K}_{HNO_3}$: With a range of 0.09 to 1.50 meq/100 g and a mean value of 0.49 meq/100 g, the difficultly exchangeable K could be termed as not being too low when compared with values for other soils. For instance Udechukwu (1975) reported a mean value of 0.16 meq/100 g for some acid sand soils of eastern Nigeria. Leaf (1958) reported a mean of 0.138 meq/100 g for some Wisconsin soils. On the basis of individual soils, however, some are relatively low; for instance in soils 3, 4, 5, 7, 10, 12, 13 and 14 the value range from 0.09 to 0.29 meq/100 g. This is comparable to some Ultisols in Florida that had values not exceeding 0.25 meq/100 g (Yuan, 1975) and some Malayan soils with values not exceeding 0.20 meq/100 g which was regarded as meagre (Kee 1965). These soils have correspondingly low values of $^{K}_{HCl}$ and total K (Table 3). Thus the paucity of K reserve in these soils is well established. There might be responses to K fertilizer under intensive cultivation as pointed out by Wild (1971). In fact soils number 12

Table 4: Sucessive extraction of K by Hot $\underline{N}$ $HNO_3$

| Soil No. | No. of Extraction 1st | 2nd | 3rd | 4th | 5th | 6th |
|---|---|---|---|---|---|---|
| 1. | 1.28 | 0.52 | 0.14 | 0.13 | 0.14 | 0.13 |
| 2. | 0.72 | 0.34 | 0.17 | 0.18 | 0.14 | 0.14 |
| 3. | 0.20 | 0.06 | 0.06 | 0.05 | 0.04 | 0.04 |
| 4. | 0.12 | 0.08 | 0.11 | 0.06 | 0.05 | 0.04 |
| 5. | 0.09 | 0.08 | 0.07 | 0.05 | 0.05 | 0.05 |
| 6. | 1.50 | 0.19 | 0.16 | 0.14 | 0.13 | 0.13 |
| 7. | 0.29 | 0.19 | 0.16 | 0.14 | 0.12 | 0.12 |
| 8. | 1.37 | 0.17 | 0.17 | 0.16 | 0.12 | 0.12 |
| 9. | 0.43 | 0.34 | 0.16 | 0.14 | 0.13 | 0.12 |
| 10. | 0.22 | 0.15 | 0.15 | 0.13 | 0.11 | 0.11 |
| 11. | 0.56 | 0.34 | 0.20 | 0.12 | 0.12 | 0.11 |
| 12. | 0.26 | 0.18 | 0.11 | 0.10 | 0.12 | 0.10 |
| 13. | 0.13 | 0.11 | 0.10 | 0.07 | 0.04 | 0.04 |
| 14. | 0.17 | 0.11 | 0.09 | 0.08 | 0.09 | 0.08 |
| 15. | 0.37 | 0.15 | 0.12 | 0.11 | 0.11 | 0.11 |
| 16. | 0.37 | 0.25 | 0.20 | 0.17 | 0.15 | 0.15 |
| 17. | 0.27 | 0.18 | 0.14 | 0.14 | 0.13 | 0.13 |
| 18. | 0.51 | 0.32 | 0.22 | 0.21 | 0.17 | 0.16 |
| 19. | 0.59 | 0.35 | 0.22 | 0.22 | 0.30 | 0.21 |
| 20. | 0.43 | 0.23 | 0.16 | 0.13 | 0.13 | 0.13 |
| Mean | 0.49 | 0.22 | 0.15 | 0.13 | 0.12 | 0.11 |

and 13 show response to K fertilization (Balasubramanian 1978, personal communication).

Consecutive extractions with hot $\underline{N}$ $HNO_3$ were carried out to study the rate of release from this reserve. The results presented in Table 4 indicate that for the soils with higher K reserve there was still considerable K reserve after the 6th extraction. Low values obtained after the 6th extraction are for the soils mentioned above which have relatively lower K reserve. A mean of 0.11 meq/100 g was obtained after the 6th extraction and this is equivalent to a value of 96 Kg K/ha of surface soil. Yuan (1975) reported similar results. There is, therefore, potential for continuous release though the case of release is not known, and this may in part explain the lack of crop response to K fertilization in some of these soils at least in the first few years of cultivation.

*Non-exchangeable K* - $^{K}HCl$: With a range of 0.20-3.50 meq/100 g, the trend in the distribution of $^{K}HCl$ is indentical to that of $^{K}HNO_3$ and the results confirm the low K reserve in soils nos. 3, 4, 5, 7, 10, 12, 13 and 14 mentioned above.

Total K: The value ranged from 0.13 to 2.15% with a mean value of 0.56% (Table 3). This compares fairly well with a mean value of 0.52% for soils over aeolian deposits reported by Wild (1971). Acquaye (1973) gave a range of 0.04 to 4.80% with a mean value of 0.70% for some Ghanaian soils while a range of 0.33 to 3.20% and a

mean value of 0.86% was reported for some Upper Volta soils by Dupont de Dinechin as cited by Wild and Jones (1972). Comparatively, therefore, the total K in these soils is not too low.

The total soil K varies widely according to parent material. Working with Nigerian savanna soils, Wild (1971) reported mean total K values of 2.18, 0.52 and 0.08%, respectively, for soils over basement complex, aeolian deposit and sandstone parent materials. The total K presented in Table 3 is in agreement with the above finding. Soils numbers 1, 2, 6, 11, 17, 18 and 19 on parent materials other than pure sands (Table 1) have relatively higher total K. Soil number 19 on Alluvium/Basement complex parent material have a value of 2.15% which compares very closely to a mean value of 2.18% obtained for soils over Basement complex in the Nigerian savanna (Wild 1971). Soil number 18, over alluvium parent material, has a value of 1.38% which compares fairly well with a mean value of 1.43% reported for soils over alluvium parent material also in the Nigerian savanna (Wild 1971). According to Wild (1971) this value for soils over alluvium parent material is not unexpected since their clay fractions contained some mixed layer minerals which might have fixed K contained in flood waters during the formation of the soils. There might be no response to K fertilization in these soils because of the high total K which could release available K with time. Unamba-Opara (1972) indicated that the higher the K reserve in a soil the greater the ability to resist depletion and

Fig. 2. Distribution pattern of K fractions

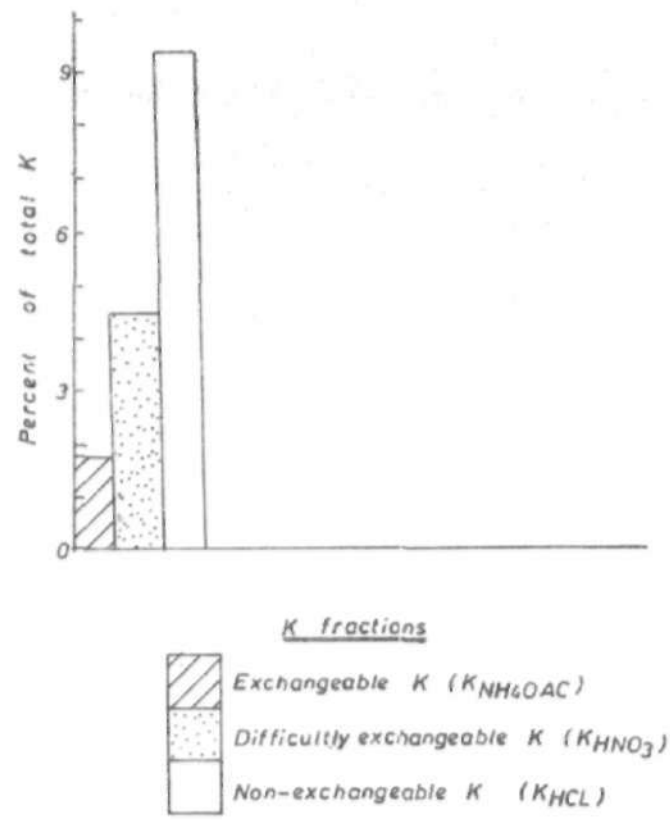


Table 5: Correlation coefficients and regression equations between the various K fractions, total K and some soil properties.

| Variables | | | Correlation Coefficients | Regression Equations |
|---|---|---|---|---|
| CEC | Vs | $K_{NH_4OAC}$ | 0.3643 ns | - |
| CEC | Vs | $K_{HNO_3}$ | 0.7073*** | Y= - 0.0768 + 0.2668 X |
| CEC | Vs | $K_{HCl}$ | 0.7287*** | Y= - 0.1855 + 0.5777 X |
| CEC | Vs | Total k | 0.5588* | Y= - 1.6137 + 6.4117 X |
| pH $H_2O$ | Vs | $K_{NH_4OAC}$ | 0.4526* | Y= - 0.2038 + 0.0651 X |
| " | Vs | $K_{HNO_3}$ | 0.5554* | Y= - 2.5012 + 0.5190 X |
| " | Vs | $K_{HCl}$ | 0.5077* | Y= - 4.7050 + 0.9973 X |
| " | Vs | Total k | 0.4221 ns | - |
| Silt | Vs | $K_{NH_4OAC}$ | 0.5435* | Y= 0.1143 + 0.0055 X |
| " | Vs | $K_{HNO_3}$ | 0.2800 ns | - |
| " | Vs | $K_{HCl}$ | 0.3051 ns | - |
| " | Vs | Total k | 0.5755** | Y= 3.2616 + 1.1706 X |
| Clay | Vs | $K_{NH_4OAC}$ | 0.0105 ns | - |
| " | Vs | $K_{HNO_3}$ | 0.3277 ns | - |
| " | Vs | $K_{HCl}$ | 0.4016 ns | - |
| " | Vs | Total k | 0.0706 ns | - |
| Sand | Vs | $K_{NH_4OAC}$ | -0.4108 ns | - |
| " | Vs | $K_{HNO_3}$ | -0.3343 ns | - |
| " | Vs | $K_{HCl}$ | -0.3834 ns | - |
| " | Vs | Total k | -0.4624* | Y= -75.5220 - 0.7209 X |

*** = Significant at 0.1%
** = Significant at 1%
* = Significant at 5%
ns = Not significant

vice versa. Table 4 shows that for these soils there was still larger amounts of K reserve after 6th extraction than for the earlier mentioned soils with lower total K.

The distribution pattern of these fractions illustrated by means of histogram using the mean value of the fractions expressed as percentage of the total K is presented in fig 2. The relationship is not unexpected since the $K_{NH_4OAC}$ is only a measure of the exchangeable K status which is always small. It constitutes from 1 to 2% of total K (Brady 1972). The mean value of 1.79% obtained falls within this range. The $K_{HNO_3}$ and $K_{HCl}$ have higher values because they are a measure of the capacity factor, an index of potential K reserve. They constitute from 1 to 10% of total K (Brady 1972), and the mean values of 4.49 and 9.43%, respectively, obtained, fall within this range.

Relationship Between the Fractions and Some Soil Properties: Simple correlation and regression analysis between the K fractions and some soil properties were carried out to determine the influence of these properties on the various K fractions. The regression lines of the relationships that were significant are shown in figures 3 - 11. The correlation coefficients presented in Table 5 show that all the fractions correlated significantly at 5% with pH. Unamba-Opara (1972) reported similar relationship ($r = 0.5934^{**}$) for Agodi and Adio soils of western Nigeria while Acquaye (1973) reported a correlation of ($r = 0.619^{***}$) for some Ghanaian soils

Fig. 1: Regression line of C E C upon $KHNO_3$

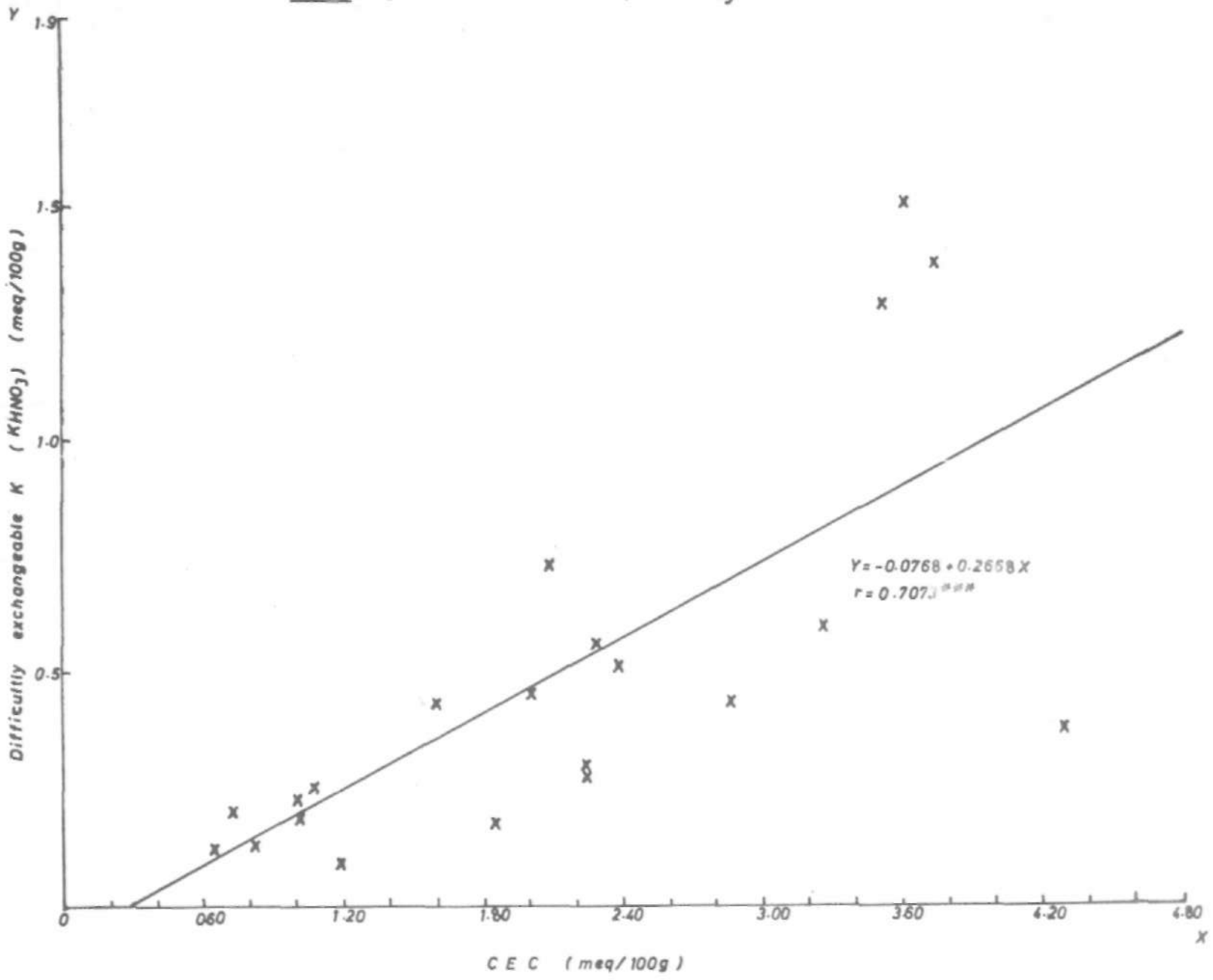
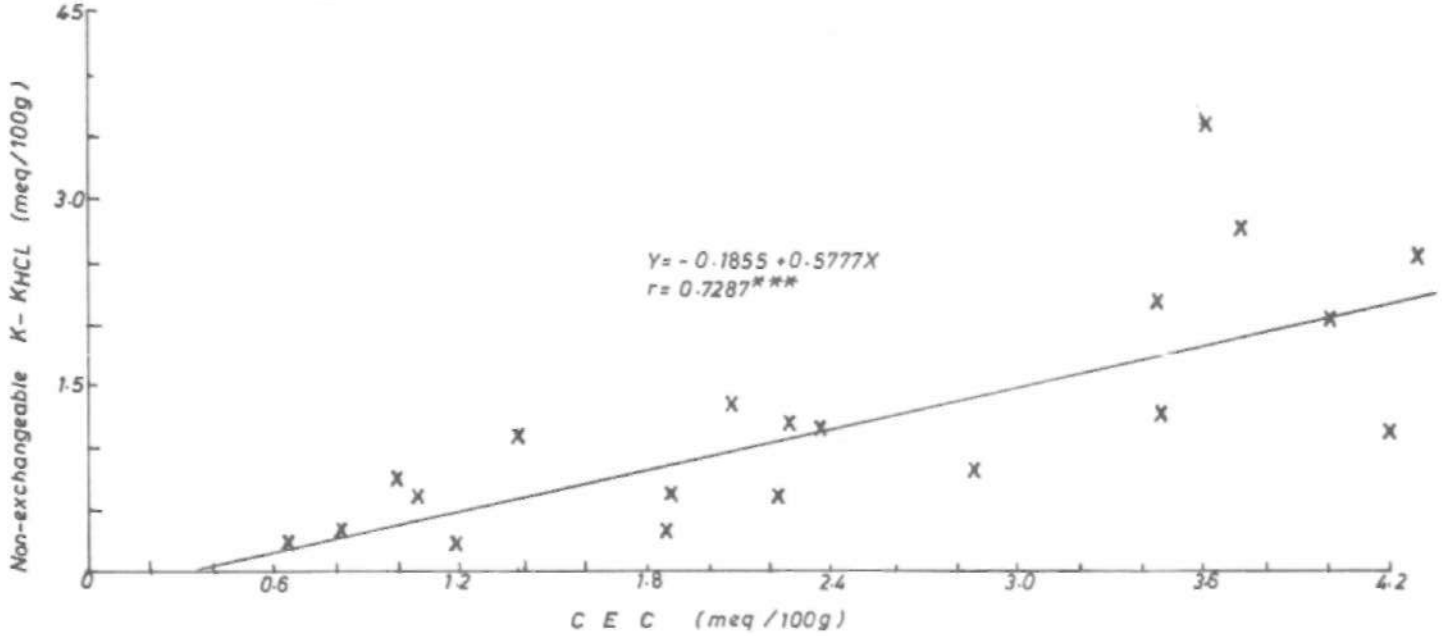


Fig. 6: Regression line of C E C upon $K_{HCL}$



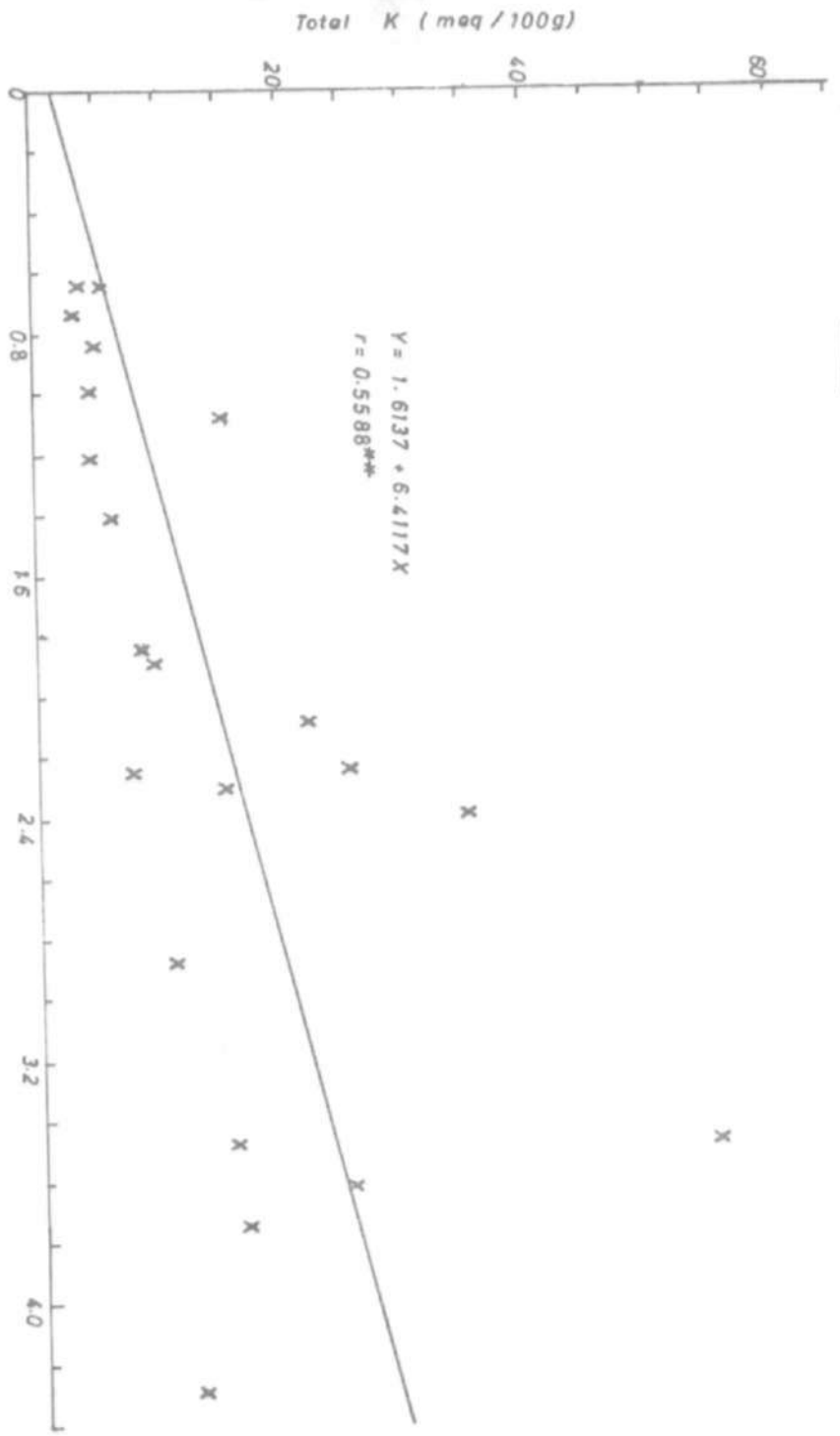



Fig.15 : Regression line of C E C upon total K

Fig. 5: Regression line of $PH_{(H_2O)}$ upon $K_{NH_4OAC}$

$Y = -0.2038 + 0.0651\ x$
$r = 0.4526^{**}$

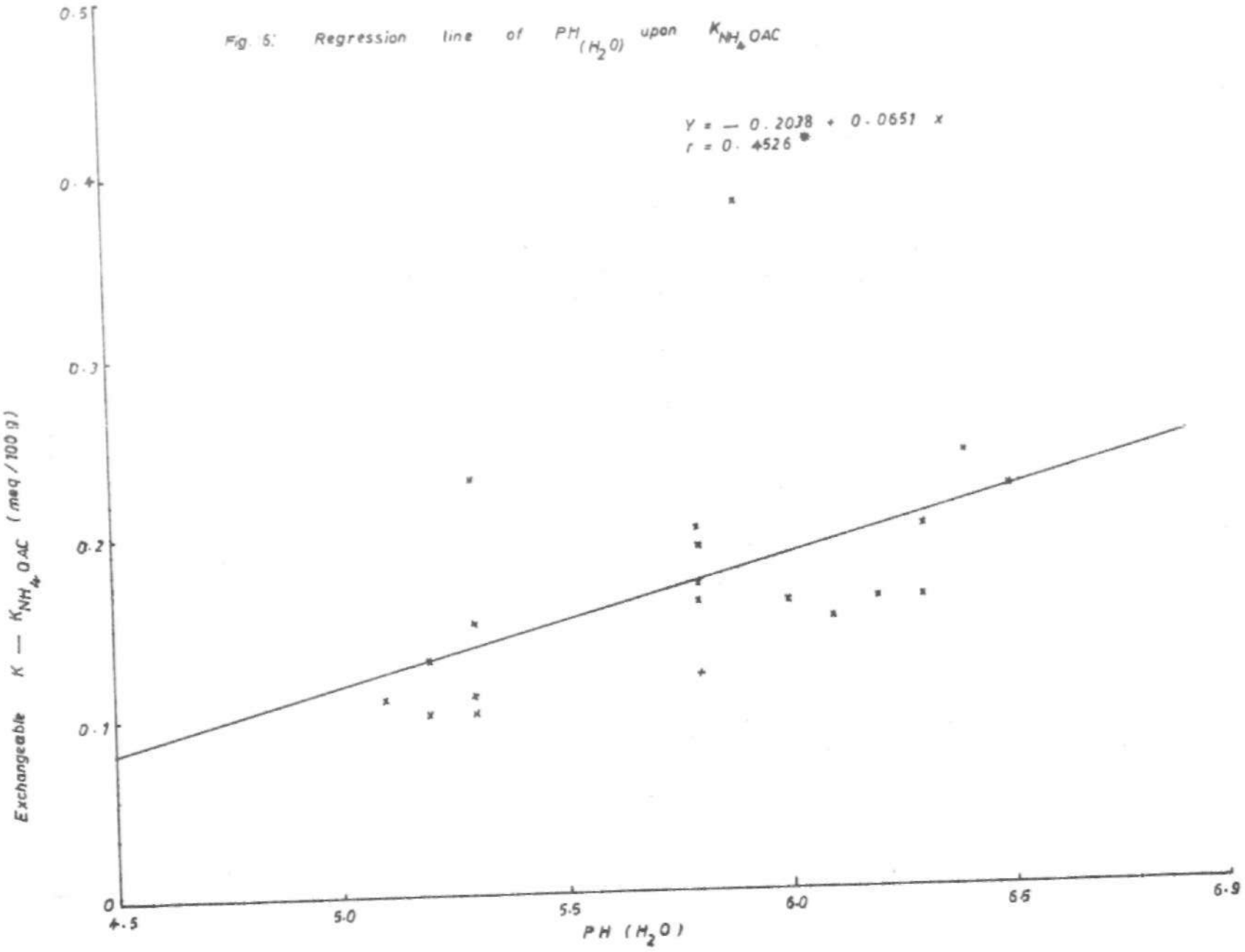


Fig. 7 : Regression line of PH upon $K_{HNO_3}$

$Y = -2.5012 + 0.5190\ x$
$r = 0.5554$ *

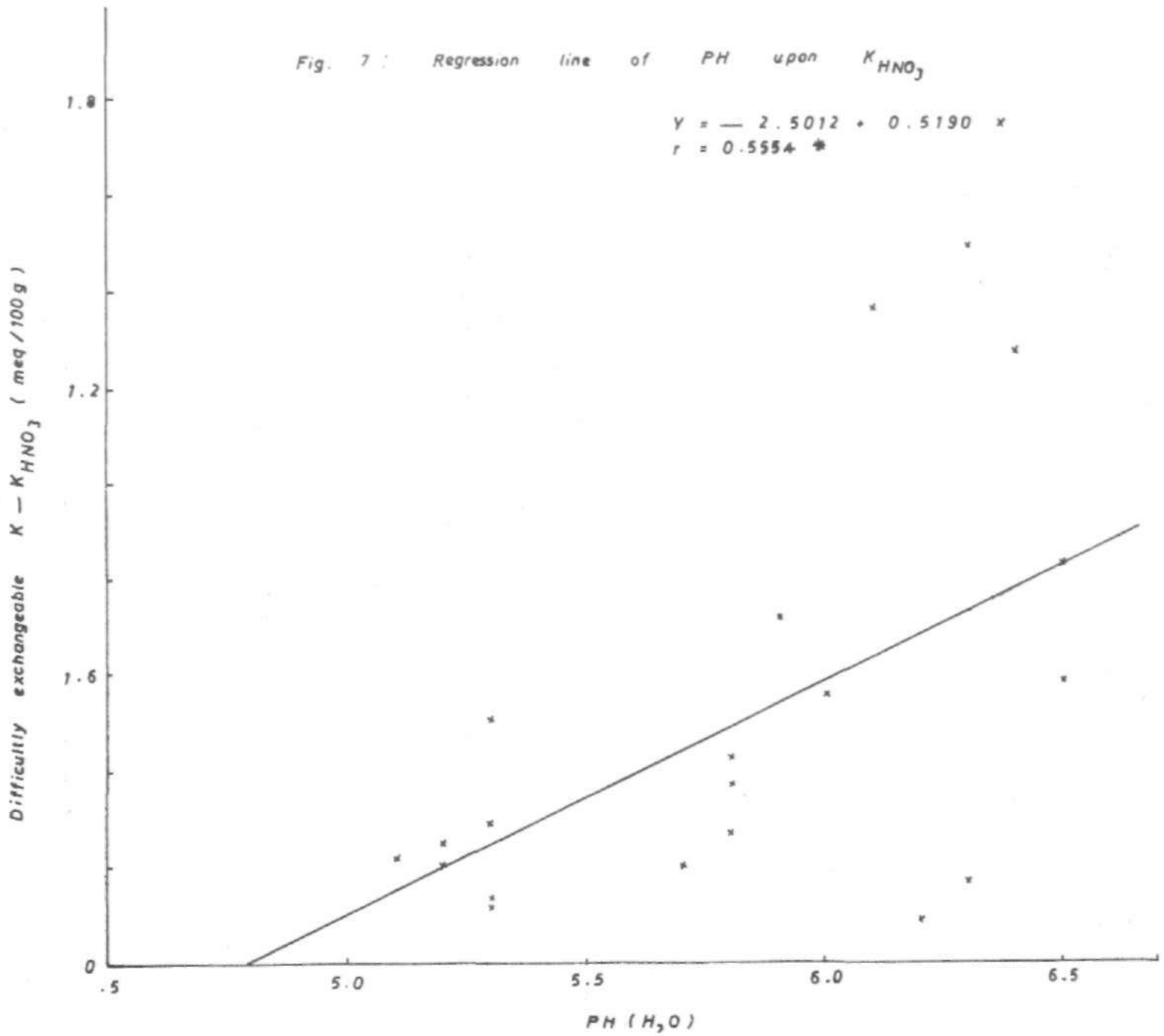


Fig. 8: Regression line of PH upon $K_{HCl}$

$Y = -4.7050 + 0.8973\ x$
$r = 0.5077\ *$

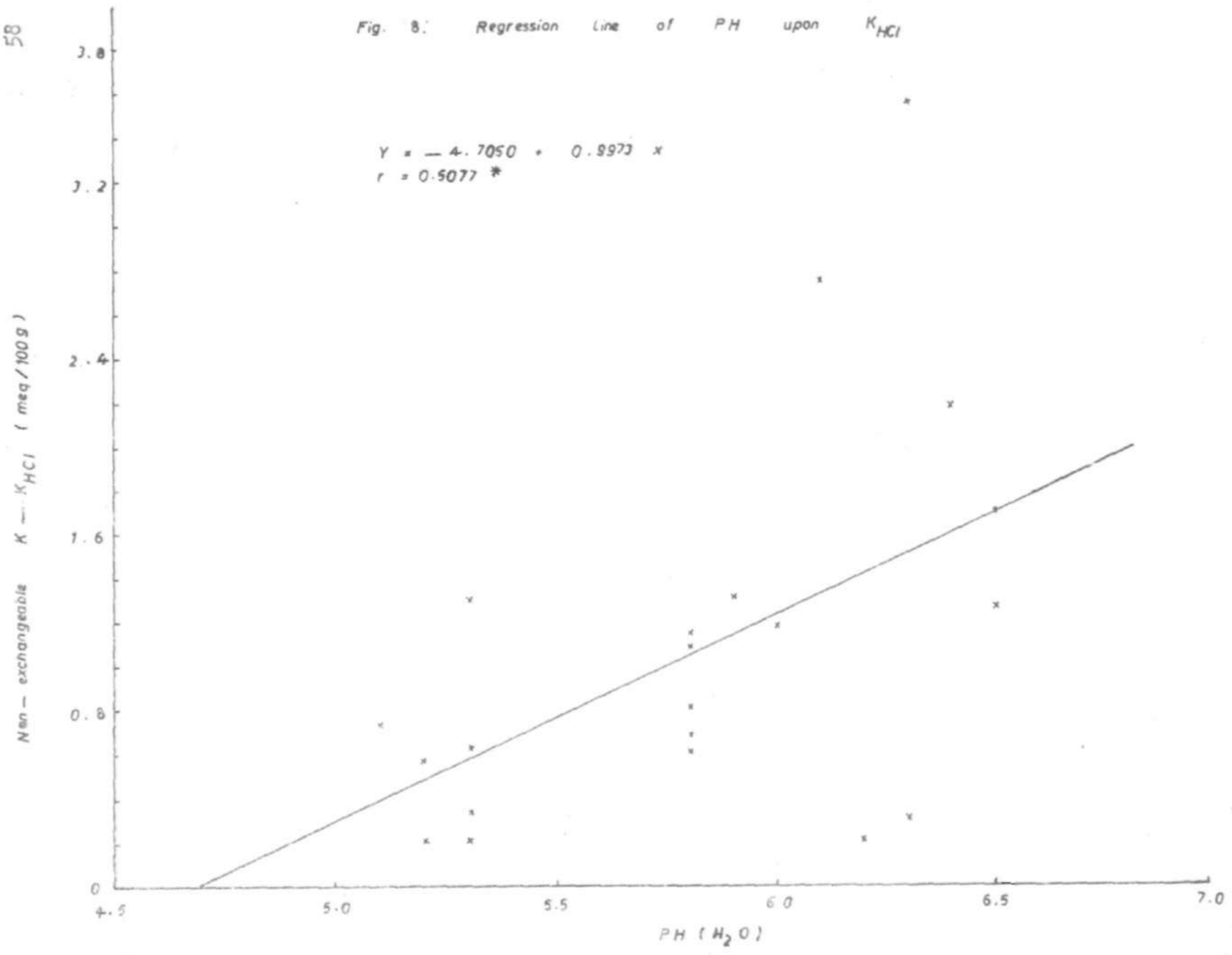


Fig. 9 : Regression line of silt upon $K_{NH_4OAC}$

$Y = 0.1143 + 0.0055\ x$
$r = 0.5435$ *

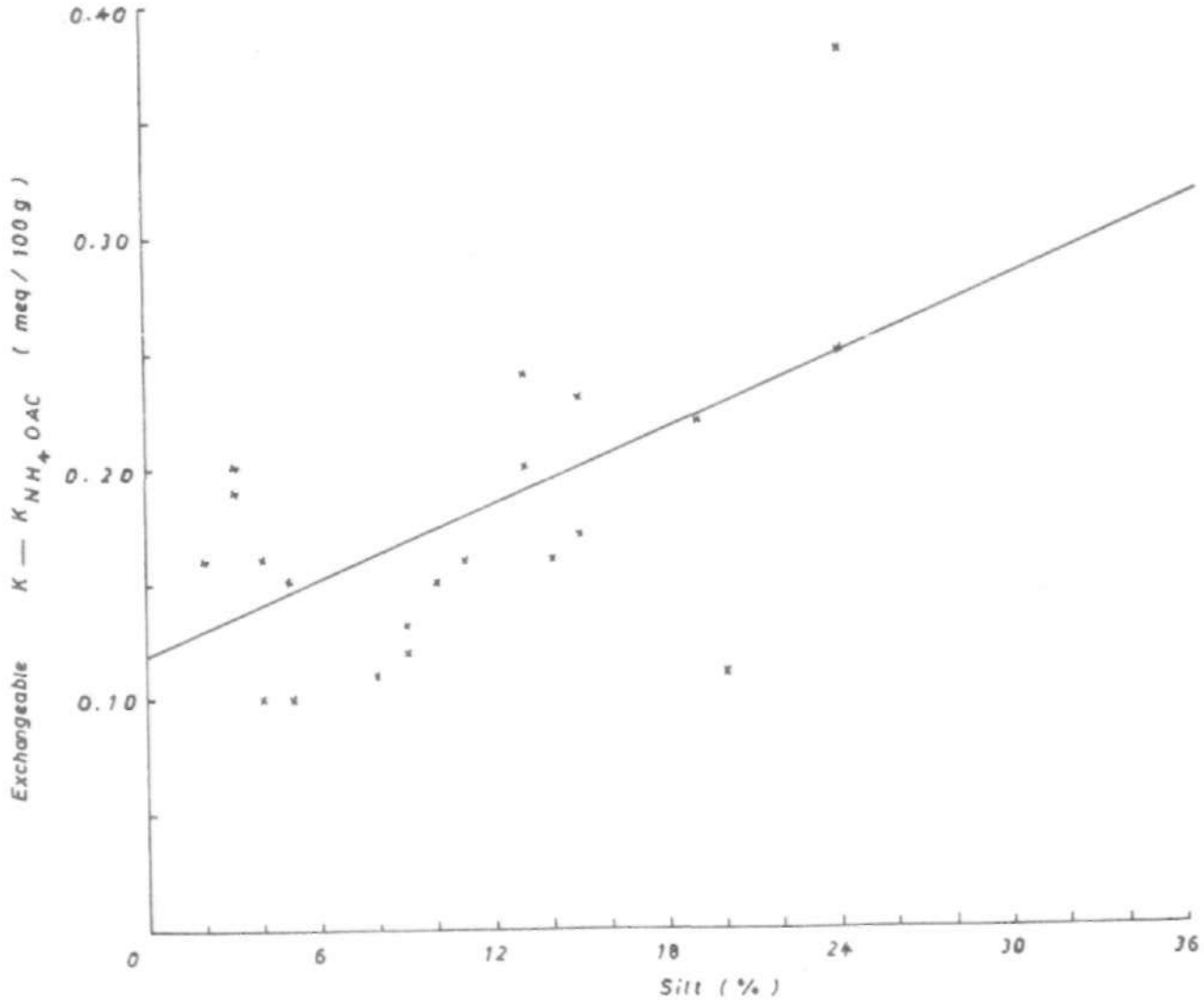
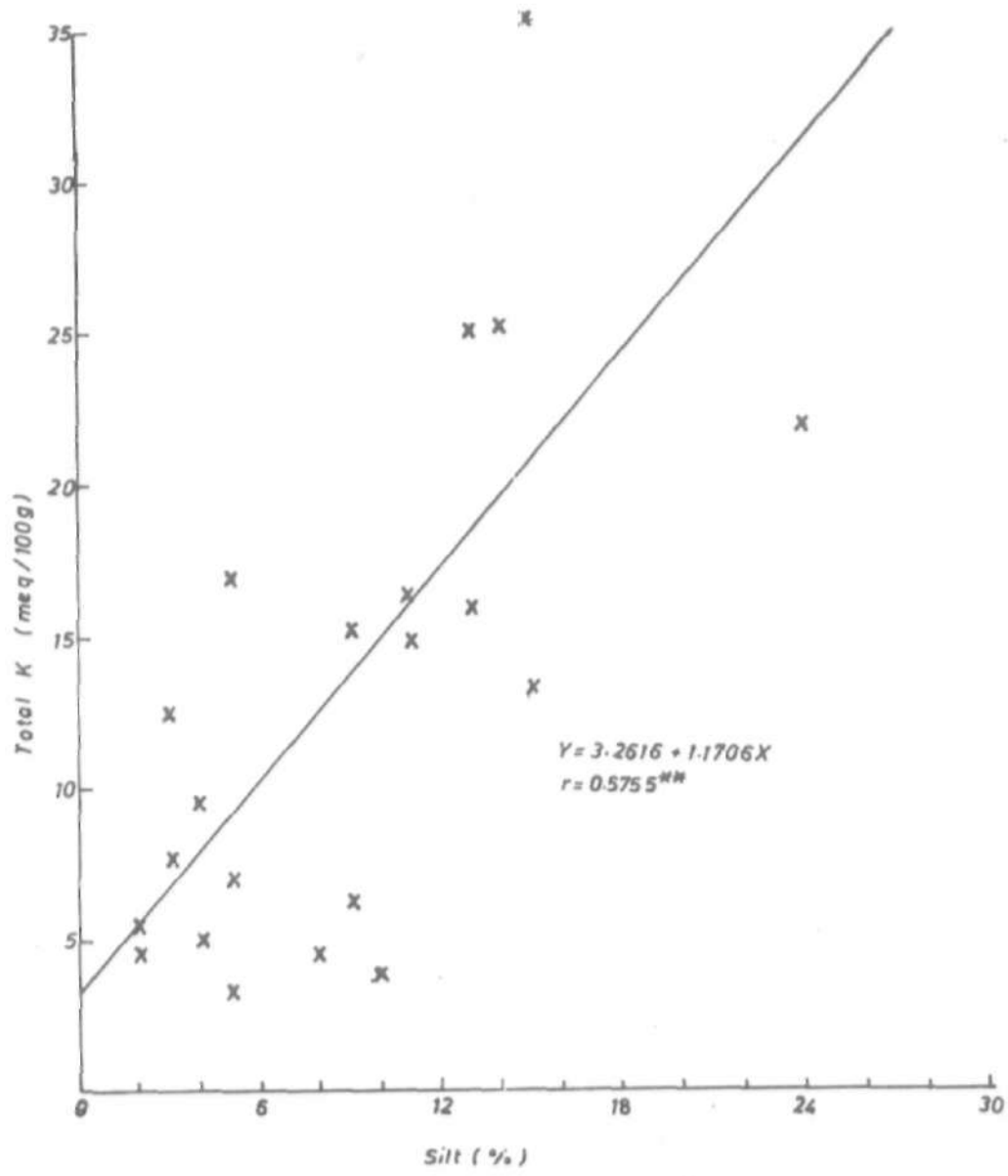


Fig.10: Regression line of silt upon total K



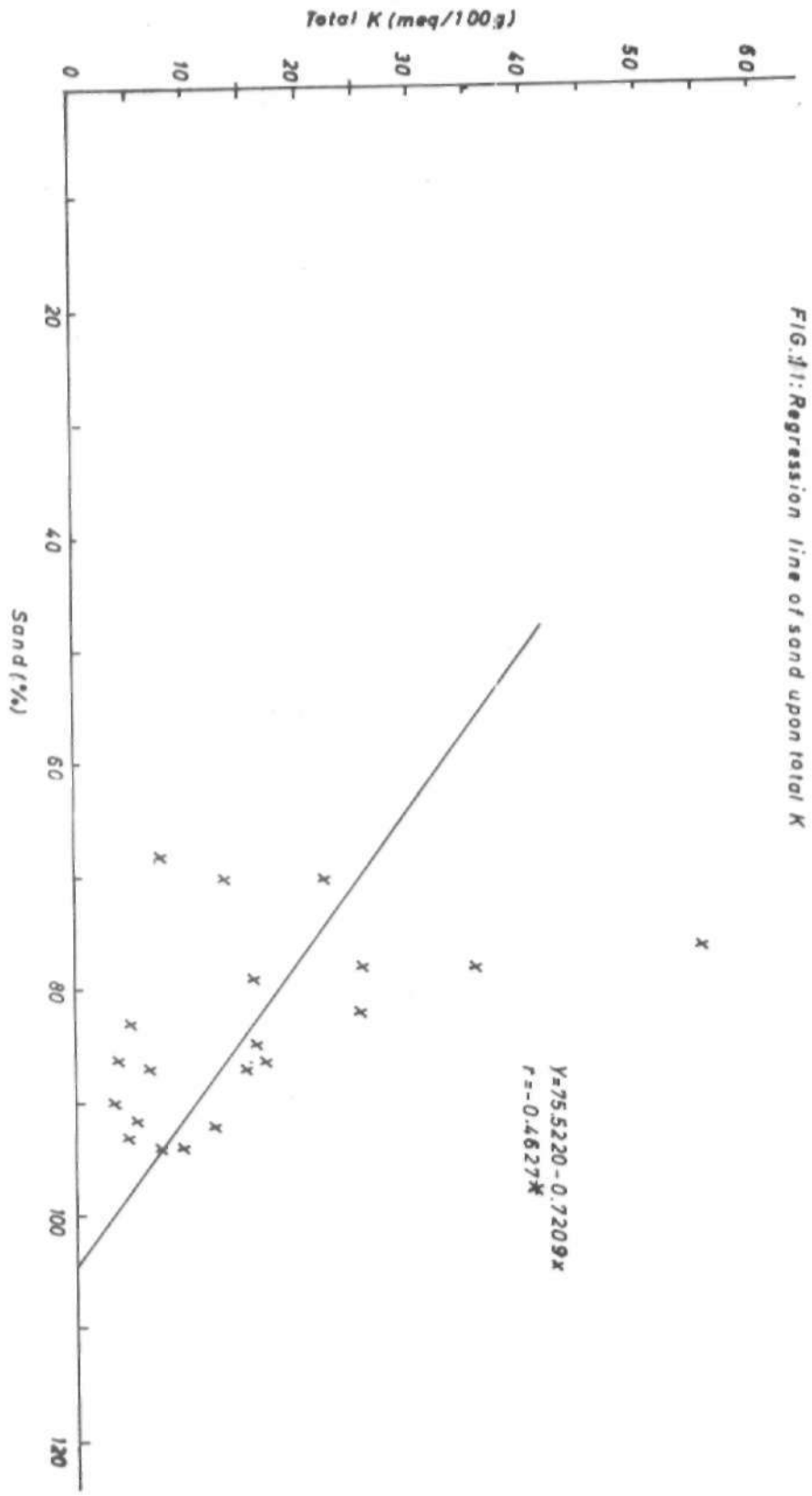



FIG.11: Regression line of sand upon total K

and advanced that this was not unexpected since the pH of a soil is often a relation of its base saturation. Unamba-Opara (1972) indicated that the higher the pH the greater the K in both exchangeable and reserve form. $^{K}NH_4OAC$ tended to increase with silt content ($r = 0.5435^{*}$) while the $^{K}HNO_3$ and $^{K}HCl$ increased greatly with CEC ($r = 0.7073^{***}$ and $0.7287^{***}$, respectively). The Total K content was not related to the clay content, hence the non-significant correlation. This is probably due to dominance of kaolinite in most of the clay fractions (Wild 1971). The total K tended to increase with silt content ($r = 0.5755^{**}$). It is likely that the silt fraction contains small amounts of K bearing minerals like feldspar, mica, etc. Acquaye et. al., (1967) and Wild (1971) reported that K is associated with the sand and silt fractions in savanna soils. However, the results of this study indicated a negative correlation between sand and all fractions and negative significant correlation with total K (Table 5). It is, therefore, concluded that K is associated mainly with the silt fraction in the Sudan savanna soils of Nigeria.

K Fixation.

The ranges and mean values of K fixed by the two methods (Wet and dry fixation) at various concentrations of added K presented in Table 6 indicate that in general K fixation increased with increase in the level of concentration of K added. Greater amount was fixed by the dry method and where there was release or 'negative' fixation

Table 6: K fixation on addition of varying amounts of K (percentages of applied K fixed are given in paranthesis).

| Methods | K added (meq/100g) | K fixation values (meq/100g) | | |
|---|---|---|---|---|
| | | range | mean | S.D. |
| Wet | 1.25 | -0.38 - 0.03 (-30.4 - 2.4%) | -0.22 (-17.88%) | 0.10 |
| Dry | 1.25 | -0.38 - 0.22 (-6.4 - 17.6%) | -0.02 (-1.60%) | 0.06 |
| Wet | 2.50 | -0.27 - 0.19 (-10.8 - 7.6%) | -0.05 (-2.06%) | 0.10 |
| Dry | 2.50 | 0.04 - 0.32 (1.6 - 12.8%) | 0.11 (4.38%) | 0.07 |
| Wet | 5.0 | 0.03 - 0.44 (1.0 - 8.8%) | 0.18 (3.53%) | 0.10 |
| Dry | 5.0 | 0.10 - 0.51 (2.0 - 10.2%) | 0.28 (5.64%) | 0.09 |

greater release occured by the wet method. These results are expressed further by means of histograms in figure 12.

The percentages of the applied K fixed are presented in Table 6 in parenthesis. When compared with results from other tropical soils, these values indicate that these soils have very low K fixing capacity. For acid sand soils of eastern Nigeria, Udechukwu (1975) obtained average values of 7.04% and 12.91% by the wet and dry fixation methods, respectively, when only 2.50 meq K/100 g was used. When the same concentration of K was used in this study, negative value (-2.06%) was obtained by the wet method and only 4.38% by the dry method while at 5.00 meq K/100 g of applied K, percentages of applied K fixed were 3.53 and 5.64% for the wet and dry fixation methods, respectively. These were not even upto the percentage values got for the application of only 2.50 meq K/100 g by Udechukwu (1975). Godfroy and Muller (1967) got 7% and 25% by the wet method for some Madagascar and Ivory Coast soils, respectively, when only 2.0 meq K/100 g was used. It is likely that the low K fixing capacity of these soils is due to the dominance of kaolinite in the clay fraction (the content of clay is also very low) in most of the Sudan savanna soils. Duthion (1968) and scheffer and schachtschable (1967) reported that in soils dominated by kaolinitic clays there shouls be little or no K fixation. It is also likely that the presence of Fe and Al oxides and hydroxides suppressed K fixation by acting as blocking agents at the K fixation sites. Mortland (1961); Rich and

Fig 12: Increase in mean K fixation with increase in the concentration of applied K

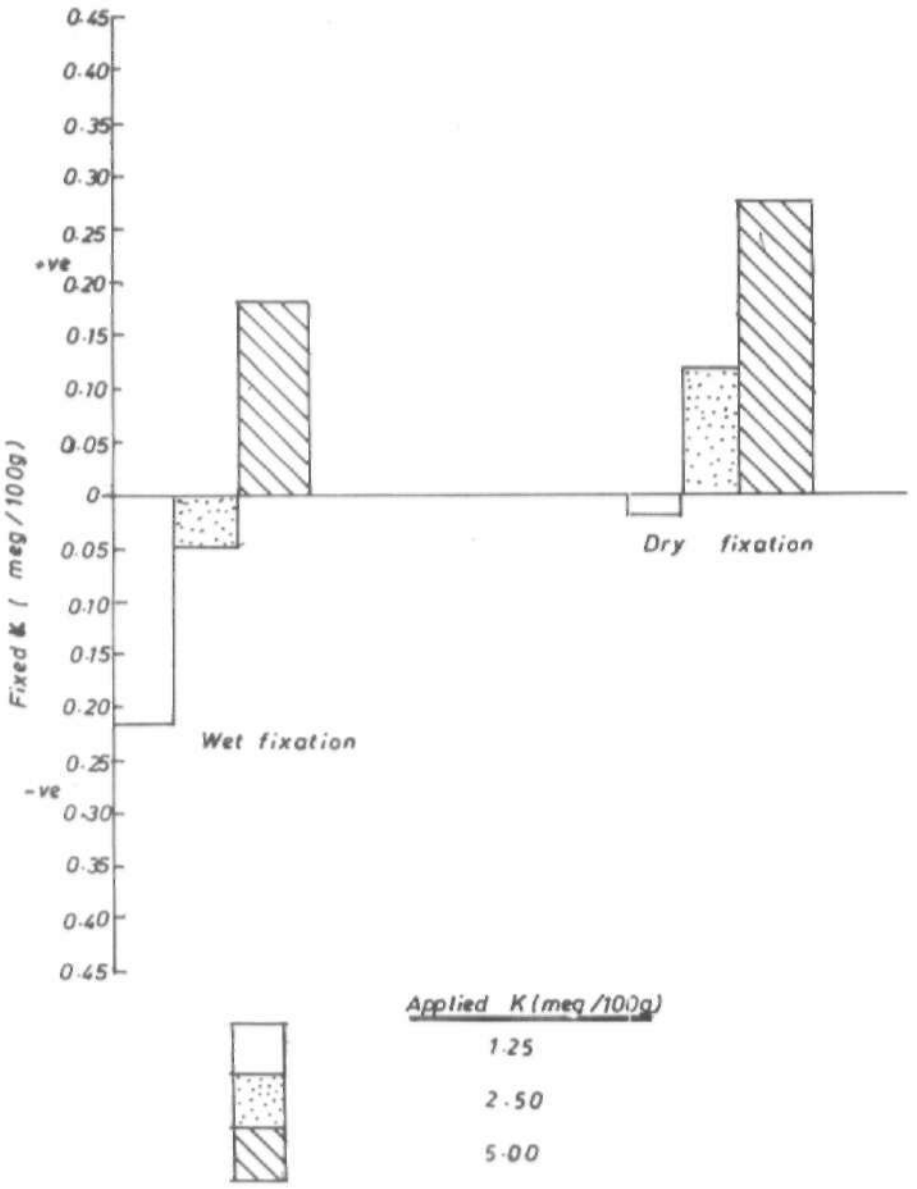


Table 7: Correlation coefficient and regression equation between the K fixation values obtained by the two methods on addition of 5.00 meq K/100g and some soil parameters.

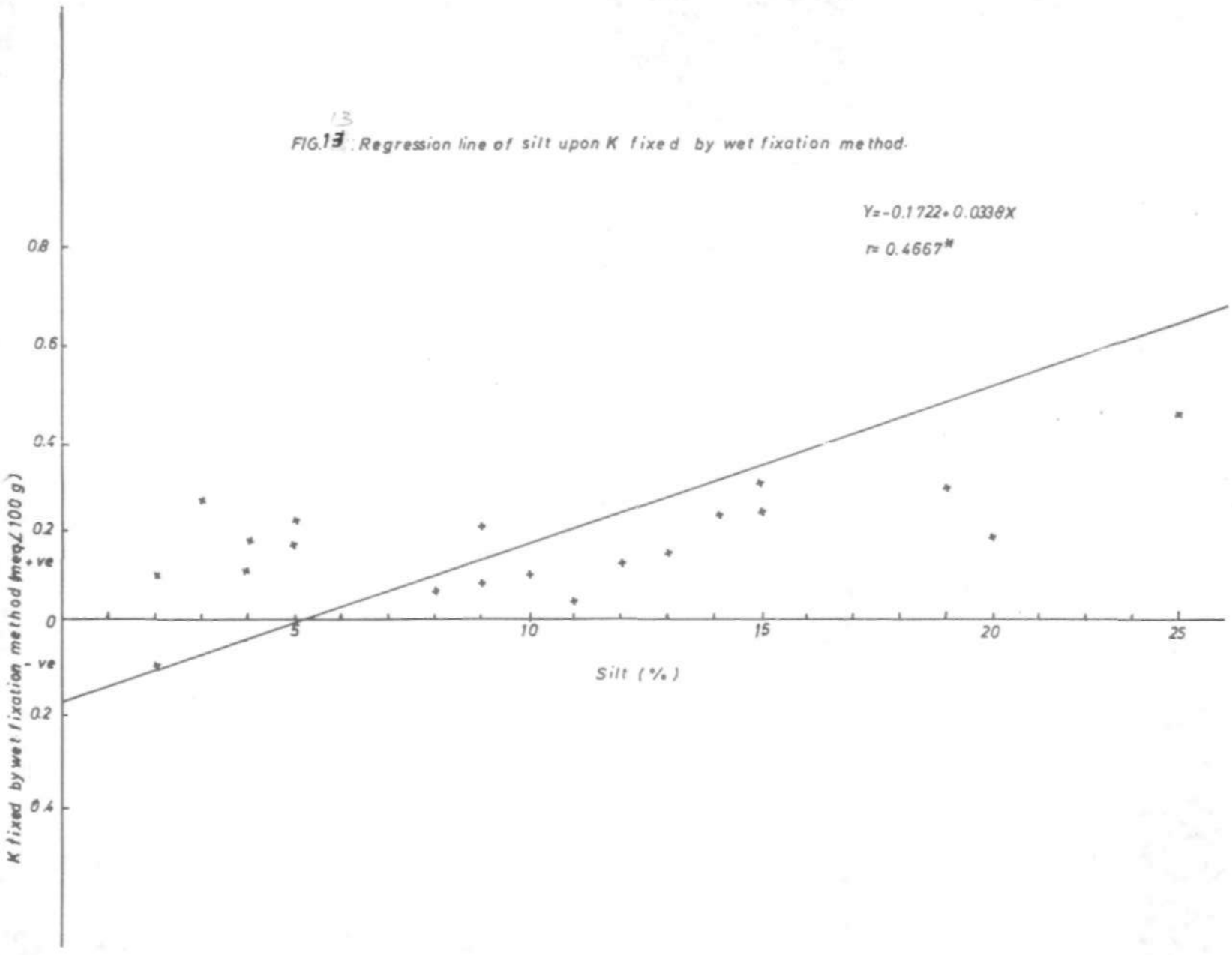
| | Variables | | Correlation Coefficients | Regression Equations |
|---|---|---|---|---|
| 1. | Silt | Vs Wet fixation | 0.4667* | Y= -0.17722 + 0.0338 X |
| 2. | Silt | Vs Dry fixation | 0.4706* | Y= -0.0173 + 0.0291 X |
| 3. | Sand | Vs Wet fixation | -0.4161 ns | - |
| 4. | Sand | Vs Dry fixation | -0.3959 ns | - |
| 5. | Clay | Vs Wet fixation | 0.1763 ns | - |
| 6. | Clay | Vs Dry fixation | 0.1154 ns | - |
| 7. | Exchangeable K | Vs Wet fixation | 0.6854*** | Y= -0.2086 + 2.2391 X |
| 8. | Exchangeable K | Vs Dry fixation | 0.8380*** | Y= -0.0091 + 1.5852 X |
| 9. | CEC | Vs Wet fixation | 0.4032 ns | - |
| 10. | CEC | Vs Dry fixation | 0.4013 ns | - |
| 11. | pH ($H_2O$) | Vs Wet fixation | 0.2699 ns | - |
| 12. | pH ($H_2O$) | Vs Dry fixation | 0.3489 ns | - |
| 13. | Organic matter | Vs Wet fixation | 0.1180 ns | - |
| 14. | Organic matter | Vs Dry fixation | 0.01107 ns | - |

Black (1964) and Scheffer and Schachtschable (1967) had reported the effect of these sesquioxides as blocking agents in K fixation. Ascertaining the presence and abundance of these sesquioxides in the Sudan savanna soils would confirm this. The presence of $NH_4^+$ and $H_3O^+$ ions may decrease K fixation since they compete with K ions for the interlayer exchange positions owing to their similar size (Wilklander 1952). Depending on their abundance in these soils they may have influenced K fixation.

The three concentrations (1.25, 2.50, 5.00 meq K/100 g) used for fixation study represented additions of 450, 900 and 1800 Kg $K_2O$/ha, respectively. These values far exceed the normal rates of K application to crops in this area (60 to 120 Kg $K_2O$/ha). At this practical K application rate, there will not be any fixation at all. More-over, farming in these areas is mostly confined to the wet season when K fixation will be negative as indicated by wet fixation in this study. During the dry season, when most of the crops will be mature and ready for harvest, not much K will be left in the soil for dry fixation to be significant. In essence, these soils face a problem of K leaching rather than K fixation.

K Fixation and Some Soil Properties: Simple correlations and regression analysis were carried out between K fixation values and some soil properties to determine the effect of these properties on K fixation. The correlation coefficients presented in Table 7 show that K fixation tended to increase with silt content ($r = 0.4667^*$

FIG.13 : Regression line of silt upon K fixed by wet fixation method.



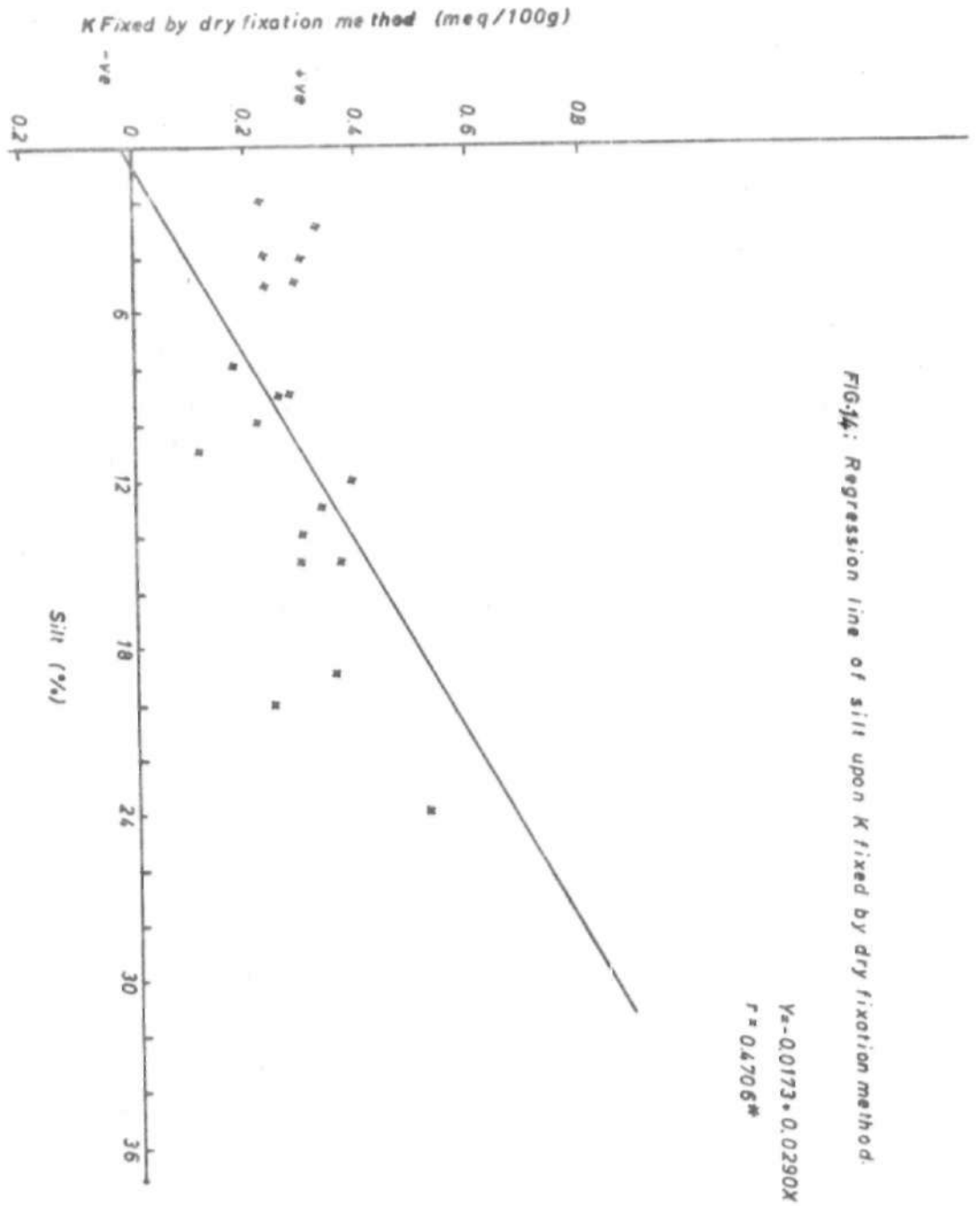



FIG.14: Regression line of silt upon K fixed by dry fixation method.

Y=-0.0173+0.0290X

r = 0.4706*

FIG. 15: Regression line of exchangable K upon K fixed by wet fixation

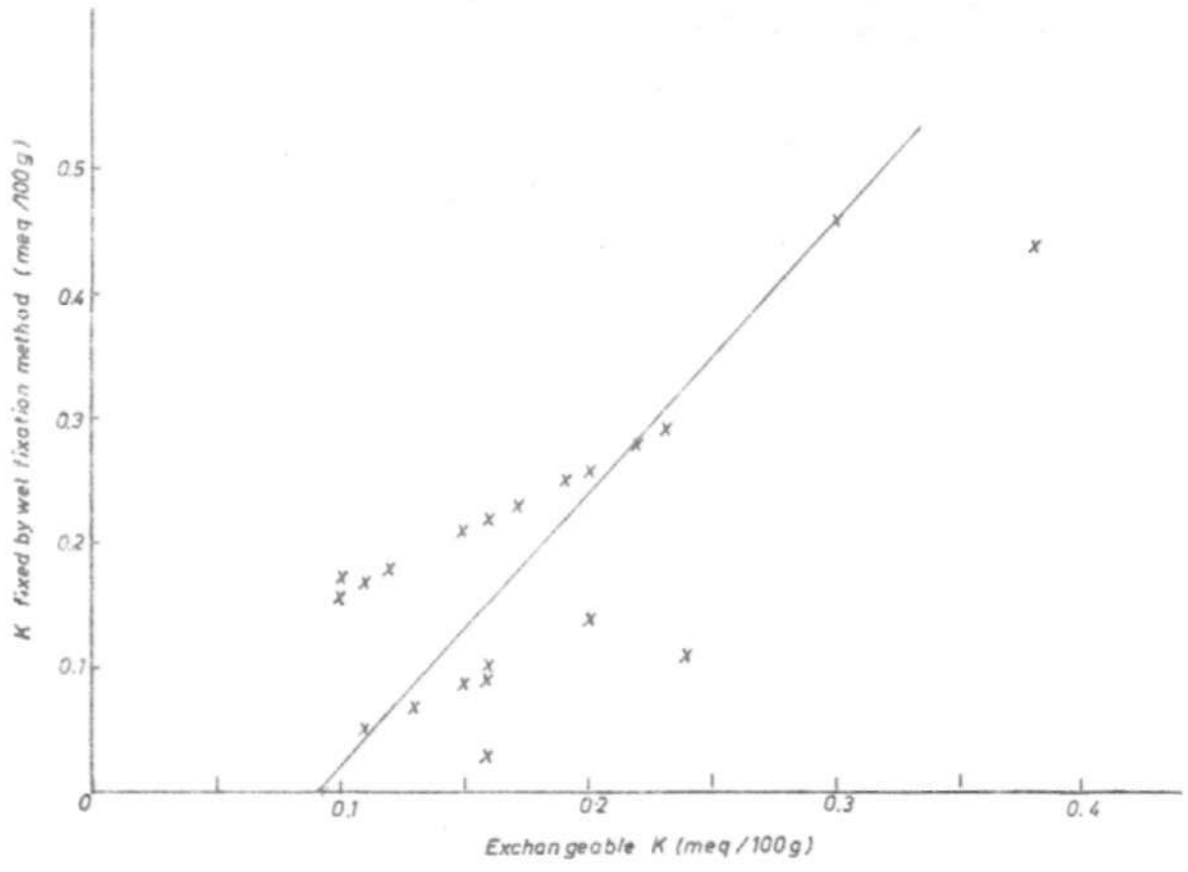
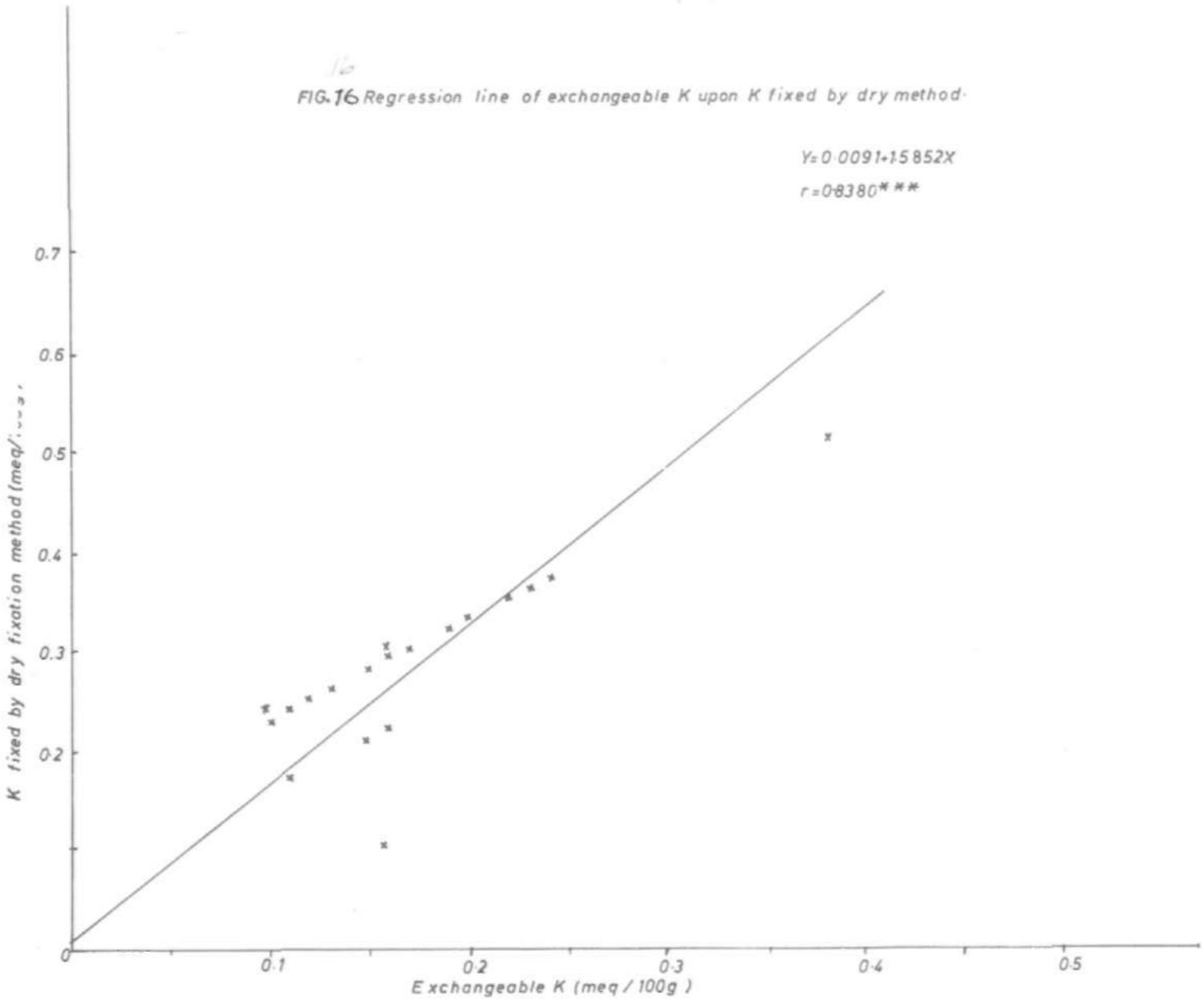


FIG. 16 Regression line of exchangeable K upon K fixed by dry method

$Y = 0.0091 + 1.5852X$

$r = 0.8380^{***}$



and 0.4706* for wet and dry fixation, respectively). The regression lines are shown in figures 13 and 14, respectively. Maclean and Brydon (1963) obtained similar relationship. It is likely that the silt fraction contains some minerals active in K fixation. The relationship between exchangeable K and K fixation was highly significant (r = 0.6854*** and 0.8380*** for wet and dry fixation, respectively). Figures 15 and 16 show the regression lines. This indicates that most of the K fixation was in the exchangeable form on the surface and edges of clay minerals in the soil.

The absence of significant correlation between K fixation and clay content is not unexpected. It merely confirms the dominance of kaolinite in most of the clay fractions. This clay mineral as earlier stated does not fix K appreciably. Udechukwu (1975) reported similar relationship between K fixation and clay content of acid sand soils of eastern Nigeria. Kee (1965), Kaila (1966) and Rajkovic (1966) reported high significant correlations with clay content. However, the soils they worked with contained a lot of illite, vermiculite and montmorillonite clay minerals which are known to be the seat of K fixation in soils. This comparison stresses the importance of type of clay in K fixation.

Methods of Determination of Available K.

The range and average values of available K determined by the various methods along with the standard deviations are presented

Table 8: Available K determined by the various methods.

| | Methods | Values (meq/100g) | | |
|---|---|---|---|---|
| | | Range | Mean | S.D. |
| I. | Extraction with neutral N $NH_4OAC$ by shaking for 2hr in 1:6 soil/ solution ratio | 0.10 - 0.38 | 0.17 | 0.06 |
| II. | Extraction with neutral N $NH_4OAC$ by leaching | 0.06 - 0.36 | 0.16 | 0.07 |
| III. | Extraction with neutral N $NH_4OAC$ by shaking for 30 min in 1:10 soil/ solution ratio | 0.09 - 0.35 | 0.16 | 0.06 |
| IV. | Extraction with 0.5 N HCl | 0.08 - 0.44 | 0.21 | 0.08 |
| V. | Extraction with 1.0 N HCl | 0.11 - 0.57 | 0.25 | 0.11 |
| VI. | Extraction with cold $H_2SO_4$ | 0.14 - 0.47 | 0.26 | 0.10 |

Table 9: Simple correlation coefficients and regression equations between the mean values of available K obtained by the various methods.

| Variables | | | Correlation Coefficients+ | Regression Equations |
|---|---|---|---|---|
| I | Vs | II | 0.9034 | Y= 0.0308 + 0.8688 X |
| I | Vs | III | 0.9257 | Y= 0.0075 + 1.0406 X |
| I | Vs | IV | 0.8876 | Y= 0.0127 + 0.7010 X |
| I | Vs | V | 0.7819 | Y= 0.0157 + 0.4574 X |
| I | Vs | VI | 0.7155 | Y= 0.0518 + 0.4703 X |
| II | Vs | IV | 0.9324 | Y= 0.0051 + 0.7657 X |
| II | Vs | V | 0.8595 | Y= 0.0317 + 0.5228 X |
| II | Vs | VI | 0.8077 | Y= 0.0214 + 0.5520 X |
| III | Vs | II | 0.9639 | Y= 0.0239 + 0.8246 X |
| III | Vs | IV | 0.9090 | Y= 0.0267 + 0.6386 X |
| III | Vs | V | 0.8244 | Y= 0.0507 + 0.4290 X |
| III | Vs | VI | 0.7750 | Y= 0.0422 + 0.4531 X |
| IV | Vs | V | 0.7970 | Y= 0.0579 + 0.5906 X |
| IV | Vs | VI | 0.7636 | Y= 0.0431 + 0.6355 X |
| V | Vs | VI | 0.8557 | Y= 0.0043 + 0.9614 X |

+ All correlation coefficients are significant at 0.1% level.

FIG17 :Regression line of K extracted with 0·5N HCl (IV)upon K extracted with ammonium acetate by shaking for 30mins (III)

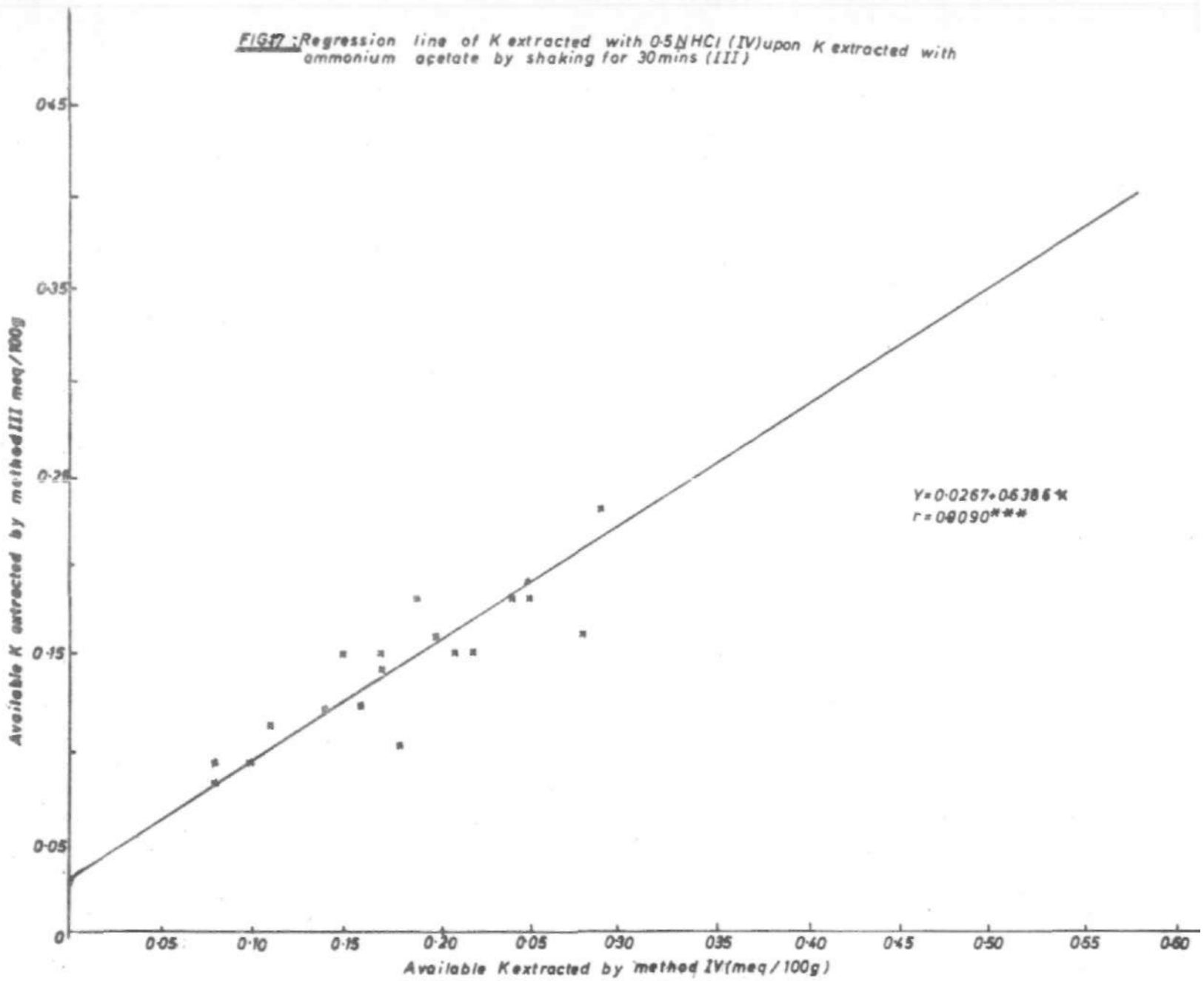


FIG 10 Regression line of K extracted with ammonium acetate by [illegible] upon K extracted with ammonium acetate by shaking for 30mins (III)

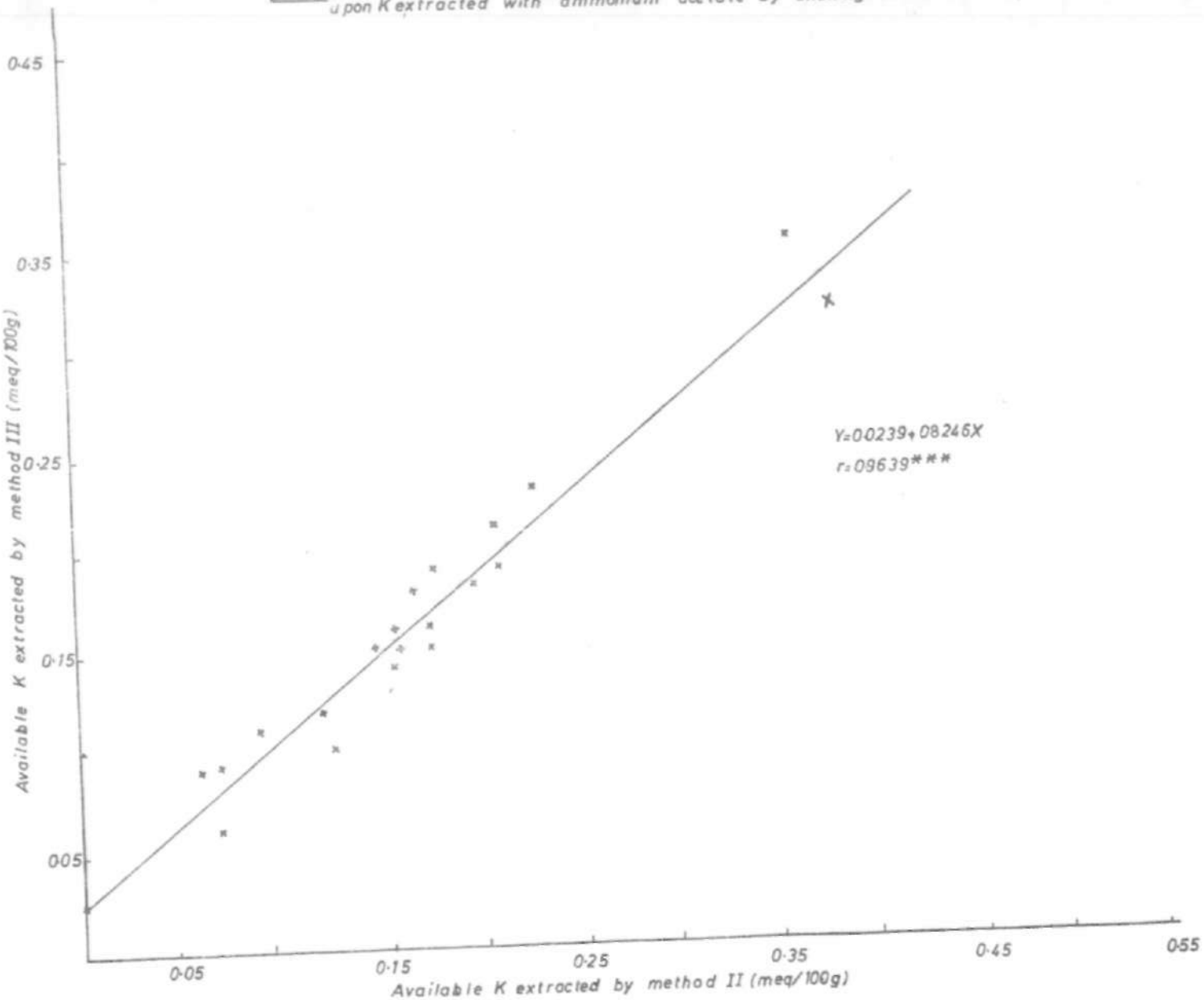


Fig. 19 : Regression line of K extracted with 0.5 N HCl (IV) upon K extracted with ammonium acetate by leaching (II)

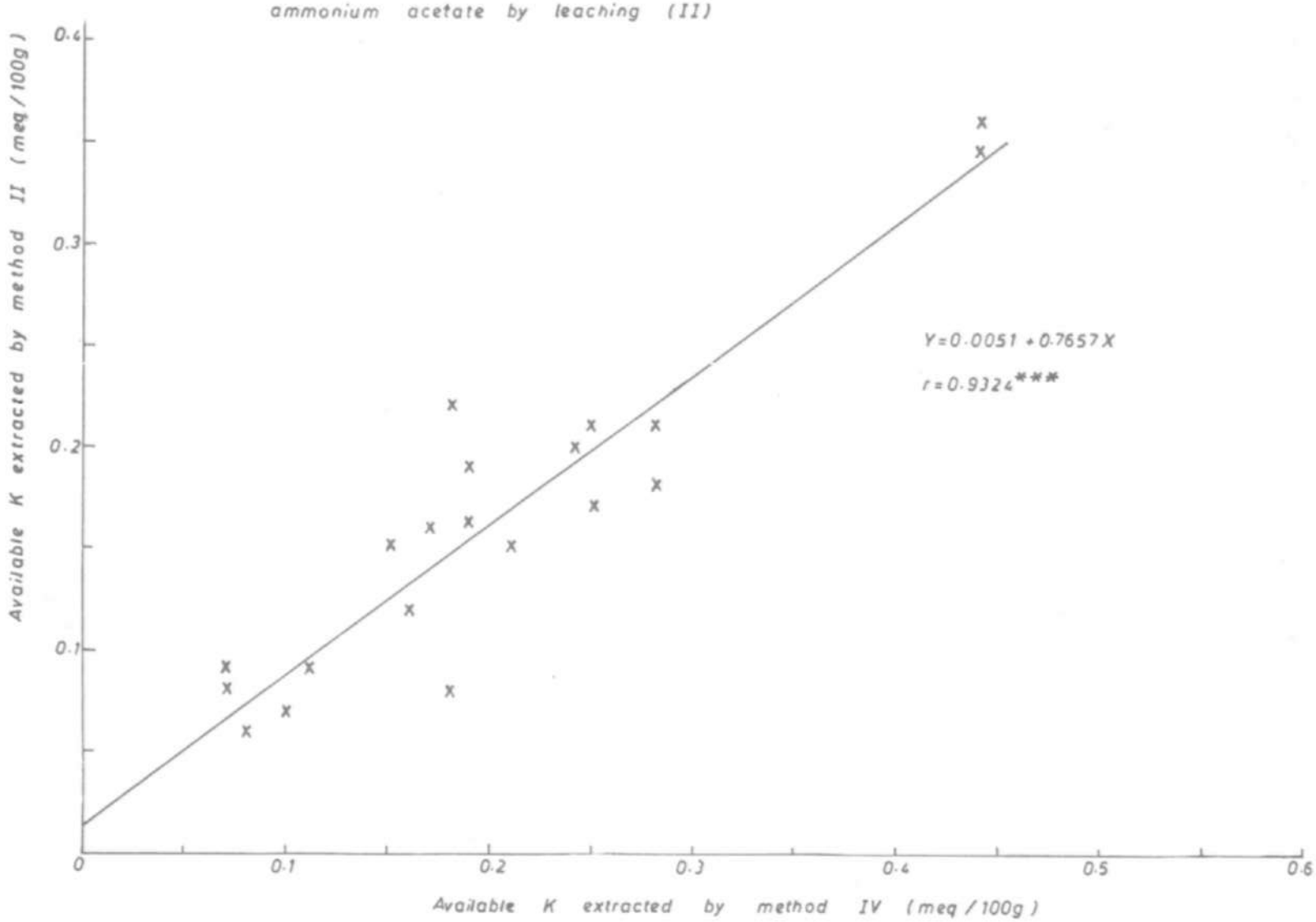


Fig 20: Regression line of K extracted with ammonium acetate by shaking for 30 mins (III) upon K extracted with ammonium acetate by shaking for 2 hours. (I)

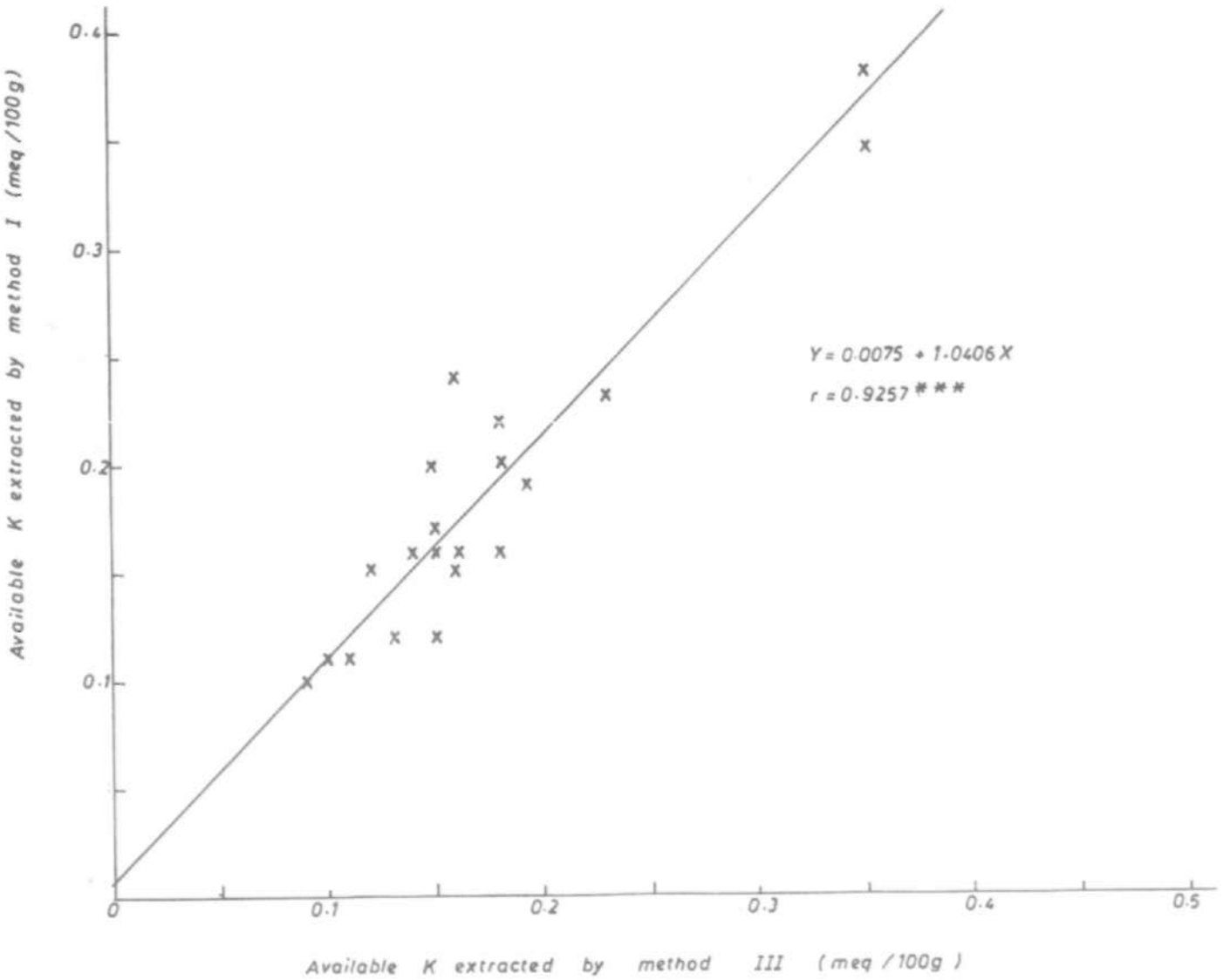
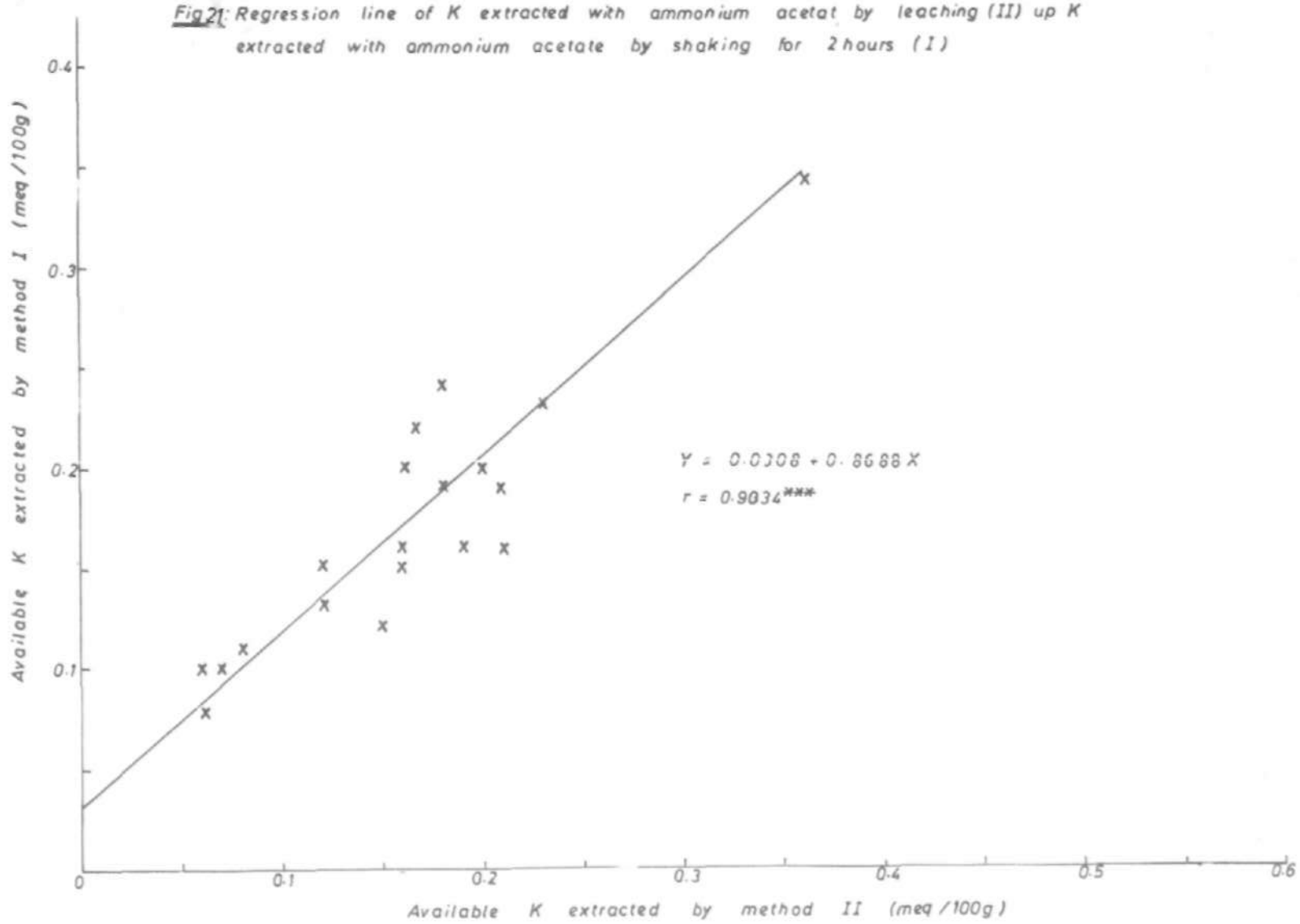


Fig 21: Regression line of K extracted with ammonium acetat by leaching (II) up K extracted with ammonium acetate by shaking for 2 hours (I)



in Table 8. The results indicate that the mineral acid extraction methods (IV, V and VI) gave higher values than the neutral N $NH_4OAC$ extraction methods (I, II and III). This is in line with results reported by Udechukwu (1975) and Ekpete (1972) for some eastern Nigerian soils. Sobulo (1969) indicated that it is likely that the acid extractants attack some primary minerals in the soil resulting in the release of some difficultly and non-exchangeable K. Rich and Black (1964) reported that solutions of acid and salts of acids mostly give higher values for the available K because the H-ions can displace the K ions in the surfaces between the primary layers more easily and quickly than $NH_4^+$ ions.

Simple correlation and regression analysis between the values obtained by the various methods were carried out to determine the relationship between them. The simple correlation coefficients presented in Table 9 show that all the values obtained by the methods correlated significantly at 0.1% level. The regression lines of those with r = 0.9034 and above are shown in figures 17-21. The K values of methods III and II have very high correlation, (r = 0.9639***). It may, therefore, be concluded that about the same proportionate amounts of available K have been extracted by these two methods.

For suitability of the methods for routine soil test, the methods whose correlation coefficients among themselves were up to 0.9034 and above were selected and correlation and regression analysis between them and K - uptake were carried out. The results along with other

Table 10: Characteristics of the methods of available K determination

| Method | Corr. Coeff. with K uptake | Coeff. of Variability (%) C.V. | Equilibration time (min) | Wt. of Soil (g) | Vol. of extractant (ml) | Cones. of reagents | No. of reagents | Reliance on electricity | Regression Equation with K-uptake |
|---|---|---|---|---|---|---|---|---|---|
| I. | 0.9259*** | 16.8 | 180 | 5 | 100 | 1N | 2 | all through the procedure | Y=562.57 + 53038.22x |
| II. | 0.9098*** | 18.5 | - | 5 | 100 | 1N | 2 | | Y=697.012+ 58588.68x |
| III. | 0.9175*** | 17.7 | 30 | 10 | 100 | 1N | 2 | For shorter Periods | Y=109.13 + 50755.96x |
| IV. | 0.9269*** | 16.7 | - | 10 | 100 | 0.5N | 1 | | Y=57.476 + 41934.19x |

Fig. 22: Regression line of K extracted with ammonium acetate by shaking for 2 hours (I) upon K—uptake

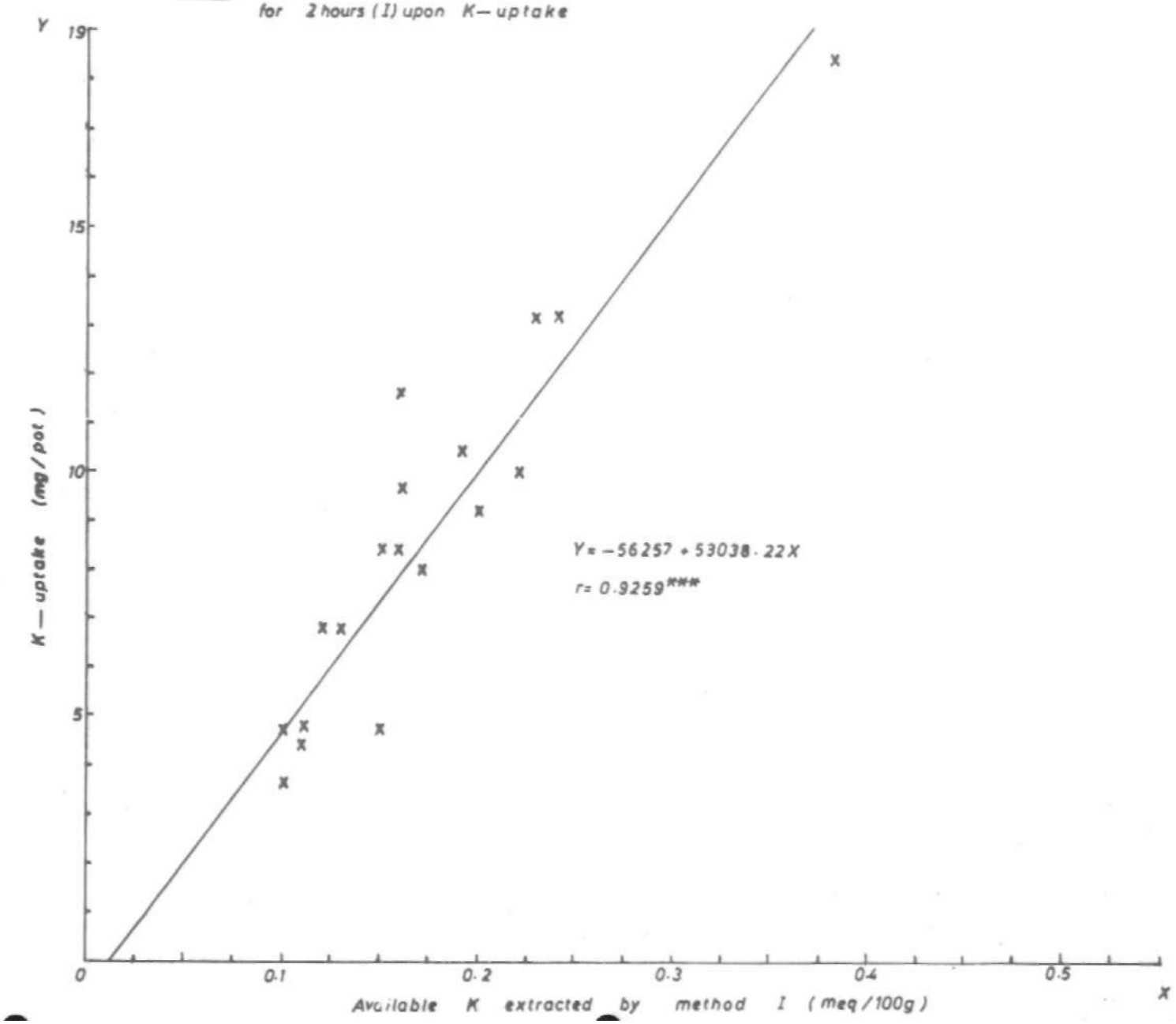


Fig 23: Regression line of K extracted with ammonium acetate by leaching (II) upon K-uptake

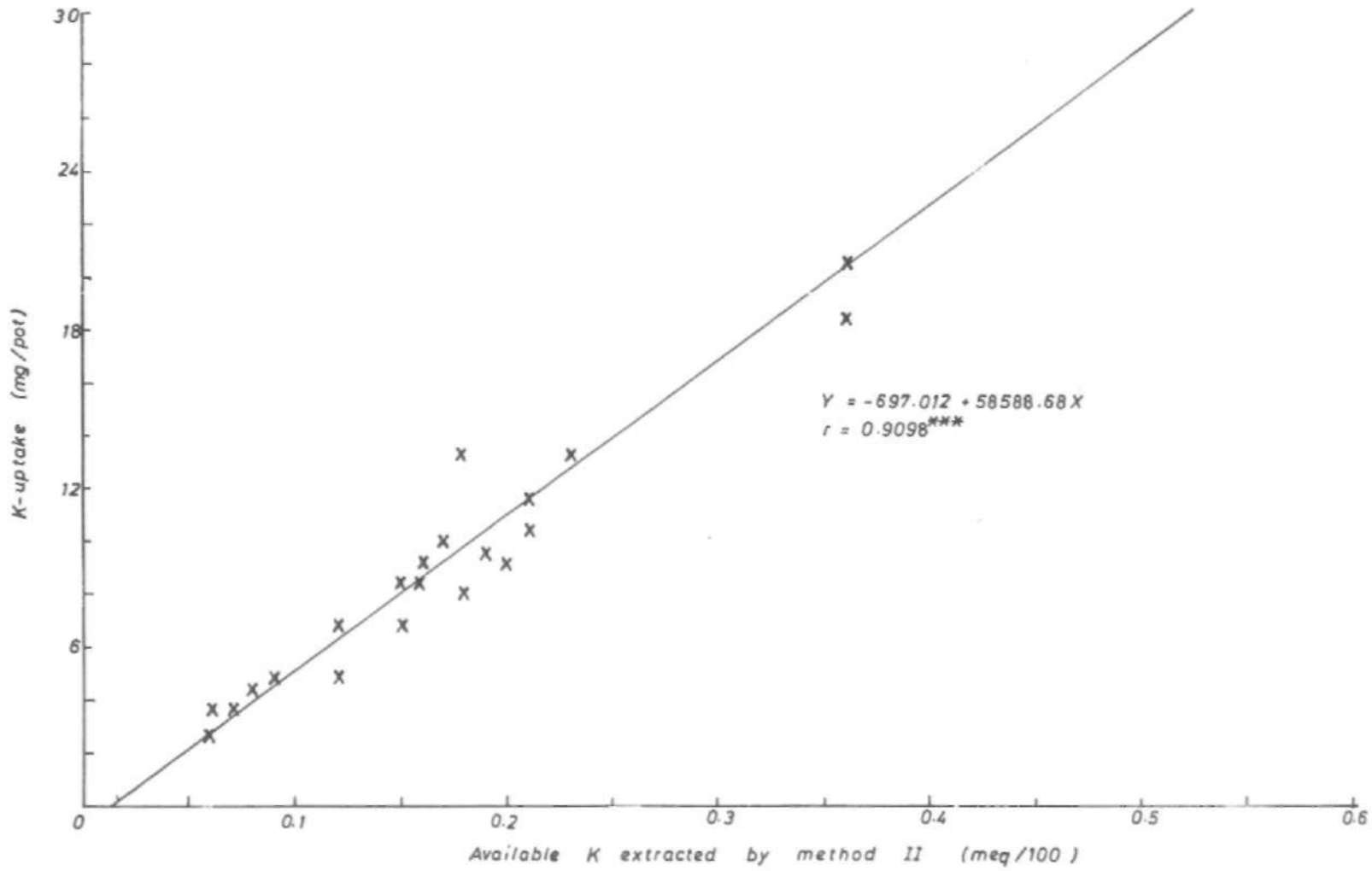


Fig 24 Regression line of K extracted with ammonium acetate by shaking for 30mins (III) upon K — uptake

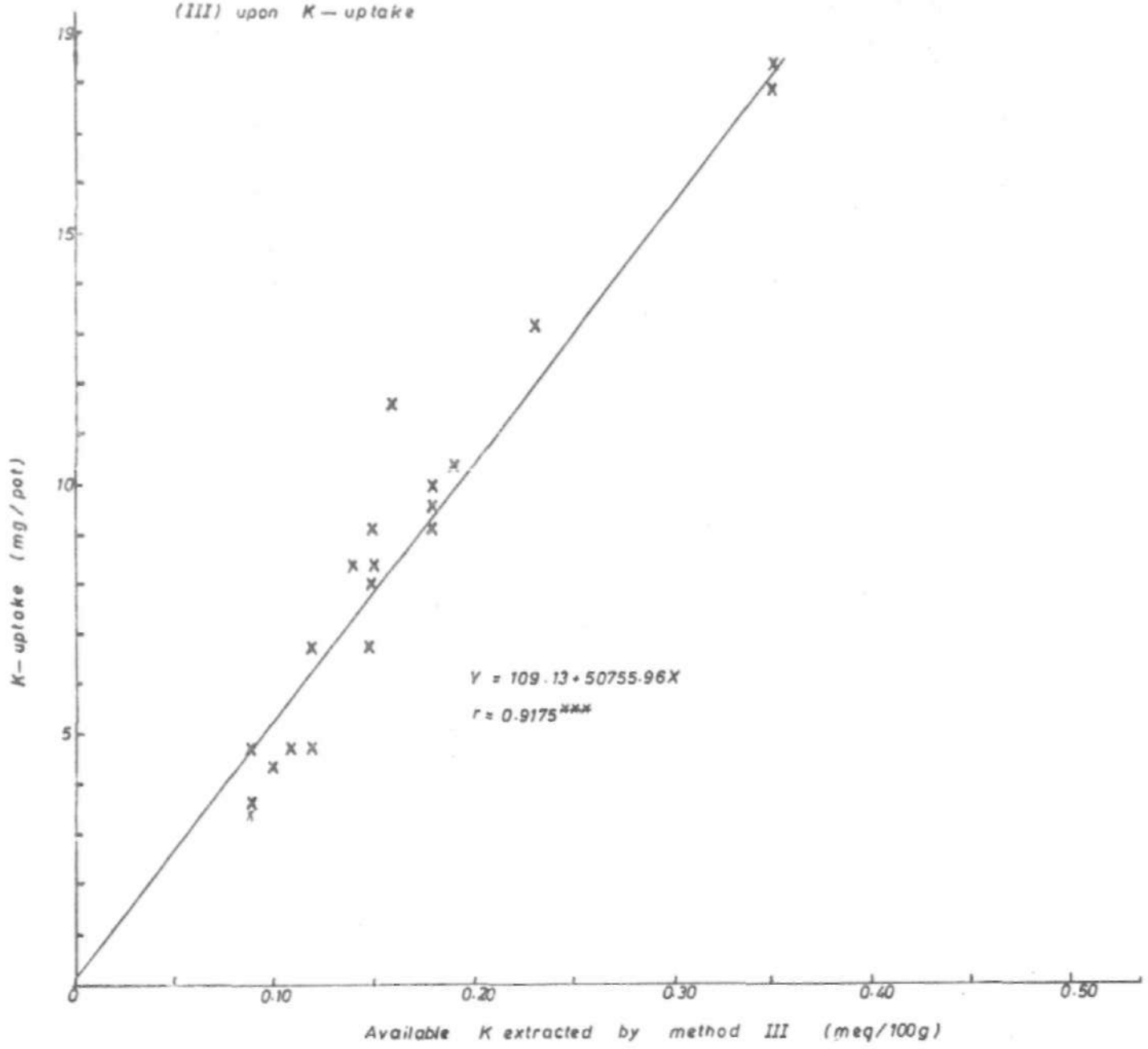
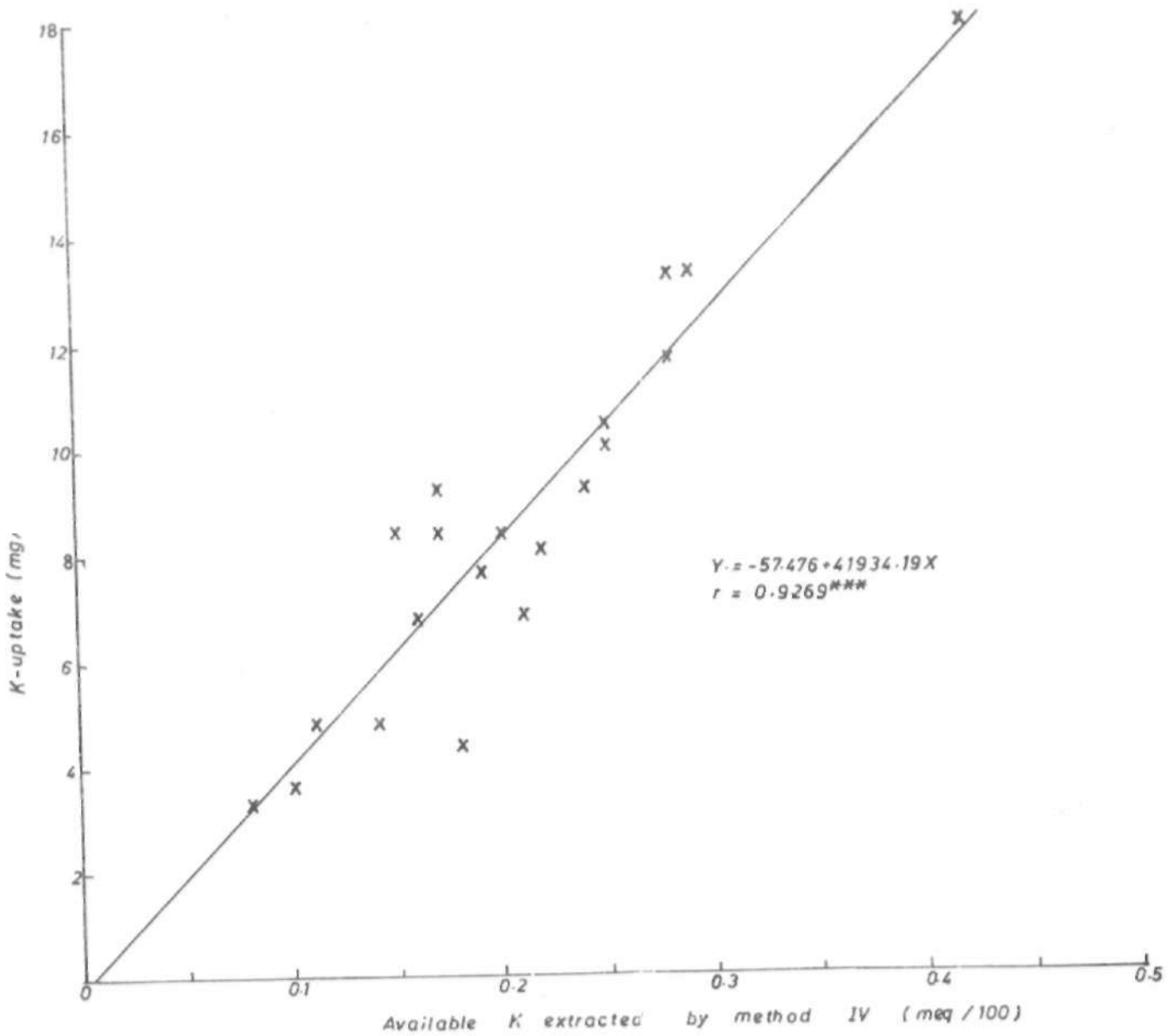


Fig. 25: Regression line of K extracted with 0.5 N HCl (IV) upon K-uptake



paramenters considered for assessing convenience of operation are presented in Table 10. Figures 22 - 25 show the regression lines between these methods and K - uptake. When convenience was assessed by considering the weight of soil, volume of extractants, number and concentration of reagents used, all the methods are acceptable since they had about the same score (Table 10). For speed, method I is rejected since it involves the longest equilibration time. It is also rejected because of its reliance on electricity all through the procedure. Electricity supply is considered important in this study since there are frequent failures in supply.

Method IV with the highest correlation coefficient and lowest coefficient of variability is considered an alternative method for available K determination. Methods II and III are found more suitable because of their minimal reliance on electricity and also less attention is required for extraction, especially method II. They also permit simultaneous determination of other cations and the CEC of the soil.

Under the conditions of this experiment, methods IV, II and III are selected and recommended as methods for routine determination of available K in Sudan savanna soils.

Successive extractions were carried out using method (II) to determine whether all the available K is removed by a single extraction which is normally employed in practice. The results

Table 11: Successive extraction of K with neutral N $NH_4OAC$ solution by the leaching method.

| Soil No. | No. of Extractions | | | | | | | | Total amount extracted from 2nd-8th | % exch. K. in single extraction to total exch. K in 8 extractions |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | | |
| 1. | 0.16 | 0.0013 | 0.0013 | 0.0013 | 0.0013 | - | - | - | 0.0052 | 96.85 |
| 2. | 0.35 | 0.0026 | 0.0013 | 0.0013 | 0.0013 | - | - | - | 0.0065 | 98.17 |
| 3. | 0.09 | 0.0026 | 0.0013 | - | - | - | - | - | 0.0039 | 95.84 |
| 4. | 0.12 | 0.0026 | 0.0013 | 0.0013 | - | - | - | - | 0.0052 | 95.84 |
| 5. | 0.15 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 97.46 |
| 6. | 0.16 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 97.62 |
| 7. | 0.10 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 96.24 |
| 8. | 0.16 | 0.0026 | 0.0013 | 0.0013 | - | - | - | - | 0.0052 | 96.85 |
| 9. | 0.15 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 97.46 |
| 10. | 0.11 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 96.57 |
| 11. | 0.18 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 97.87 |
| 12. | 0.12 | 0.0026 | 0.0013 | 0.0013 | - | - | - | - | 0.0052 | 95.84 |
| 13. | 0.09 | 0.0013 | 0.0013 | - | - | - | - | - | 0.0026 | 97.19 |
| 14. | 0.15 | 0.0013 | 0.0013 | - | - | - | - | - | 0.0026 | 98.29 |
| 15. | 0.14 | 0.0013 | 0.0013 | 0.0013 | - | - | - | - | 0.0039 | 97.28 |
| 16. | 0.15 | 0.0026 | 0.0013 | - | - | - | - | - | 0.0039 | 97.46 |
| 17. | 0.18 | 0.0026 | 0.0013 | 0.0013 | 0.0013 | - | - | - | 0.0065 | 96.51 |
| 18. | 0.23 | 0.0013 | 0.0013 | 0.0013 | 0.0013 | - | - | - | 0.0052 | 97.78 |
| 19. | 0.18 | 0.0013 | 0.0013 | 0.0013 | 0.0013 | - | - | - | 0.0052 | 97.19 |
| 20. | 0.19 | 0.00013 | 0.0013 | - | - | - | - | - | 0.0026 | 98.65 |

presented in Table 11 indicate that after the first extraction, subsequent extractions (2-8) gave extremely small values which were constant for most soils. Except for a few soils-Shinkafe, Maiduguri, Kauranamoda, and Bama nothing was recovered after the 4th extraction. These soils in fact have the highest exchangeable K values (Table 2). Udechukwu (1975) reported similar results for some acid sand soils of eastern Nigeria. The very small amounts recovered in the subsequent extractions could be due to incomplete removal of the extracted K which was eventually removed when more of the extracting solution was used. Since the amount of K left after the first extraction is negligible the available K determined by single extraction practically represents the total exchangeable K. This is confirmed by the fact that 95.05 to 98.65% of the total exchangeable K is removed in single extraction.

Effect of Lime on the Availability of Native Soil K.

The effect of lime on the availability of native soil K was studied by considering K release and uptake in limed soils. The average values presented in Table 12 indicate that liming these soils neither increased K release nor uptake since about the same values were obtained for zero and other lime rates. This is more so for K release than for K uptake. The analysis of variance tables for K release and uptake presented in appendix Table 6 indicate that differences between rates and the interaction between rates and soils were non-significant while the difference between soils were highly

significant. This high significance between soils indicate the differences in initial exchangeable K content of the soils.

Many conflicting results abound in literature as to the effect of lime on K availability. The results of this study is in line with observations by Mehlich and Reed (1954) and Dean (1936) cited by York and Rogers (1946) while it disagrees with some results reported by York and Rogers (1946), Powell and Hutcheson (1965) and Khomvilai and Blue (1978).

Mehlich and Reed (1954) reported that K retention increased with increase in the degree of calcium saturation by liming. They advanced that K can replace calcium from the exchange complex much more readily that it can replace H and Al.

The results obtained in this study could be due to the low initial exchangeable K and total K contents of the soils. Powell and Hutcheson (1965) reported similar results with some Kentucky soils with low initial exchangeable K. The reverse was the case with the soils high in exchangeable K. They indicated that limed soils with initial low exchangeable K levels released K to cropping stress in much the same magnitude as the same not limed. York and Rogers (1946) attributed the relatively small K release got for some Alabama soils to their low total K content.

Recovery of Exchangeable K on Wetting and Drying of Cropped Soils.

The results presented in Table 13 indicate that all soils showed a recovery of different levels of exchangeable K. There was practically no change in the samples held at field capacity for 60 days. Average

Table 13: Recovery of exchangeable K on wetting and drying cropped soils

| Soil No. | Exch. K before cropping | Exch. K after cropping i.e. 0 Cycle | 1st Cycle | 5th Cycle | 20th Cycle | F/capacity |
|---|---|---|---|---|---|---|
| 11 | 0.160 | 0.110 | 0.100 | 0.130 | 0.155 | 0.110 |
| 12 | 0.130 | 0.070 | 0.065 | 0.106 | 0.120 | 0.071 |
| 13 | 0.100 | 0.060 | 0.040 | 0.060 | 0.093 | 0.060 |
| Mean | 0.130 | 0.080 | 0.068 | 0.098 | 0.124 | 0.080 |

values of 0.080, 0.068, 0.098, 0.124, and 0.080 meq/100 g were got after 0, 1, 5, 20 cycles and at field capacity, respectively. Similar results were reported by Wild (1971) and Udechukwu (1975) for savanna soils and acid sand soils of eastern Nigeria, respectively. The result of the experiment presented in appendix Table 3 further confirm the lack of K release by the addition of lime. The same results were obtained for all lime rates.

# SUMMARY AND CONCLUSIONS

The K status of Sudan savanna soils was evaluated by fractionation and fixation studies using soil samples from 20 random locations. The relationship between the different fractions; Total K; K fixed by the wet and dry methods and some soil properties were determined by correlations and regression analysis. Available K was determined by six different methods and attempts were made to determine which of the methods are best suited for routine soil test. Three of the soils - Kadawa, Kano and Dambatta were used to study the effect of lime on the availability of native soil K in the green house. After cropping, the soils were subjected to wetting and drying cycles to determine the extent of recovery of exchangeable K.

The results of this study lead to the following conclusions:-

The exchangeable K content of the sudan savanna soils tend to be low while the difficultly exchangeable K, non-exchangeable K and total K are fairly high in some soils and low in others. This explains the differential response of crops to applied K in these soils. The total K content varies widely according to parent material, with lowest values associated with aeolian sand parent material and highest values with basement complex. The difficultly exchangeable K and non-exchangeable K fractions are much greater than the exchangeable K fraction. All fractions correlated significantly with pH while the exchangeable K increased with silt content and difficultly

exchangeable K and non-exchangeable K increased with CEC. Potassium in these soils is mainly associated with silt separate.

In general, K fixation increased with increase in K concentration, greater amount being fixed by the dry than by the wet methods. These soils have very low K fixing capacity. In essence, therefore, they face problems of K leaching rather than K fixation. Potassium fixed by both wet and dry methods correlated significantly with silt and exchangeable K contents. This indicates that the fixed K exists as exchangeable K in these soils.

The available K determined by the dilute mineral acid extraction methods were higher than the values obtained by the neutral N $NH_4OAC$ extraction methods. The available K obtained by all methods correlated highly significantly among themselves and with K-uptake. The available K determined by single extraction with neutral N $NH_4OAC$ by leaching practically represents the total exchangeable K. Extraction with 0.5 N HCl (IV), neutral N $NH_4OAC$ by leaching (II) and by shaking for 30 min (III) have been recommended for routine soil test for available K.

Liming these soils neither enhanced K release nor uptake. The cropped soils showed a recovery of some levels of exchangeable K on wetting and drying but not under moist storage.

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Appendix Table 1: Available K determined by various methods (meq/100g)

| Soil No. | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| 1 | 0.24 | 0.18 | 0.16 | 0.28 | 0.29 | 0.32 |
| 2 | 0.38 | 0.36 | 0.35 | 0.44 | 0.57 | 0.47 |
| 3 | 0.10 | 0.07 | 0.09 | 0.10 | 0.11 | 0.14 |
| 4 | 0.15 | 0.12 | 0.12 | 0.14 | 0.21 | 0.19 |
| 5 | 0.16 | 0.15 | 0.15 | 0.15 | 0.23 | 0.20 |
| 6 | 0.16 | 0.21 | 0.16 | 0.28 | 0.32 | 0.29 |
| 7 | 0.11 | 0.08 | 0.10 | 0.18 | 0.15 | 0.16 |
| 8 | 0.15 | 0.16 | 0.16 | 0.20 | 0.24 | 0.42 |
| 9 | 0.12 | 0.15 | 0.15 | 0.15 | 0.20 | 0.19 |
| 10 | 0.11 | 0.09 | 0.11 | 0.11 | 0.21 | 0.16 |
| 11 | 0.16 | 0.19 | 0.18 | 0.19 | 0.25 | 0.28 |
| 12 | 0.13 | 0.12 | 0.12 | 0.16 | 0.18 | 0.17 |
| 13 | 0.10 | 0.16 | 0.09 | 0.08 | 0.09 | 0.14 |
| 14 | 0.20 | 0.16 | 0.15 | 0.17 | 0.20 | 0.21 |
| 15 | 0.16 | 0.16 | 0.14 | 0.17 | 0.36 | 0.29 |
| 16 | 0.17 | 0.18 | 0.15 | 0.22 | 0.21 | 0.21 |
| 17 | 0.20 | 0.20 | 0.18 | 0.24 | 0.22 | 0.29 |
| 18 | 0.23 | 0.23 | 0.23 | 0.29 | 0.26 | 0.28 |
| 19 | 0.22 | 0.17 | 0.18 | 0.25 | 0.25 | 0.26 |
| 20 | 0.19 | 0.21 | 0.19 | 0.25 | 0.45 | 0.44 |
| Mean | 0.17 | 0.16 | 0.16 | 0.21 | 0.25 | 0.26 |

Appendix Table 2: K fixation and percent K-fixed on addition of 1.25 meq K/100 g soil

| Soil No. | Wet Fixation | | Dry Fixation | |
|---|---|---|---|---|
| | K-fixed (meq/100g) | % K fixed | K-fixed (meq K/100g) | % K fixed |
| 1 | -0.11 | -8.8 | -0.08 | -6.4 |
| 2 | 0.03 | 2.4 | 0.22 | 17.6 |
| 3 | -0.38 | -30.4 | -0.06 | -4.8 |
| 4 | -0.20 | -16.0 | -0.01 | -0.8 |
| 5 | -0.19 | -15.2 | -0.06 | -4.8 |
| 6 | -0.19 | -15.2 | -0.06 | -4.8 |
| 7 | -0.37 | -29.6 | -0.05 | -4.0 |
| 8 | -0.33 | -26.4 | -0.01 | -0.8 |
| 9 | -0.23 | -18.4 | -0.04 | -3.2 |
| 10 | -0.24 | -19.2 | -0.05 | -4.0 |
| 11 | -0.32 | -25.6 | 0.00 | 0.0 |
| 12 | -0.22 | -17.6 | -0.03 | -2.4 |
| 13 | -0.38 | -30.4 | -0.06 | -4.8 |
| 14 | -0.15 | -12.0 | -0.02 | -1.6 |
| 15 | -0.19 | -15.2 | 0.00 | 0.0 |
| 16 | -0.31 | -24.8 | -0.05 | -4.0 |
| 17 | -0.15 | -12.0 | -0.02 | -1.6 |
| 18 | -0.25 | -20.0 | 0.01 | 0.8 |
| 19 | -0.13 | -10.4 | 0.00 | 0.0 |
| 20 | -0.16 | -12.8 | -0.03 | -2.4 |
| Mean | -0.22 | -17.88 | -0.02 | -1.60 |

Appendix Table 3: K fixation and percent K-fixed on addition of 2.50 meq K/100g soil

| Soil No. | Wet Fixation | | Dry Fixation | |
|---|---|---|---|---|
| | K-fixed (meq/100g) | % K fixed | K-fixed (meq K/100g) | % K fixed |
| 1 | 0.05 | 2.0 | 0.18 | 7.2 |
| 2 | 0.19 | 7.6 | 0.32 | 12.8 |
| 3 | -0.10 | -4.0 | 0.04 | 1.6 |
| 4 | -0.23 | -9.2 | 0.04 | 1.6 |
| 5 | -0.03 | -1.2 | 0.10 | 4.0 |
| 6 | -0.03 | -1.2 | 0.10 | 4.0 |
| 7 | -0.08 | -3.2 | 0.05 | 2.0 |
| 8 | -0.04 | -1.6 | 0.09 | 3.6 |
| 9 | -0.14 | -5.6 | 0.06 | 2.4 |
| 10 | -0.27 | -10.8 | 0.05 | 2.0 |
| 11 | -0.03 | -1.2 | 0.10 | 4.0 |
| 12 | -0.06 | -2.4 | 0.07 | 2.8 |
| 13 | -0.16 | -6.4 | 0.04 | 1.6 |
| 14 | 0.01 | 0.4 | 0.14 | 5.6 |
| 15 | -0.10 | -4.0 | 0.10 | 4.0 |
| 16 | -0.02 | -0.8 | 0.11 | 4.4 |
| 17 | -0.06 | -2.4 | 0.14 | 5.6 |
| 18 | 0.04 | 1.6 | 0.17 | 6.8 |
| 19 | 0.03 | 1.2 | 0.16 | 6.4 |
| 20 | 0.00 | 0.0 | 0.13 | 5.2 |
| Mean | -0.05 | -2.06 | 0.11 | 4.38 |

Appendix Table 4: K fixation and percent K-fixed on addition of 5.0 meq K/100 g soil

| Soil No. | Wet Fixation | | Dry Fixation | |
|---|---|---|---|---|
| | K-fixed (meq/100g) | % K fixed | K-fixed (meq K/100g) | % K fixed |
| 1 | 0.11 | 2.2 | 0.37 | 7.4 |
| 2 | 0.44 | 8.8 | 0.51 | 10.2 |
| 3 | 0.16 | 3.2 | 0.23 | 4.6 |
| 4 | 0.09 | 1.8 | 0.21 | 4.2 |
| 5 | 0.09 | 1.8 | 0.22 | 4.4 |
| 6 | 0.22 | 4.4 | 0.29 | 5.8 |
| 7 | 0.17 | 3.4 | 0.24 | 4.8 |
| 8 | 0.21 | 4.2 | 0.28 | 5.6 |
| 9 | 0.18 | 3.6 | 0.25 | 5.0 |
| 10 | 0.05 | 1.0 | 0.17 | 3.4 |
| 11 | 0.03 | 0.6 | 0.10 | 2.0 |
| 12 | 0.07 | 1.4 | 0.26 | 5.2 |
| 13 | 0.16 | 3.2 | 0.23 | 4.6 |
| 14 | 0.26 | 5.2 | 0.33 | 6.6 |
| 15 | 0.10 | 2.0 | 0.29 | 5.8 |
| 16 | 0.23 | 4.6 | 0.30 | 6.0 |
| 17 | 0.14 | 2.8 | 0.33 | 6.6 |
| 18 | 0.29 | 5.8 | 0.36 | 7.2 |
| 19 | 0.28 | 5.6 | 0.35 | 7.0 |
| 20 | 0.25 | 5.0 | 0.32 | 6.4 |
| Mean | 0.18 | 3.53 | 0.28 | 5.64 |

Appendix Table 5: Recovery of exchangeable K on wetting and drying cropped soils

| Lime Rates (t/ha) | Soils No. | K recovered (meq/100g) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Before Cropping | After Cropping | 1 | 5 | 20 | F/ Capacity |
| 0 | 11 | 0.16 | 0.11 | 0.10 | 0.14 | 0.17 | 0.10 |
| | 12 | 0.13 | 0.07 | 0.07 | 0.11 | 0.13 | 0.07 |
| | 13 | 0.10 | 0.06 | 0.04 | 0.07 | 0.09 | 0.06 |
| 1 | 11 | 0.16 | 0.10 | 0.10 | 0.13 | 0.17 | 0.11 |
| | 12 | 0.13 | 0.07 | 0.06 | 0.10 | 0.13 | 0.08 |
| | 13 | 0.10 | 0.05 | 0.04 | 0.06 | 0.10 | 0.06 |
| 2 | 11 | 0.16 | 0.11 | 0.10 | 0.13 | 0.14 | 0.11 |
| | 12 | 0.13 | 0.07 | 0.06 | 0.11 | 0.13 | 0.07 |
| | 13 | 0.10 | 0.06 | 0.44 | 0.06 | 0.08 | 0.06 |
| 3 | 11 | 0.16 | 0.12 | 0.10 | 0.13 | 0.18 | 0.11 |
| | 12 | 0.13 | 0.07 | 0.07 | 0.10 | 0.11 | 0.07 |
| | 13 | 0.10 | 0.08 | 0.04 | 0.05 | 0.10 | 0.07 |
| 4 | 11 | 0.16 | 0.11 | 0.10 | 0.13 | 0.14 | 0.11 |
| | 12 | 0.13 | 0.07 | 0.06 | 0.11 | 0.11 | 0.07 |
| | 13 | 0.10 | 0.06 | 0.04 | 0.06 | 0.10 | 0.06 |
| 5 | 11 | 0.16 | 0.11 | 0.10 | 0.13 | 0.15 | 0.12 |
| | 12 | 0.13 | 0.07 | 0.07 | 0.11 | 0.10 | 0.07 |
| | 13 | 0.10 | 0.06 | 0.04 | 0.07 | 0.09 | 0.05 |

Appendix Table 6: Analysis of variance table for K release

| Source of Variation | Degrees of Freedom | Sum of Squares | Means Square | F. Value |
|---|---|---|---|---|
| Blocks | 3 | 0.00033 | 0.00011 | 1.57 |
| Rates | 5 | 0.00029 | 0.00006 | $1.81^{ns}$ |
| Soils | 2 | 0.00228 | 0.00114 | $16.159^{**}$ |
| R X S | 10 | 0.00049 | 0.00005 | 0.69 |
| Error | 51 | 0.00353 | 0.00007 | |
| Total | 71 | 0.00693 | | |

Analysis of variance table for K - uptake

| Source of Variation | Degree of Freedom | Sum of Squares | Means Square | F. Value |
|---|---|---|---|---|
| Blocks | 3 | 60.15111 | 202.38370 | 3.90 |
| Rates | 5 | 652.58926 | 130.51785 | 2.51 |
| Soils | 2 | 9695.1028 | 4847.5514 | $93.302^{**}$ |
| R X S | 10 | 1573.8017 | 157.38017 | 33.03 |
| Error | 51 | 2597.7722 | 50.93671 | |
| Total | 71 | 15126.417 | | |

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to my major advisors, Dr. V. Balasubramanian and Dr. A. U. Mokwunye for their constant guidance and help throughout the graduate studies.

My very special thanks go to Mr. S. M. Abed of the data processing unit, Institute for Agricultural Research, Zaria and his colleagues for carrying out all the statistical analysis reported in this thesis.

I like to thank my colleagues in the Soil Science Department and Institute for Agricultural Research, especially Mr. Idika Mba, Mallam Lamidi Lawal, Mrs. Christiana Achugbue and Victor Odigie for their technical support and also to Mr. Emmanuel Oyegoke who typed the thesis.

Margaret Ikpo, Ifenyinwa Iwuafor and my younger brothers Ono, Chukwudi and Chide deserve special thanks for the patience and understanding they showed throughout the period of the graduate studies.

Finally, I am deeply grateful to Institute for Agricultural Research Ahmadu Bello University, Zaria who provided the research fund for these studies.