THE ROLE OF CONCRETIONS IN PHOSPHORUS AVAILABILITY IN A TYPICAL CONCRETIONARY SOIL OF NORTHERN GHANA

A Thesis

Submitted to the Faculty of Agriculture in partial fulfillment of the
requirements for the award of the Degree

Master of Philosophy

in the

Department of Soil Science
University of Ghana
by

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October, 1989

DECLARATION

I hereby declare that this thesis has been written by me and that it is the record of my own research work. It has neither in whole nor in part been presented for another degree elsewhere. Work of other researchers have been duly cited by references to the authors and all assistance received also acknowledged.

Candidate's Name

The above declaration is affirmed.

Senior Supervisor

CERTIFICATION

This thesis entitled: **The Role of Concretions in Phosphorus Availability in a Typical Concretionary Soil of Northern Ghana** by Mark Kofi Abekoe meets the regulations governing the award of the degree of Master of Philosophy (Soil Science) of the University of Ghana and is approved for its contribution to knowledge and literary presentation.

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ACKNOWLEDGEMENT

I wish to express my sincere appreciation and thanks to Professor D.K. Acquaye and Dr. E. Owusu-Bennoah for their persistent efforts in guiding, supervising and encouraging me throughout the course of this study. My thanks also go to Dr. S. Duah-Yentumi for the prompt actions he often took in his capacity as the acting Head of Soil Science Department, on matters relating to the work reported here.

I am equally thankful to Mr. Amartey and the rest of the technical staff of the Department for their cooperation during the course of the study.

I am highly indebted to Dr. Holm Tiessen of University of Saskatchewan, Canada for coming up with the research proposal on which I worked and his personal involvement in correcting the thesis. I am grateful for the constructive criticisms he made during the correction of the script. I cannot forget the competent technical assistance and suggestions given to me by Jackie O. Moir and Betty P.Chow during part of my analytical work in the preparation of this thesis. I thank them. I also thank Ben Ellert for sparing the time he hardly had to help me in the use of the computer. To all other members of staff of Saskatchewan Institute of Pedology, I am grateful for their cooperation during my six months' training course in Canada.

My sincere thanks go to International Development Research Centre (IDRC) for funding the research programme both at the University of Ghana and Saskatchewan Institute of Pedology, Canada. I am very grateful to the Centre for granting me a three-month extension to complete work on this thesis.

Finally I wish to thank my friends particularly, Gabriel Nii-Noi Dowuona who for his brotherly advice and directions made my stay in Canada very pleasant.

ABSTRACT

Phosphorus deficiency is widespread in most soils of northern Ghana. Presence of lateritic concretions in some of the soils constitute an additional limitation to crop production in the region because the concretions act as an effective sink for added P.

To assess the role of the concretions on phosphorus availability in a typical concretionary soil of northern Ghana, a soil originally containing 70% concretions was fractionated into soil fines and concretions and the soil reconstituted to represent varying amounts of the concretions. Phosphate sorption and desorption studies were carried out on samples containing 0%, 35%, 70%, 100% and a 2-mm sieved original soil.

Phosphate sorption maximum varied among the test soils. The sample containing 0% concretion sorbed the least amount of P (110 µg/g) while increasing concretion content increased sorption with the highest sorption found with the 100% concretions (194 µg/g).

Successive desorption of adsorbed phosphate using 0.01M KCl indicated a lower percent P released by the sample containing 100% concretions (37% P released) than the soil fines, (67% P released) which desorbed the highest amount of P. However, the cumulative P desorbed after 8 successive extractions in both 0% and 100% concretions were similar, 117 µg/g and 103 µg/g respectively. This result suggests that both concretions and soil fines have an equivalent amount of labile P pool though the rate of P release is lower in the concretions than in the soil fines.

The reversibility of P sorption in the concretions was also investigated in a greenhouse experiment. The test soils, (0%, 35%, 70% concretions and the original soil) were fertilized at two levels of P and were cropped with millet (*Pennisetum typhoides*). At the first cropping, both dry matter yield and total P uptake were highest in the sample containing 0% concretion at all levels of P applied. Total P uptake in the soil fines was 56.2 to 67.1 mg/pot, and that of the 70% concretions, 38.2 to 43.0 mg/pot. Subsequent croppings showed higher dry matter yield and P uptake in the concretionary soils but a sharp drop in the soil fines. This result is an indication of higher P release in the concretionary soils and an earlier exhaustion of P in the soil fines. At the end of the sixth cropping, the total quantities of P removed by the crop in the soil fines were 69.9 to 86.1 mg/pot, and in the test soil sample containing 70% concretions, 64.8 to 78.0 mg/pot. These results showed that differences in P released between soil fines and concretions had narrowed with successive croppings. In general the original soil behaved similarly to the 70% concretionary soil sample.

Phosphate desorbed by the 0.01M KCl extraction was found to be higher than plant P uptake but both followed the same trend. The results of both desorption studies and pot experiment suggest that the concretions do release part of the phosphorus sorbed but the major difference between the concretions and soil fines is the rate of P release.

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CHAPTER ONE

INTRODUCTION

Widespread phosphorus (P) deficiency in most soils in northern Ghana and generally low available P levels (Halm 1968; Kanabo et al. 1978; Nyamekye 1987) have led many workers to suggest that the soils require application of phosphorus fertilizers to obtain higher yields. The low phosphorus level in these highly weathered soils has been attributed to the nature of the parent material, which is mainly sandstone or shale (Adu 1957) and/or sesquioxides in the soils.

Among the dominant groups of soils in the northern region of Ghana are the concretionary soils with the concretions containing large quantities of iron oxides. Such soils are typical of the "middle belt" of West Africa (Adu 1957) and other parts of the world (Phillipe et al. 1972; Gallaher et al. 1973). Some horizons of soils investigated by Phillipe et al. (1972) contain more than 40% by weight of ironstone concretions. The "middle belt" represents an ecological zone of semi-arid savanna with a pronounced dry season (4 to 5 months), low productivity and widespread ferruginous crust soils.

The climate of the northern region of Ghana is typically hot and dry most of the year. Daily temperatures ranged between 28 ^{o}C to 33 ^{o}C. Although the region has a moderate annual rainfall of 965 to 1270 mm (Obeng 1975), it is concentrated only within a few months (June to October) and the rest of the year is dry. The dry season is severe due to the harmattan air mass, which is a dust-laden, dry hot wind that blows in a north-easterly direction across the region from the Sahara desert.

In the northern region of Ghana, agriculture is rainfed and therefore farming activities are mostly concentrated within the wet season restricting cropping to only one season per year. The zone is characterised by low productivity; largely due to the climatic and soil fertility constraints. Farmers of the region have been cultivating these soils without the use of fertilizers but instead maintain soil fertility by prolonged fallow periods. Some of the crops grown are sorghum, millet, cowpea, groundnuts, yams and tobacco often with low yields.

With the increasing population pressure and demands for food production the fallow periods are becoming shorter. In addition, permanent land cultivation is being introduced increasingly to replace the traditional bush fallow system (Schmidt and Frey 1988a). The situation has led to a serious decline in soil productivity in some areas. The farmers usually practise mixed cropping to reduce the risk of crop failure which can be caused by poor soil fertility, drought or erratic rainfall pattern. Owing to the low fertility status of some of these soils of the region, compound farming is a common practice and the farmers maintain soil fertility by the use of household refuse. On bush farms, there is the need for fertilizers to increase yields.

Phosphorus sorption studies have been reported for many types of soils of the humid tropics (Ahenkorah 1968; Juo and Fox 1970; Udo and Uzu 1972 and Rhodes 1975) but very little has been done on the lateritic concretionary soils of the semi-arid zone of northern Ghana and similar regions. Past reports have indicated relatively low P sorption for West African savanna soils (Juo and Fox 1977; Sobulo 1982). However, the presence of large amounts of lateritic concretions in some of the soils of the semi-arid savanna zone of northern Ghana may have an effect on the sorption capacity of the soils. Concretions have high sorption ability and do raise the P sorption capacity of soils (Tiessen et al., 1987). Though the concretions are main sorbers of P in soils,it is not known whether the sorbed phosphorus is inactive or reversible and therefore available to plants over a series of cropping periods. So far no work has been done on the reversibility of P sorbed by concretions although Tiessen et al. (1987) speculated that P sorbed by concretions may also be a potential reservoir of available phosphorus.

Considering the fact that some farmers of northern Ghana have only concretionary soils to cultivate because of the prevailing land tenure system, a knowledge of the influence of concretions on phosphorus sorption and desorption is of primary importance in understanding phosphate availability and how the concretions affect the fertility status of soils that contain them. The objectives of this study are therefore:

(i) to assess the relative importance of concretions in P availability to a crop in a typical concretionary soil of northern Ghana,

(ii) to determine the sorption - desorption characteristics of the soil reconstituted to represent different levels of concretions, and

(iii) to evaluate the reversibility of P sorption by the concretions using a test crop.

CHAPTER TWO

2. LITERATURE REVIEW

Phosphorus is an essential element in plant nutrition and crop production. P is one of the major nutrients required by plants along with nitrogen and potassium. However, phosphate in soils tends to react with soil components to form relatively insoluble compounds, many of which have limited availability to plants (Singer 1978; White 1981). P sorption and desorption in soils are widespread and, because of their agronomic importance, have been the subject of numerous investigations. Interest in the subject is undiminished as the mechanisms of P sorption and desorption are still not entirely clear. To elucidate this, many researchers have attempted to study P sorption and desorption characteristics of soils as they relate to P availability. As far as phosphorus availability in soils is concerned this review will consider (i) sorption and some of the mechanisms associated with the process, (ii) sorption and desorption in relation to phosphorus availability.

2.1 Mechanisms of adsorption and desorption

2.1.1 Adsorption

Various definitions have been given to the process of adsorption. According to Larsen (1967) the phenomenon of concentration of liquid or gaseous materials on the surface of a solid is known as " adsorption"; while the incorporation of a solid is known as "absorption". When applied to the soil, Syers and Curtin (1988) stated that if the phosphate ions removed from solution by soil are restricted to the surface of the soil colloid then an adsorption reaction occurs. The adsorption reaction if followed by the diffusive penetration of P into the retaining component then absorption reaction is considered (Syers and Curtin, 1988). It is often difficult to distinguish between these two reactions and the term sorption is often used as a collective name for both (Bache 1964). During (1968) used the term sorption to describe the relationship between the quantity of phosphate in the solid phase at a given concentration of P in the liquid phase. Barrow (1978) used the term phosphate adsorption to describe any process in which phosphate ions in solution react with atoms on the surface of soil particles.

2.1.2 Mechanisms of phosphorus adsorption

Many phosphate-adsorption studies have been conducted and some mechanisms have been proposed. Hsu and Rennie (1961), De Detta et al.(1963), Ryden and Syers (1975), studying the kinetics of P fixation reported the involvement of two processes- an initial rapid stage and a second relatively slow stage. Munns and Fox (1976) mentioned that in moist undisturbed soils the fast reaction between soil and phosphate continued for 20 to 30 days after the addition of phosphate. After some time a slow reaction continued for 100 days or more. Hsu and Rennie (1961) described the initial rapid stage as true adsorption while Barrow (1974) suggested that the slow reaction is a consequence of movement into inner surfaces of hydroxides, particularly amorphous hydroxides, and perhaps of rearrangement of the crystal structure. Two other explanations were advanced for the slow reaction by Chen et al. (1973) and Talibudeen (1974). The first is that with time, discrete crystalline P compounds form, or that discrete compounds of imperfect crystallinity become more crystalline and less soluble. The second explanation is that adsorbed P penetrates into porous solids becoming absorbed and leaving surface sites to adsorb more P. This second explanation is in agreement with the work of Ibrahim and Pratt (1982). Barrow (1978) remarked that the boundary between the rapid and slow processes is not sharp but it is the first step which workers usually aim at to characterise the quantity/ intensity, (Q/I) plots.

A mechanism which is often invoked to explain the fast and slow reactions is that the initial adsorption reaction is through one of the oxygen atoms of phosphate and the second reaction involves a link through a second oxygen atom, thus giving a ring structure. This mechanism was proposed by Kafkafi et al. (1967) to explain their inability to desorb P from soil by washing and also by Atkinson et al. (1967) to explain the slow isotopic exchange of adsorbed P. Based on infra-red studies, Parfitt et al. (1975) indicated that P was specifically adsorbed by two adjacent surface hydroxyl ions. Two oxygen atoms of the phosphate ion are linked to two iron ions giving a binuclear surface complex: Fe-O-(PO-OH)-O-Fe. Earlier evidence for this mechanism comes from the work of Hingston et al. (1974). They showed that phosphate could not be readily desorbed from goethite, but fluoride could,and suggested that this was because fluoride was unable to form a second link. Barrow and Shaw (1977), however, doubted the formation of a second link as the mechanism of the slow reaction. They found that fluoride reacted with a range of soils in much the same way as phosphate.

An important characteristic of the adsorption and of other specifically adsorbed anions is that adsorption increases the negative charge on surface of the soil (Hingston et al. 1972; Mekaru and Uehara, 1972; Sawhney 1974). This means that it becomes increasingly difficult for each additional increment of phosphate to be adsorbed. In other words the affinity of the surface decreases as adsorption increases.

2.1.3 Phosphate sorption by variable surface charge minerals

Mokwunye et al. (1986) stated that in general, agricultural soils of temperate regions are characterised by surfaces bearing a constant surface charge, whereas soils of the humid tropics are characterised by having a variable surface charge, examples are hydrous oxides of iron and aluminium. Amorphous oxides and hydroxides of aluminium and iron in soils are mainly responsible for P sorption (Harter 1969; Syers et al. 1971;

McLaughlin et al. 1981). These minerals are characterised by a surface of negatively charged OH groups which take up and dissociate protons according to their acid strength and ambient pH.

A model for changes in surface charge and possible changes in configuration following sorption of phosphate ion on the surface of iron and aluminium oxides has been presented by Barrow (1980). An important feature of these processes (Figure 1) is the transformation of the phosphate ion from the monodentate ligand-sorbed form to the bidentate ligand-sorbed (or ring structure) form. Kafkafi et al. (1967) and Hingston et al. (1974) suggested that the phosphate sorption in the former form is reversible, whereas the latter form favours irreversibility. In other words, the phosphate ion in the latter would be less likely to be desorbed and hence available to plants.

2.1.4 Equations that relate sorption reactions.

The reactions between phosphate and soils have often been described mathematically with adsorption isotherm equations (Olsen and Watanabe 1957; Syers et al. 1973; Barrow 1978; and Mead 1981). Among the isotherms that are commonly used are the Freundlich's, Langmuir's and Temkin's.

(i) Freundlich equation may be written as

$$x = ac^{1/n} \qquad [1]$$

where a and n are constants, x is the amount of P sorbed per unit soil and c is the equilibrium P concentration. The equation was derived empirically but could be applied to soil-phosphate solution systems. Over limited ranges of P concentration the Freundlich equation describes adsorption well (Barrow and Shaw 1975; Holford 1982).

(ii) Langmuir equation may be written as

$$x = ax_mc / (1 + Ac) \qquad [2]$$

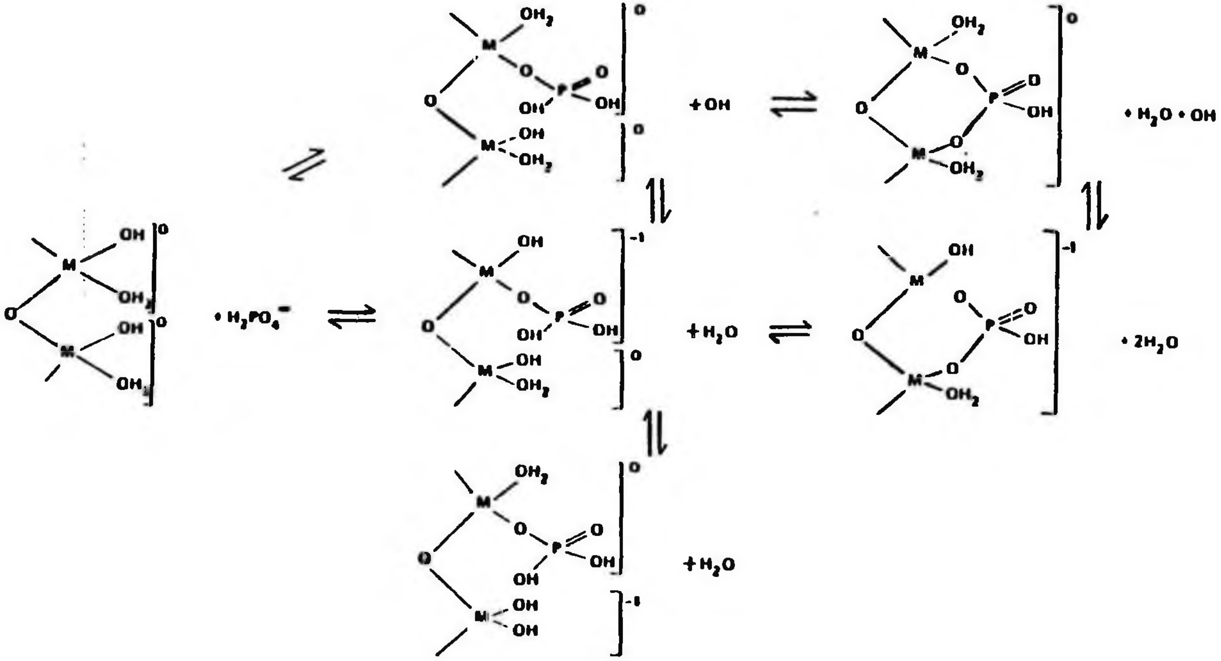

Figure 1. Changes in charge and possible changes in configuration following adsorption of phosphate on the surface of a metal oxide (adapted from Barrow 1980).

where x is the amount of phosphate adsorbed per unit of soil, c is the phosphate concentration in solution, a is a coefficient which reflects the relative rates of adsorption and desorption at equilibrium and x_m is the adsorption maximum. The Langmuir adsorption isotherm was developed to describe the adsorption of gas molecules onto a solid surface as a monolayer with specific energy of adsorption (Gunary 1970). The equation has also been applied to phosphate solutions and soil to estimate adsorption maximum and bonding energy of the phosphate on soil colloid particles (Olsen and Watanabe 1957). However,according to Barrow (1978) the Langmuir equation only describes adsorption over a limited range of concentrations and the "maximum" calculated from observations at low concentrations is unrealistic since it is exceeded at higher concentrations.

(iii) Temkin equation

$$x = (RT / B) x_m \ln Ac \qquad [3]$$

where A and B are constants, has been used to describe P sorption by soils (Bache and Williams 1971). The equation assumes that the energy of adsorption decreases linearly with increasing phosphate addition.

All three equations ([1], [2], [3]) can be used to describe adsorption adequately (Barrow 1978; and Polyzopoulous et al. 1985). Sorption equations, however, offer no clues to the mechanisms of adsorption of P by soils (Sample et al.1980).

2.1.5 Factors affecting sorption of phosphorus

The availability of applied phosphorus is controlled by the retention (sorption) and release (desorption) characteristics of the soil. The reactions involved in these phenomena are complex and range from true adsorption through isomorphous substitution to precipitation (Muljadi et al. 1966; Harter 1969). The major factors which influence these reactions include: phosphorus concentration in solution, amount of free oxides of iron and aluminium, type and amount of clay, soil pH and organic matter (Syers et al. 1973; Juo and Fox 1977). Results of studies to estimate the individual contribution of these factors (Syers et al. 1971; Biddappa and Rao 1973) suggest that they are not additive and that they interact with each other. Correlation or regression equations can be established, but they do not always reflect cause-effect relationships (Sanchez and Uehara 1980).

2.1.5.1 Phosphorus sorption in relation to oxides of iron and aluminium

The results of several studies (Broomfield 1965; Saunders 1965; Syers et al. 1971) indicate that the sorption of inorganic phosphate by soils of pH less than 7.0 is closely related to the amounts of reactive iron and aluminium components. It is well documented, however, that the iron and aluminium components which occur in soils vary appreciably in their ability to sorb P (Hsu 1965; Sample et al. 1980). In general, amorphous hydrous metal oxides of iron and aluminium sorb considerably greater amounts of P than do their crystalline counterparts (Bache 1964; McLaughlin et al 1981).

Syers et al. (1971) obtained a reduction in phosphorus adsorption in soils following the removal of aluminium with oxalate. Vig and Dev (1984) reported maximum reduction of adsorption in acid soils of India. They remarked that the greater reduction in P adsorption in the acid soils due to dithionite treatment may be ascribed to the removal of active iron and aluminium oxides.The extraction procedure is important because reagents such as oxalate or citrate will block the remaining adsorption sites (Nagarajah et al. 1968) and thereby give erroneous results.

When applying soluble P to acid, upland soils, the soluble P is believed to precipitate rapidly to form colloidal aluminium-phosphate and iron-phosphate (Taylor et al. 1963). Because of their small particle sizes, greater surface area and amorphous structure, these colloidal forms are readily available to plants. It has been suggested that these aluminium and iron phosphates tend to crystallise slowly to compounds such as variscite ($AlPO_4$-$2H_2O$) and strengite ($FePO_4$-$2H_2O$) which are much less available for plant growth (Juo and Ellis 1968). However, such metal phosphates are unlikely to be stable in soils because congruent dissolution, which appears to be required for stability of strengite and variscite, is restricted to pH values below 1.4 and 3.1 respectively (Bache 1963; Hsu 1982). Evidence from studies using hydrous ferric oxide gel, a common and important component for P sorption, indicated that the levels of P sustained in solution by hydrous ferric oxide gel is lower than those sustained by strengite (Bache 1964; McLaughlin and Syers 1978). It therefore seems unlikely that such compounds will persist even if they form in soils. The colloidal phosphates may crystallise in the soil to form products representing a large variety of compounds of aluminium and iron as suggested by Kaila (1964).

According to Syers and Curtin (1988), dissolution-precipitation theory is still used to describe the interaction of P with soil components, although good evidence for the participation of such reactions in phosphorus cycling is rarely forthcoming. Perhaps the uptake and release of P by soils can be described better by sorption-desorption reactions.

There has been a controversy in literature over whether iron or aluminium is more active in P sorption. Saini and MacLean (1965) investigating P retention capacity and its relationships with iron and aluminium concluded that aluminium plays a dominant role in P retention. They found a poor relationship between P fixation and free iron oxide. Ahenkora (1968) working on some cocoa growing soils of Ghana observed no significant relationship between P retention capacity and extractable aluminium but instead indicated that dithionite extractable iron is mainly responsible for the magnitude of the P retention. This is, however, contrary to the findings of Owusu-Bennoah and Acquaye (1989) who found dithionite extractable aluminium to be a more important determinant of P-sorption maximum of some selected major Ghanaian soils. Juo and Fox (1977) and Juo (1981) have shown that the total amounts of P sorbed from solutions by soils of southern Nigeria are well correlated with total free iron oxides, extracted by sodium dithionite in Alfisols and Ultisols derived from acidic rocks.

2.1.5.2 Uses of phosphate sorption information

The phosphate sorption capacity of soils is a useful criterion in soil fertility studies (Juo 1981). P sorption measurements may be unsuitable for routine soil testing but progress towards better characterization of soil P status could be made by identifying soil properties which are correlated with sorption and which can be simply and cheaply measured. As pointed out by Fox (1985) phosphate- sorption capacity reflects the reactivity of iron and aluminium oxides present in soils and such properties can be easily measured in the laboratory. Fox and Kamprath (1970) used phosphate sorption capacity to evaluate the residual P in soils.

Phosphate sorption characteristics and standard phosphate requirement of some selected benchmark soils of West Africa have been reported by Juo and Fox (1977). They concluded that because these soils were collected in a systematic manner on the bases of soil classification, mineralogy, parent material and agronomic conditions, phosphate-sorption data (using a standardised technique) may be used to construct phosphate-requirement maps. Such maps may be useful for national and regional agricultural planning and development in many parts of the tropics, particularly where fertilizer resources are limited. The phosphate sorption capacity of soils has also been incorporated in soil classification (Breeuwswa et al. 1986) and therefore useful in soil taxonomy.

Juo and Fox (1977) grouped soils into five categories based on the standard phosphate requirement data for West African benchmark soils (Table 1).

Table 1. Standard Phosphate Requirement (SPR) of Soils (from Juo and Fox 1977).

SPR, µg/g soil	scale	Dominant Mineralogy
<10	very low	quartz, organic materials
10-100	low	2:1 and 1:1 layer silicates, quartz
100-500	medium	1:1 layer silicates with low specific surface, oxides
500-1000	high	high specific surface oxides, weathered ash
>1000	very high	allophanes and desilicated amorphous materials

The above table indicated that most of the West African benchmark soils studied fall within the low to medium phosphate requirement groups.

2.2 Desorption of phosphate

Due to the minute concentration of phosphate in the soil solution, the bulk of the phosphate taken up by plants must come from phosphate adsorbed to soil particles and by dissolution of sparingly soluble phosphate salts in the soil. Elrashidi and Larsen (1978) noted that these are the two possible mechanisms which are responsible for replenishing the soil solution with phosphate. The amount of P desorbed is related to the P in equilibrium solution. Bhat and Nye (1974) found out that the amount of P desorbed was related to the logarithm of the level of P in the equilibrium solution.

The process that describes the release of sorbed phosphorus into the soil solution is known as desorption and is related to the P buffering capacity (Quantity/Intensity) of the soil. Soil's buffer power for desorbing phosphate has important implications for crop growth because it is a limiting step for availability of phosphate by crops (Cabrera et al. 1981). The diffusion coefficient for an ion in the soil is inversely related to the buffer power of the soil for that ion. For a slowly diffusible ion such as phosphate, this is especially important because it affects the rate of uptake of the nutrients by plants (Nye 1966) thereby affecting the final yield of the crop.

2.2.1 Desorption by neutral salt solution and anion exchange resins

Various salt solutions have been used to desorb P in soils (Shapiro and Fried 1956; Nagarajah et al. 1968; Evans and Syers 1971). Brewster et al. (1975a), Barrow and Shaw (1975) reported some readsorption of P when they desorbed phosphorus with 0.01M $CaCl_2$ from P-incubated soils. They suggested that this readsorption was due to the breakdown of soil particles and exposure of new surfaces. On the contrary, White and Taylor (1977) stated that freshly adsorbed P will be reversible if the soil is pretreated with soluble P sufficient to satisfy the high energy sites. This is consistent with Ryden and Syers' (1977) finding that loosely bound surface P, but not chemisorbed P, was completely desorbable at constant pH and ionic strength. White (1981) in a review of phosphorus retention in soils stated that there is an insignificant reversion of freshly adsorbed P to more tightly forms in soils during desorption with neutral electrolyte like 0.01M KCl solution.

Anion exchange resins (AER) have been used extensively to measure the rate of P release from soils and as an index of the quantity of available P in soils (Amer et al. 1955; Cooke and Hislop 1963; Vaidyanathan and Talibudeen 1970; Taylor and Ellis 1978). The action of the AER is to release the anion into solution to exchange with P. The P is then sorbed onto the exchange resin and phosphorus is later extracted from the exchange resin. The action of the AER to remove phosphorus from soil is considered to be similar to the action of the plant roots (Amer et al. 1955; Kadeba and Boyle 1978). Amer et al. (1955) showed that if an anion exchange resin is added to a soil suspension under appropriate conditions, P uptake by resin occurs at a rate which is independent of the properties of the resin and dependent only on the rate of dissolution of P from the solid phase of the soil.

Cooke (1966) measured the release rate of phosphate ions from the solid phase with an anion exchange and assigned a numerical parameter to the release rate. This parameter was highly correlated with P uptake by rye-grass in greenhouse trials from a wide range of soils. Gunary and Sutton (1966) suggested that the resin method provided a good measure of an intensity/kinetic complex, which included an inter-related complex of intensity, rate of release and diffusion factors. Vaidyanathan and Talibudeen (1970) studied the mechanisms controlling the transfer of phosphate ions to anion exchange resins. They observed that the labile P pool as measured by ^{32}-P isotopic dilution was the source of all the desorbed P. Anion resins provide a sink for soil P, thus simulating a withdrawal of P from solution and from the labile P by plant roots. Generally the rate of P desorption decreases with time and its release is described by a curve of gradually decreasing slope (Barrow 1980).

Although neutral salt solutions and anion exchange resins have been used extensively to desorb phosphate from soils, their use in desorption studies depends upon the form of anion used, the volume of solution, equilibration time, pH changes and the amount of resins used (Barrow and Shaw 1977). Rather than anion exchange resin or salt solution desorption curves, Le Mare (1981) and Bowman and Olsen (1985) considered the use of adsorption isotherm buffer curves more useful because they are easily reproducible and also highly correlated with phosphate requirements and phosphate release. Plants instead of resins or salt solutions were used by Holford and Mattingly (1976) and Novais and Kamprath (1978) to estimate soil P-buffering capacity (release) by successive greenhouse cropping.

2.2.2 Plant P uptake and desorption by neutral salt solution in soils

As discussed previously various methods are in use to measure soil P desorption but according to White (1981) the results do not often agree with P removal calculated from plant uptake. Brewster et al. (1975b) found that the P concentration measured in soil samples after depletion by plants were less than predicted from a desorption curve measured in 0.01M $CaCl_2$. White (1968) found that "plant desorption" curve gave higher P concentrations and had a steeper slope than a Q/I plot obtained by desorption into 0.01M $CaCl_2$. These differences highlight the difficulty of simulating in a laboratory the complex environment of the root, where anions and cations are absorbed and substantial amounts of soluble and insoluble exudates and secretions are produced by the root and rhizosphere microorganisms. According to Olsen and Khasawneh (1980) only the plant can measure the amount of available P in soils. Chemical tests and simulation models must be evaluated by correlation with appropriate plant observations

2.3 Labile and nonlabile phosphorus in soils

According to Larsen (1967), soil P can be described in terms of the following relationship: soil solution $\Longleftrightarrow$ labile P $\Longleftrightarrow$ nonlabile P where equilibrium is rapidly established between labile and soil solution P. True equilibrium is seldom, if ever, established between the labile and nonlabile pool of soil P (Olsen and Khasawneh 1980). It is possible that when fertilizer P is applied to high P-fixing soils, some of the phosphorus may be converted to nonlabile form which is not immediately available to crops but not necessarily lost (Barrow 1985) to the crop but may desorb with time for plant uptake. The role of the labile P fraction is primarily the renewal of phosphorus removed from the soil solution by plant roots. Depletion of the labile P usually causes nonlabile P to become labile again though at a slow rate. According to Holford (1982) the amount of available P, and therefore the plant uptake of phosphate,is a direct function of the quantity of labile phosphorus in the soil.

2.3.1 Phosphate buffer capacity of a soil.

Phosphate buffer capacity refers to the ability of the phosphate concentration or intensity of the soil solution to resist change when phosphate is added to or removed from the soil. It is one of the most important soil properties in determining phosphate availability to crops because it characterises the dynamic relationship between labile solid phase phosphate and the solution phase from which plants and microorganisms withdraw their nutrient supply (Beckett and White 1964). The relation between the intensity and quantity of labile P is controlled by the buffer capacity in such a way that at any level of labile P, the higher the buffer capacity, the lower the concentration of phosphorus in solution (Holford 1980). Buffer capacity may be controlled by adsorption/desorption processes (Holford and Mattingly 1976) and/or by precipitation/dissolution processes (Murrman and Peech 1969), particularly around fertilizer granules, but the former are more likely to be dominant at the very low phosphate concentrations existing in most soils (Holford 1979). For this reason it is measured usually from the slope of a sorption isotherm or a quantity/intensity (Q/I) curve.

Description of P availability is made more complete if the Q/I relationship is measured (Ozanne and Shaw 1968). This relationship has been shown to be important in the P nutrition of plants grown in pots by Barrow (1967). The immediate source of P for plants growing in a soil is that provided by the inorganic phosphate ions in the soil solution, the intensity factor. At any given time it is determined by the amount of P in the solid phase that will release P into the soil solution. The solid phase P is a quantity factor. Since growing plants continually remove phosphate ions from the soil solution, the measure of the capacity of the soil P system to maintain P concentration during P withdrawal by plants is important. To the relationship (Q/I) the term potential buffering capacity has been applied (Beckett and White 1964).

Phosphate buffer capacity is usually assessed by laboratory procedures to construct a sorption curve relating labile or easily removed surface P to soil solution P, (Bache and Ireland 1980). Buffer capacity will vary according to the solution concentration at which the isotherm slope is measured, and consequently various indices have been used to express this parameter. The following types of buffer capacity measurements are recorded in the literature: the initial "linear" slope of a Q/I curve up to a solution concentration of 0.4 ppm P (Olsen and Watanabe 1963); the slope at a standard equilibrium of 0.2 ppm P (Barrow 1967); and the maximum slope of the sorption isotherm as the solution concentration tends to zero (Holford and Mattingly 1976; Holford 1988). In addition, the amount of phosphorus sorbed at a standard equilibrium solution concentration of 0.3 ppm P (Ozanne and Shaw 1967) has been suggested as useful measurement related to buffer capacity.

Because the ratio of surface P to soil P is seldom predictable (Vaidyanathan and Talibubeen 1970), phosphate uptake by plant roots provides a standard of P availability with which to assess buffering capacity, or rates of P released or desorbed from the solid phase to solution phase (Bowman and Olsen 1985). Moody (1978) related P sorbed to P buffer capacity and remarked that soils of high potential buffer capacity adsorb more P at a given supernatant solution P concentration than soils of low potential buffer capacity. To reach a given intensity, larger quantities of P will have to be added to soils with a high buffer capacity than with a low buffer capacity (Fox and Kamprath 1970). Thus, as P is removed by cropping there will be less change in the intensity of soils with high than low buffering capacities.

2.3.2 Residual P

Limited recovery of phosphorus fertilizer during the year of application has often been attributed to "fixation" reactions converting the P to unavailable forms. In a review of residual P in western Canadian soils, Sadler and Stewart (1974) compiled considerable evidence indicating that a large portion of the P remaining after the first crop year is not "fixed" but is indeed available to subsequent crops.

Large variations in the persistence of fertilizer residues and recovery are reported in literature: 27.7% by five crops (Thomas 1964), 87% by 14 greenhouse crops (Read et al. 1973) and Fixen and Ludwick (1982) reported that a residual effect of a fertilizer treatment persisted beyond six greenhouse crops for nearly one-half of the 28 soils they worked with. Wagar et al. (1986) realised that after 5 and 8 years of cropping, half of the fertilizer residues remained in plant-available forms. In tropical savanna soils, Goldsworthy (1967) and Stephens (1960) have shown a pronounced residual effect from a single application of phosphate fertilizer in northern Nigeria and Ghana respectively. More recently in the northern region of Ghana, Schmidt and Frey (1988b) reported a residual effect of fertilizer phosphorus on maize crop after 5 years' application at the Nyankpala Agricultural Research station. Variations in magnitude of residual P have led to the investigation of its chemical nature and factors influencing the residual value of phosphate fertilizers. Phosphorus availability indices are typically correlated with the quantity of available residual P in soils. Bowman et al. (1978) compared the correlation of Olsen-P, Resin-P,and labile-P with long-term greenhouse P uptake and found the relationship to be highly significant.

The quantification of response to residual P has been the object of much study. Devine et al. (1968) related residual available P to annual application of fertilizer materials reporting results as percentage of "superphosphate equivalents" where uptake or yield from most recently applied single superphosphate was used as the standard. Fox and Kamprath (1970) were able to calculate the residual effectiveness of P fertilizer 10 years after application by a measure of the displacement of the adsorption isotherm. Fixen and

Ludwick (1982) showed that the critical level of residual available P in near-neutral and alkaline soils is 10 ppm $NaHCO_3$-P (Olsen-P) below which deficiency is expected.

The residual plant-available P in soils can be quantified by successive cropping experiments. In such experiments, plant-available P is removed until P deficiency occurs or a response to added P is measured (Aquino and Hanson 1984). After reviewing greenhouse and field studies of the availability of residual P, Barrow (1980) concluded that the general trend for the decline in available P from a previous P fertilization is best described by a rapid initial decline, followed by a gradual geometric decline with time.

P-fertilizer applied may be temporarily converted to unavailable forms to crops but research has shown that with time the previously applied P is gradually released to increase crop production.

2.4 Phosphorus availability in savanna soils

In highly weathered tropical soils, P deficiency is a major constraint to crop production due to the presence of P forms not readily available to plants (Akinola et al.1983). According to Udo and Uzu (1972), phosphorus applied to tropical acid soils has limited availability to plants because of high P-fixing power of the soils. This is because tropical acid soils contain appreciable amounts of sesquioxides, exchangeable aluminium and iron and other soil factors which are active in P fixation. However, from a review of field experiments carried out in the tropics, Russell (1968) showed that it is wrong to describe tropical soils as generally having high phosphate fixation capacities in the sense that they rapidly convert applied phosphate into unavailable forms since residual P fertilizer effects have been recorded in such soils.

Deficiency of phosphate occurs widely in the savanna soils. In some acid soils, deficiency is so acute that plant growth virtually stops as soon as the seed reserves of phosphate have been used up (Jones and Wild 1975). In 181 topsoil samples of ferruginous tropical soil, mostly Alfisols in Nigeria, the total P contents ranged from 13 to 560 ppm P with an average of 125 ppm P (Baker et al. 1965). Total P contents of 67 topsoils from high-grass savanna of Ghana averaged 134 ppm P (Nye and Bertheux 1957) whereas Acquaye and Oteng (1972) reported a range of 104 to 270 ppm for topsoils of 48 soil series developed over the principal parent materials in the different ecological zones of Ghana. These average values are far lower than the means reported for some Australian (350 ppm) and American (560 ppm) soils (Jones and Wild 1975). The low values may be due to the advanced weathering process and low phosphorus content of the parent material.

For West African surface soils available P levels are low. Sobulo (1982) used Bray No.1 method to obtain 2.9 to 10.1 ppm P for some soils of the Guinea savanna of Nigeria. Oteng and Acquaye (1971) using various conventional extraction methods on 48 representative Ghanaian soil series obtained mean values ranging between 0.9 to 7.7 ppm available P. Nyamekye (1987) also used the Bray No.1 method and reported 3.5 ppm available phosphorus for the Tingoli soil series of the Nyankpala Agricultural station. Kanabo et al. (1978) reported a low value of less than 10 ppm P in some soils of northern Ghana.

2.5. Lateritic ironstone concretions

Concretion is used in this study as a term to indicate a generally indurated mass or concentration of a chemical compound such as iron oxide in the form of a grain or nodule of varying size, shape, hardness and colour found in soil. Such a definition conforms to that listed in Glossary of Terms in Soil Science (Canada Dept. of Agriculture Publication No. 1459). The typical feature of ironstone is a high content of iron relative to the soil matrix. The concretions used in this study, however, were of uniform size (<2mm).

Laterite according to Sivarajasinghan et al.(1962) can be described as highly weathered material that is rich in secondary forms of iron, aluminium or both; poor in humus; with or without diagnostic substances such as quartz with the presence of limited amounts of weatherable primary minerals and silicate clays. It is either hard or subject to hardening upon exposure to alternating wetting and drying. In addition the term includes certain highly weathered materials in sesquioxide-rich, humus-poor nodules that are hard or that harden upon exposure, though they may be surrounded by earthy material that does not harden. It also includes masses of such nodules cemented together by sesquioxide-rich material.

Concretions have been found in many soils. The quantity, chemical composition, and size of concretions in soils depend upon the action of weathering process for the locale. Murthy and Mathur (1964) remarked that concretions were a mixture of soil material cemented together. For instance, the cementing agents for iron-manganese concretions were iron and manganese (Murthy and Mathur 1964).

Conditions favourable for soil concretion formation include poor drainage (Raikov and Sapundzhier 1966; Arshad and St. Arnaud 1980), usually associated with level topography and light coloured soils. A possible mechanism for concretion formation, in poorly drained soils, could be due to the presence of iron on the aggregate surface becoming dissolved on reduction and transported into the interior of the aggregate. If upon drying, oxygen diffuses into the aggregates and causes precipitation of $Fe(OH)_3$, nodules or mottles are formed.

Hem (1972) noted that the formation of iron-manganese concretions is due, primarily to the ability of iron and manganese to change their oxidation states in response to pH and E_h changes that occur naturally in aqueous systems. Iron and manganese originally present in highly insoluble forms may become relatively soluble when pH and/or E_h changes occur, enabling relocation in response to diffusion gradients and water movement (Childs 1975).

Lateritic concretions are commonly formed from local accumulation of iron and manganese oxides. Weathering under tropical climates tends to result in the accumulation of iron and aluminium in the soil. This accumulation is a result of the removal of other constituents, particularly, the combined silica leaving sesquioxides behind. Iron oxides may coat, impregnate, and sometimes bind together clay and larger particles and are often individualised as ironstone concretions or indurated iron-rich horizons and layers (Ahn 1972).

2.5.1 Fertility of lateritic soils

From the time of their first definition, areas characterised by laterite have been recognised as being of low soil fertility (Prescott and Pendleton 1950). The weathering and pedogenic processes that result in the development of the characteristic laterite profile tend to remove plant nutrients by leaching. In some cases the plant nutrients become concentrated with iron in the laterite mass or concretions and are rendered inaccessible. Nye and Bertheux (1957) found the total amount of P locked up in the ironstone concretions of a Nigerian soil to be 700 ppm and Tiessen et al. (1987) obtained 300 ppm P as the total P value of concretionary Tingoli soil series. They reported that lateritic ironstone concretions by their nature, act as sink and thus raise P requirement of the soil.

2.5.2 Summary of literature review

It is clear from the review that phosphorus status of the soil solution is governed by the P sorption and desorption characteristics of the soil. The buffer capacity is equally important as it reflects the soil's ability to resist changes in soil solution P. Many factors affect P-sorption but it appears dithionite and oxalate extractable free oxides of iron and aluminium, in particular,contribute largely to P retention in acid or near neutral soils. Soils of semi-arid savanna zone of northern Ghana and similar regions are P-deficient probably because of the low P content of the parent material and also the advanced weathering process. Ironstone concretionary soils tend to have high P sorption capacity because of their high reactive iron and aluminium oxide content.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Soil.

The soil used for this study was sampled between Tingoli and Daswili near the Nyankpala Agricultural Experimental Station in the Northern Region of Ghana. The sampling site is shown in figure 2. The soil is classified as Tingoli / Tolon series which falls under Savanna Ochrosols (local classification) or Paleustalf (U.S.D.A. 1975) or Chromic Luvisols (FAO) (Serno and van de Weg 1985). It is well drained and occupies summit to upper slope positions on the landscape and is derived from ironstone gravel and ferruginised sandstone. The topsoil (0 - 20 cm depth) consists of brown loamy sand with about 70% ironstone concretions. The soil sample was taken from a field (bush farm) under sorghum crop with no history of phosphorus fertilization. The vegetation around the sampling site was grass and scattered shea butter trees*(Butyrospermum parkii).*

The soil was transported to the laboratory and air-dried. The undecomposed plant materials were sorted out and the soil passed through a 2-mm sieve. A portion of the sieved 2-mm soil was further divided into lateritic concretions (< 2mm) and soil fines using 0.5 mm sieve. Concretions above 2 mm size were discarded. The soil fines and the concretions were reconstituted into experimental " soils" in the following proportions: (a) 100% (v/v) soil fines (0% concretions); (b) 65% soil fines + 35% concretions, and (c) 30% soil fines + 70% concretions to represent different levels of concretions. A sample of the concretions (0.5-2mm size) were ground for chemical analysis. Some physical and chemical characteristics of the soil and concretions are given in Table 2.

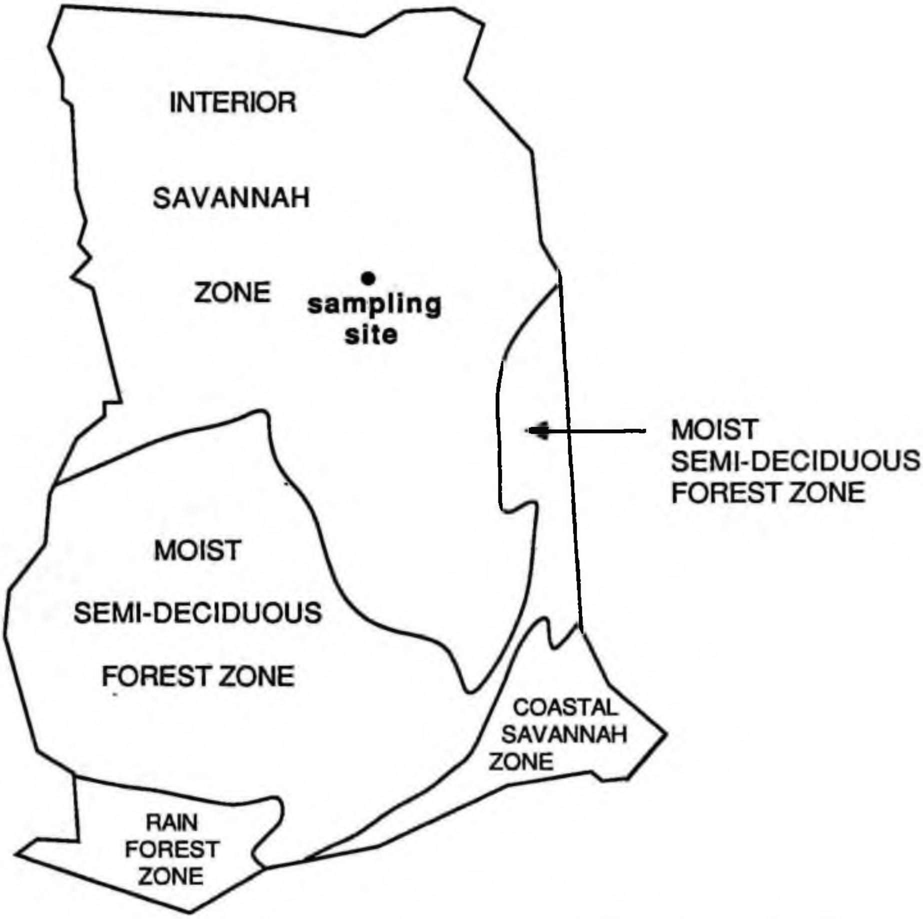

Figure 2. Map of Ghana showing the major ecological zones and sampling site.

3.2 Chemical analysis

3.2.1 Soil pH.

Soil pH was determined in both distilled water and 0.01M $CaCl_2$. In both water and 0.01M $CaCl_2$, soil pH was measured in 1: 2 soil to solution ratio using a Pye-Unicam pH meter. Similar measurements were done for the ground concretions (< 0.5 mm).

3.2.2 Organic carbon

Organic carbon was determined by the wet combustion method of Walkley and Black (1934). Ten mls of potassium dichromate ($K_2Cr_2O_7$) solution and 20 mls of concentrated sulphuric acid were added to one gram of soil in a conical flask and digestion allowed for 2 hrs. The $K_2Cr_2O_7$ remaining in solution after the digestion was titrated against 0.2N ammonium ferrous sulphate using barium diphenylamine sulphonate as an indicator.

3.2.3 Available phosphorus determination

Available phosphorus was determined using the method of Olsen et al.(1954). Five grams of soil were weighed into a centrifuge tube and 100 mls of 0.5M $NaHCO_3$ (pH 8.5) were added. The suspension was shaken for 30 mins on end-to-end mechanical shaker. After centrifugation and filtration P was determined in the filtrate using the Murphy and Riley (1962) method. All P determinations were read using the Eel Spectra at a wavelength of 660 mμ.

3.2.4 Total phosphorus determination

Total phosphorus was determined by digesting 1.0 gram soil with 15 mls of 60% perchloric acid. To avoid explosion the soil sample was pre-digested with 10 mls of nitric acid for 20 mins and the sample cooled before adding the perchloric acid. The digest was filtered into a 250 ml volumetric flask and made to volume. Phosphorus in the digest was measured as stated above.

3.2.5 Organic phosphorus determination

Organic phosphorus was determined by modified method of Anderson (1960). 0.5 gram of soil was shaken for 16 hours with 30 mls of 0.3N NaOH. The suspension was centrifuged at 10,000 rpm for 10 mins and at 0 ^{o}C. The supernatant was decanted into 100 ml volumetric flask (solution A). The soil residue was heated with 10 mls of concentrated HCl at 82 ^{o}C for 10 mins in a waterbath. A further 5 ml concentrated HCl was added and stirred and the soil mixture allowed to stand at room temperature for 1 hour and stirred gently every 15 mins. It was centrifuged and the supernatant decanted into 50 ml volumetric flask and made to volume (solution B). Twenty mls of 0.5N NaOH were added to the soil residue and shaken to disperse it. The suspension was allowed to stand for 1 hour and stirred gently every 15 mins. After that it was centrifuged and the supernatant decanted into the 100 ml flask (solution A). Thirty mls of 0.5N NaOH were added to the soil residue and shaken. The suspension was heated at 82 ^{o}C in an oven for 8 hours and later centrifuged. The supernatant was added to the previous 100 ml flask and the solution was diluted to volume. Total and inorganic P were determined on both solutions A and B. The difference between the total and inorganic P of each solution is the organic P. The sum of the differences is equal to the total organic P of the soil.

3.2.6 Other determinations

3.2.6.1 Exchangeable cations and cation exchange capacity

Exchangeable cations were extracted by 1.0 N NH_4OAc (pH 7.0). Potassium and sodium in the extract were read by flame photometer; magnesium and calcium were determined by 0.002M EDTA titration using cal-red and eriochrome black-T indicators. The soil was washed three times with methyl alcohol and later extracted with 1N KCl solution. Ten mls of 40% NaOH were added to 5 mls of the KCl extract and distilled. To determine NH_4-N in the sample the distillate was collected into 2% boric acid to which a mixed indicator containing methyl red and methylene blue was added and then titrated against 0.01N hydrochloric acid. Particle size analysis was determined by the hydrometer method. Total nitrogen was by the Kjeldahl method.

3.2.6.2 Dithionite-citrate extractable iron (Fe) and aluminium (Al) oxides

Dithionite-citrate extractable iron and aluminium were determined using the method of Mckeague (1978). 0.5 g soil, ground to pass a 35-mesh sieve, was weighed into a 50 ml centrifuge tube and 25 mls of 0.68M sodium citrate solution were added. Using a calibrated scoop, about 0.4 g of sodium dithionite was added to the centrifuge tube. The centrifuge tube was tightly stoppered and shaken on mechanical shaker overnight. The suspension was centrifuged for 5 mins at 500 rpm and then filtered using the millipore system. The filtrate was saved in a clean plastic vial. In order to obtain a convenient concentration for analysis on an atomic absorption spectrophotometer the extract was diluted 1 in 10 using an autodilution machine. Standard solutions containing Fe and Al were prepared in a matrix containing the extracting solution (0.68M sodium citrate) and sodium dithionite (3.2 g) was dissolved in a litre of this solution. The standard solutions for both Fe and Al were in the range of 0 to 100 ppm. The concentration in the extract was estimated using the atomic absorption spectrophotometer. The percent Fe and Al content of the soil was determined using the relation:

$$\%\ \text{Fe or}\ \%\ \text{Al} = \frac{\mu\text{g/ml in final solution x extractant (ml) x dilution factor x100}}{\text{sample wt (mg) x1000}} \qquad [4]$$

3.2.6.3 Tamm's oxalate extractable iron and aluminium oxides

Tamm's oxalate extractable iron and aluminium were determined again by method of Mckeague (1978). One gram of soil ground to pass through 35-mesh sieve was weighed into 50 ml centrifuge tube. Forty mls of Tamm's solution (10.92 g oxalic acid +

16.11 g of ammonium oxalate in a litre of deionised water) were added to the tube and shaken in the dark at room temperature for 4 hrs. The suspension was centrifuged at 5000 rpm for 5 mins and filtered into a clean vial using a millipore system. Iron and aluminium standards were prepared (Fe, 0 to 100 ppm; and Al, 0 to 40 ppm) and used to construct a calibration curve on the atomic absorption spectrophotometer. Samples which were diluted 1 in 4 to avoid clogging of the spectrophotometer were read and referred to the calibration curve. The percent Fe and Al were determined using equation 4.

3.3 Phosphorus adsorption isotherm

Adsorption isotherm was determined on the four types of soil (soil fines or 0% concretion; 35% and 70% concretions; and a 2-mm sieved original soil). For comparison, 100% concretions have been included in the sorption studies. A 3 g soil sample was weighed accurately into each of six 40 ml polythene centrifuge tube and the tube plus its content weighed again. The weight of the tube plus the soil will be needed in the subsequent desorption studies. Thirty mls of 0.01M KCl solution containing 0, 3.33, 10, 20, 50, 100 and 200 $\mu g\ ml^{-1}$ P as KH_2PO_4 were added to each of the seven polythene bottles. In order to prevent microbiological activity two drops of toluene were added per sample per bottle (Fox and Kamprath 1970). The soil suspension was equilibrated by shaking end-over-end on a reciprocal shaker for one hour daily for 3 days at room temperature (25 ^{o}C) and thereafter centrifuged at 10,000 rpm for 10 mins at 0 ^{o}C. The supernatant was filtered using a millipore system into a clean dry vial. The filtrate was analysed using the Murphy and Riley method (1962). The amount of P sorbed by the different soils was calculated as the difference between the amount of P applied and the P remaining in solution. The P sorbed was plotted against P in the equilibrium solution.

3.3.1 Desorption studies

Desorption studies were carried out using the residual soil which received 200 μg P/ml. After filtering the supernatant from the previous sorption experiment the tube plus the wet soil was weighed and total of 30 mls of 0.01M KCl solution were added to the soil in the polythene tube on a weighing balance. The suspension was then shaken for 2 hrs and centrifuged at 10,000 rpm for 10 mins at 0 °C. The supernatant was filtered using a millipore system and a suitable aliquot taken for P analysis. The P carried over between desorption steps was determined from the weight of the entrapped solution that remained after decanting the supernatant solution. The extraction was repeated for 8 successive times and P released into the supernatant at each extraction period was then measured. To determine the rate of P release from the soils, the P released per extraction expressed as percentage of adsorbed P was plotted against the extraction number.

3.4 Resin P determination

The resin used was De Acidite FF, employed by Cooke and Hislop (1963). It is a strongly basic anion-exchange resin bead containing quaternary ammonium group, chloride form, with particle size of -16 to 36 mesh. The resin was charged by soaking it in 0.5N HCl until needed. It was washed several times with distilled water and left moist. Four grams of the moist resin were added to 5 g portions of soil in polythene centrifuge bottles and 100 mls of distilled water were added and shaken for 16 hrs.at ambient laboratory temperature of about 28 °C· The resin beads plus soil were poured onto a sieve mesh of 710 microns and the beads separated from the soil by washing them with distilled water several times until all soil particles were removed and the water became clear. The resin beads were carefully transferred into a 125 ml centrifuge tube and 20 mls aliquot of 0.5N NaOH solution were added and shaken for 10 mins to desorb P from the resin. This process was repeated five times and each time the solution was filtered using Whatman paper No. 542 into a clean 100 ml volumetric flask. A suitable aliquot was taken for phosphorus determination.

3.5 The greenhouse experiment

A greenhouse experiment was established using fertiliser additions at two rates, P_1 and P_2. Although the P levels chosen are higher than what may be necessary for agronomic activity the effect of the concretions are likely to be realised better at such high P saturation levels. There was also a check treatment for which no phosphorus was added. The reconstituted soils with different contents of concretions used for the pot experiment differed markedly in bulk density and the weights used per pot were adjusted to provide a constant volume for all soils (Smith and Scaife 1973; Kadeba and Boyle 1978). The soils used were: 0% concretion or soil fines (<0.5 mm) , 35% concretion + 65% soil fines, 70% concretions + 30% soil fines and a 2-mm original soil of about 60% concretions.

Equal volumes of soil (1150 cc) were measured into each pot and weighed. The equivalent weights were: 0% concretions 1.30 kg, 35% concretions 1.60 kg, 70% concretions 2.0 kg and original soil 1.77 kg. The preference for this approach was based on the concept that plants generally explore soil for nutrients on volume rather than on weight basis. The amount of P required by each soil was dissolved in the volume of water equivalent to the water holding capacity of each soil. The phosphate solution was used to soak the soil in the pot and allowed to stay for three days before sowing the test crop.

Table 3 shows the rate of P and equivalent weights of KH_2PO_4 per kg soil applied to each pot. All soils were cropped with six consecutive plantings of millet, (*Pennisetum typhoides)*, as a test crop. Cropping was replicated 5 times at each P level. Pots were arranged on greenhouse benches in completely randomised design with the pots re-randomised within each block and the blocks rotated weekly to minimize uneven environmental effects within the greenhouse. With plantings 1 to 3, the pots were thinned to 10 plants. In order to increase P depletion the plant population was increased to 15 for plantings 4 to 6. Thinning was done 3 days after emergence and the plants were allowed to grow for 28 days.

To ensure adequacy of nutrients, other than P, the pots were fertilized as follows: 45 mg N kg^{-1} soil, as $(NH_4)_2SO_4$ per planting in three equal portions (pre-planting, after 10 and 20 days) during plantings 1 to 3; for plantings 4 to 6 the N rate was 100 mg N kg^{-1} soil in three increments (40 mg kg^{-1} pre-planting and 30 mg N kg^{-1} at 10 and 20 days). For plantings 1 to 3, 40 mg K kg^{-1} soil KCl was applied and increased to 60 mg K kg^{-1} soil for plantings 4 to 6.

The pH of the soil was constantly checked because of the addition of $(NH_4)_2SO_4$ solution to the soils in the pots. After the fourth planting the pH dropped and 60 mg Ca per kg soil in the form of $CaCl_2$ solution was applied to the fifth planting to arrest the drop in pH. The pots were watered to 75% field capacity with distilled water by weighing daily.

The millet plants were harvested 4 weeks after sowing to minimize the interception of roots by pot walls (Fox and Kamprath 1970). Plants were cut at the soil surface, and were immediately weighed and the fresh weight recorded. The plants were thoroughly washed with distilled water to remove any soil particles on them. The washed plants were dried on a pad of soft tissue paper and placed in paper bags and dried in an oven at 70 ^{o}C to constant weight. The dried plant material was ground to pass through a 1 mm sieve and later stored in a small plastic bag for subsequent P analysis.

Before the next cropping was done the soil in each pot was poured out and spread into an aluminium container and the roots hand-picked as much as possible. These roots were shaken thoroughly to remove soil particles and the weight taken. The weighed roots were washed with distilled water, dried on a pad of soft tissue paper, placed in an envelope and oven dried at 70 ^{o}C. The dry weight was then taken. The root-free soils were air-dried and put back into the pots for subsequent cropping.

3.5.1 Digestion of plant material

Approximately 0.2 g of the ground plant material was weighed into tubes of a Tecator Block Digester and 10 mls of concentrated nitric acid were added to each tube and digested at a low temperature until all the plant materials were converted into a slurry mass. The tubes were cooled and then 5 mls of tenary mixture of concentrated HNO_3, H_2SO_4 and 60% $HClO_4$ in the ratio of 10:1:4 respectively were added to each tube. The digestion was continued until white fumes of $HClO_4$ and H_2SO_4 ceased. The digestate was washed with 20 ml aliquots of distilled water into a 100 ml volumetric flask. Suitable aliquots of the solution were taken for the determination of P concentration in the plant material.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 General soil characteristics

Selected properties of the soil and concretions are shown in Table 2. The Tingoli / Tolon soil series was selected because it typifies the concretionary soils of the semi-arid zone of northern Ghana. The soil has loamy sand as texture and is slightly acid in reaction. The low clay (5.4%) and high sand content (78.6%) is typical of savanna Alfisols (Akinola et al. 1983). The surface soil of the series is characterised by low organic matter (< 1.0%) and low total nitrogen contents.

The surface soil (0-20 cm) contains a high level of ironstone concretions (70% by weight), and the < 2mm fraction contains 60% (wt /wt) concretions. Total P content of the soil fines (< 0.5 mm) is 171 ppm and that of the concretions is 900 ppm. The total P level of the soil fines is close to that obtained by Ayodele and Agboola (1983) in savanna soils of Nigeria. The high total P value of 900 ppm obtained for the concretions agrees with the suggestion of Nye and Bertheux (1957) that P trapped in ferruginous concretions is higher than the P content of the surrounding soil. Available P levels of the soils are relatively low probably because of the poor phosphorus content of the parent material (Adu 1957). Also in the savanna zone there is little concentration of the P through vegetative cycling and therefore organic phosphate levels are low (Halm and Bampoe-Addo 1972). Table 2 shows that there is not much difference in chemical characteristics between the soil fines and the concretions except for an elevated iron content in the latter.

4.1.2 Phosphorus sorption characteristics of the soils

4.1.2.1 The sorption isotherms

The sorption isotherms for the various soils are presented in figure 3. Generally, sorption continued to increase gradually with increasing equilibrium P concentration but a

Table 2. Some physical and chemical properties of soil fines and ground concretions of the Tingoli / Tolon soil series of northern Ghana.

Soil properties	Soil Fines	Ground Concretions
Clay (%)	5.40	nd
Silt (%)	16.00	nd
Sand (%)	78.60	nd
pH (1 : 2, soil : water)	6.60	6.70
pH (1 : 2, soil : 0.01M $CaCl_2$)	5.70	5.60
Organic carbon (%)	0.70	0.43
Total N (%)	0.09	0.04
Total P (ppm)	171.00	900.00
Organic P (ppm)	71.6	26.20
Available P Olsen-P (ppm)	3.70	4.80
Exchangeable bases (meq / 100g soil)		
K	0.42	0.58
Na	0.07	0.08
Ca	4.12	2.44
Mg	1.12	0.96
C.E.C.	6.12	4.32
Dithionite-citrate extractable Fe and Al (mg / g)		
Fe-d	1.10	199.60
Al-d	0.80	10.20
Ammonium oxalate extractable Fe and Al (mg / g)		
Fe-o	0.58	1.56
Al-o	0.31	0.60
Fe-o/Fe-d	0.52	0.01

nd = not determined

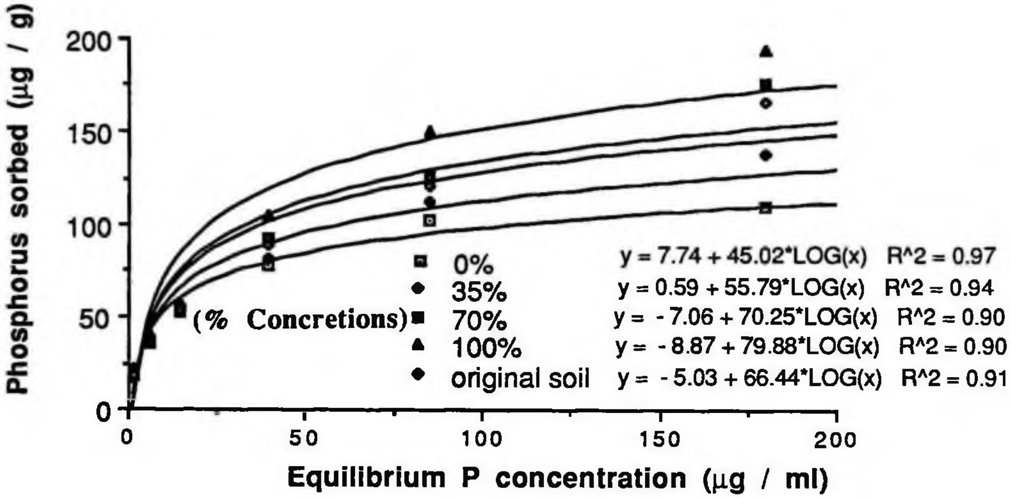

Figure 3. Sorption curves for reconstituted soils containing 0%, 35%, 70% concretions and original soil plotted using log function.

well defined maximum was not attained. This is in conformity with a review by Bache and Williams (1971). The sample containing 0% concretion sorbed the least amount of P while increasing concretion content increased sorption with highest sorption found in the 100% concretion sample. Sorption maxima derived from Langmuir isotherms varied greatly and are shown in table 3. Differences in sorption between samples are small at low solution P levels and it appears the concretions are the main sorbers of P at higher equilibrium P concentrations. Thus the soils which had relatively high amounts of lateritic concretions possess the greatest capacity to sorb P at higher equilibrium concentrations. This seems to be a characteristic of the concretionary soils of northern Ghana, (Tiessen et al. 1987).

Table 3. Sorption maximum, P and its equivalent as KH_2PO_4 applied per kg soil in the pot experiment

Concretions (%)	Sorption maximum (µg / g)	P applied ----- µg / g-----		KH_2PO_4 ---------- µg / g----------	
		P_1	P_2	P_1	P_2
0[†]	110	94	118	0.4129	0.5184
35	133	110	152	0.4832	0.6677
70	175	154	178	0.6765	0.7819
Orig[‡]	166	138	164	0.6062	0.7204

[†] Soil fines (< 0.5mm)

[‡] Orig = Original soil

The sorption maximum of the concretions alone (194 µg P/g) differs from the sorption maxima reported for concretions by previous workers. Juo and Maduakor (1974) obtained a sorption maximum of 120 µg P/g for concretions contained in Gambari soil of Nigeria. The concretions in the Gambari soil had P content of 2000 µg/g. Tiessen et al.(1987) reported a sorption maximum of 1500 µg P/g in concretions that contained 300 µg P/g. The P content of the concretions in this study is 900 µg/g. It appears the sorption capacity of concretions depends on their previous P saturation.

The ability of the concretions to sorb P is related to their high dithionite-citrate extractable iron and aluminium (Fe-d, Al-d) and the ammonium oxalate extractable iron and aluminium (Fe-o and Al -o) contents (Table 2) which were much higher in concretions than in soil fines (Table 2). Taylor and Schwertmann (1974) and Tiessen (1988) obtained a similar result for dithionite-citrate extractable iron oxide in concretions The dithionite-citrate extractable Fe and Al in both soil fines and concretions are much higher than the oxalate extractable levels. This suggests that the iron and aluminium oxides are in the crystalline state especially in the concretions. The crystalline nature of the Fe and Al oxides in the concretions may be due to the advanced weathering process, and also constant exposure to high temperatures prevalent in the semi-arid zone of northern Ghana.

With P fixation, it appears the influence of high levels of Fe-d and Al-d tend to predominate over the amorphous Fe-o and Al-o content. Sanchez (1976) remarked that although amorphous Fe and Al oxides are main fixers of P in soils, when a soil contains much more crystalline Fe and Al than the amorphous forms the former becomes dominant in P fixation. Ahenkora (1968) and Juo and Fox (1977) have shown significant increases in P sorption with increase in crystalline iron oxides. Toreu et al. (1988) obtained a significant correlation between P sorbed and citrate-dithionite extractable iron on soils derived from basalt. Taylor and Schwertmann (1974) studied P association with ferruginous concretions from Australian soils and indicated that in the concretions there was a preferential association of phosphorus with goethite. This preferential association they attributed to differences in surface area of different mineral phases in the concretions.

The sorption maximum of the original soil (166 µg P/g) is very similar to the P sorption maximum value of 152 µg P/g obtained by Mokwunye et al. (1985) in Samaru, a semi-arid zone of Nigeria. On the other hand, Kanabo et al. (1978) reported a low figure of about 90 µg P/g for a similar soil from Nyankpala.

4.1.2.2 Desorption of adsorbed phosphate

The results of the percent adsorbed phosphate released from the soils by successive extractions with 0.01M KCl are presented in Figure 4. The P desorption isotherms indicate generally, a decrease in P release with successive extractions until the fourth extraction when further extractions produced relatively constant small amounts of P. This pattern of P desorption followed that described by Fried and Shapiro (1956) and Manikandan and Sastry (1986). The pattern indicates that the soils have very low content of clay colloids (Daughtrey et al.1972). The percentage of P released from each sample at the first extraction in relation to P sorbed is highest in the sample containing 0% concretion, (67% P released),and lowest in that containing 100% concretions, (37% P released). The high initial P extracted suggests that the soils' surface coverage with P was relatively high and the exchangeable P was loosely held on the soil colloid. By successive extractions, the surface coverage had decreased (Kuo and Lotse 1973) and therefore the desorption had gradually decreased.

The percent P desorbed at the initial extraction was lower in the concretions than in the soil fines but the quantity of P desorbed was about the same in both samples. The relatively low percent P desorbed by the concretions may be due to the phosphorus being occluded by the iron oxide content. Smeck (1985) remarked that it is the iron oxide in soil materials that is responsible for the occlusion of phosphorus. At the end of the eighth extraction the soil fines desorbed 117 µg P/g representing 106% of the total P adsorbed by the soil and the sample containing 100% concretions desorbed 103 µg P/g equivalent to 54% P adsorbed. The rest fall in between. It follows from the results that the concretions

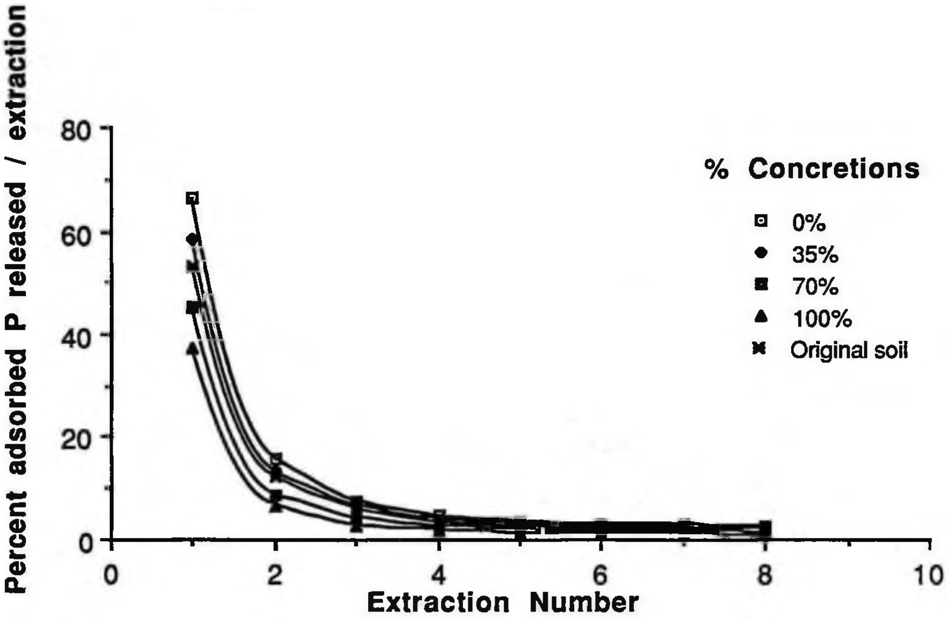

Figure 4. Percent adsorbed P released from the soil after each successive extraction with 0.01 M KCl.

retain phosphorus in the labile pool,as measured by 0.01M KCl extract, equivalent to the labile pool of the soil fines though the rate of P release is different in the two samples (fig 4) and the concretions contained additional P that was not desorbed in the experiment. Phosphorus desorbed by the soil fines was either overestimated or part of the soil's native P was desorbed by the KCl extraction. The slow rate of release of phosphorus by the concretions suggests that they may maintain a low solution P concentration over a long period of time when phosphorus is withdrawn by plants (discussed in the following section). Soil fines with higher rate of P desorption would release P to soil solution at a faster rate but for a shorter duration.

4.2 Greenhouse Studies

4.2.1 Dry matter yield of shoot

In both reconstituted and original soil samples dry matter yield increased significantly over the control when P was applied at both P_1 and P_2 (Figure 5) confirming that the soils which received no P were deficient in phosphorus. Table 4 shows values for Olsen-P and Resin-P for both reconstituted and original soils. Both Olsen and Resin-P are high in the sample containing 0% concretions compared to the other soils. There was generally a decline in dry matter production with repeated cropping up to the third planting. This was followed by a slight increase in growth in the fourth and fifth plantings due to higher planting density and the effect of increase in the basal nutrients added. Thereafter there was a further decline in growth. The basal nutrients were increased to cater for the increase in the plant population.

It is equally significant to note that the $CaCl_2$ added to arrest the fall in pH of the soil due to the continuous addition of $(NH_4)_2SO_4$ as a source of nitrogen has increased the dry matter production in the fifth planting over the fourth. The pH increased from 5.6 to

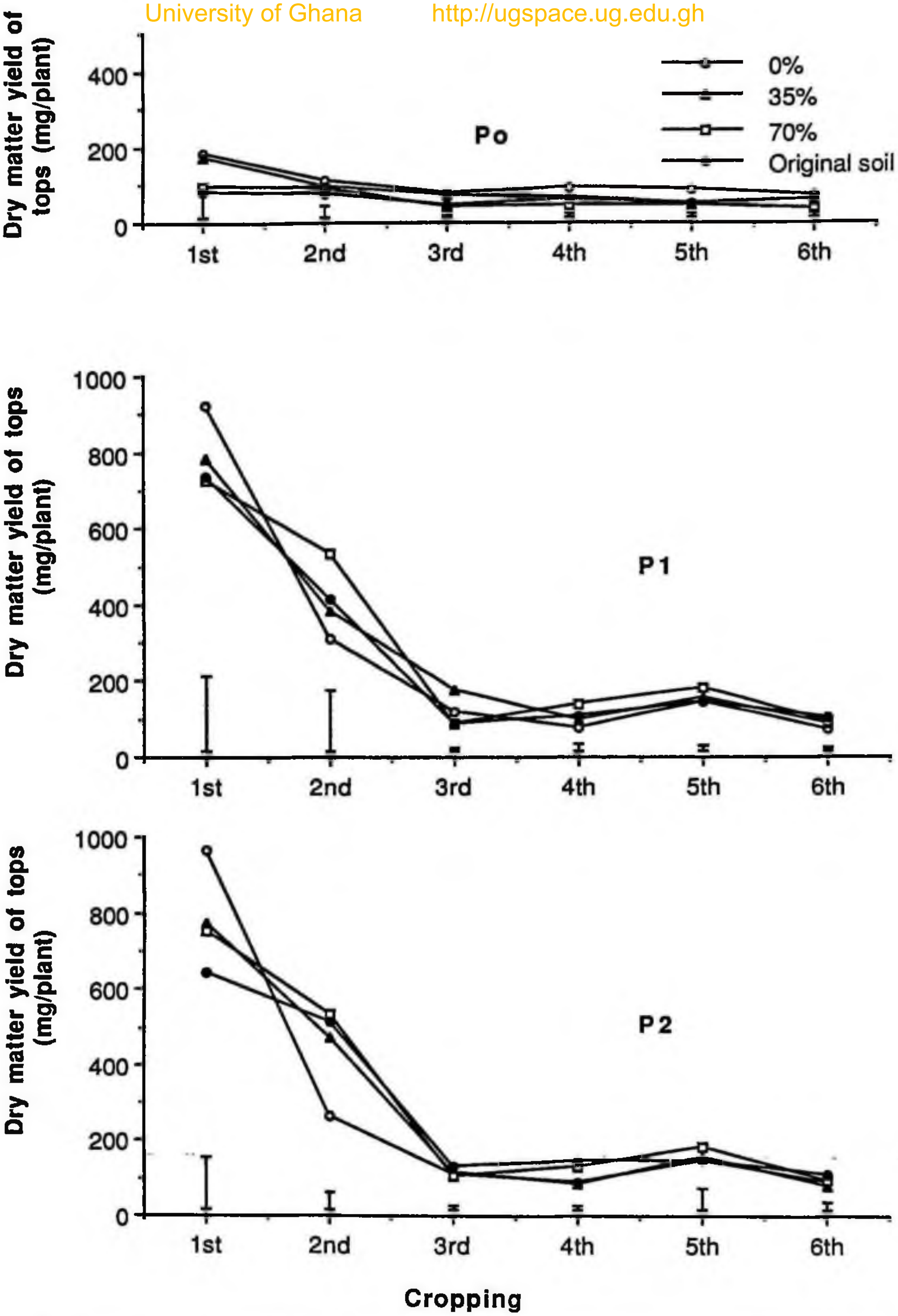

Figure 5. Effect of P on dry matter yield of millet grown on reconstituted soils containing 0, 35, and 70% concretions and original soil (error bars represent LSD at p=0.05).

6.2 after the addition of the calcium chloride.

Table 4 $NaHCO_3$-P (Olsen-P) and Resin-P of both reconstituted and original soils

Concretions (%)	$NaHCO_3$-P (µg/g)	Resin-P (µg/g)
0	3.90	6.53
35	3.00	5.30
70	2.40	3.53
Original soil	2.8	4.10

Figure 5 indicates that, at the first cropping, dry matter yield of shoot was highest in the soil fines compared with the concretionary soils in both unfertilized and P fertilized soils. The high dry matter yield obtained on the soil fines is accompanied by a significantly higher total P uptake from that soil (Figure 6). The results suggest that the P added to the soil fines was held in readily-soluble form (Johnston 1989) and this was readily extracted by the plants at first cropping. This is confirmed by the rate of desorption of P in the soil fines compared to the rest of the soils (Figure 4). The relatively high resin-P content of the soil fines may also contribute to the high dry matter yield in the soil fines (Table 4). In the second cropping dry matter yield of shoot continued to be low at the 0-P treatment. On the fertilized soil samples, dry matter yield was lowest on the soil fines and highest in the 70% concretionary soil sample (Figure 5). This may be due to a higher P release by the 70% concretionary soil sample (Table 5 and Figure 6). Subsequent croppings showed that the concretionary soils gave better yield (Figure 5). This suggests that more phosphorus has been released by the concretionary soils for plant uptake after the first cropping. In all the

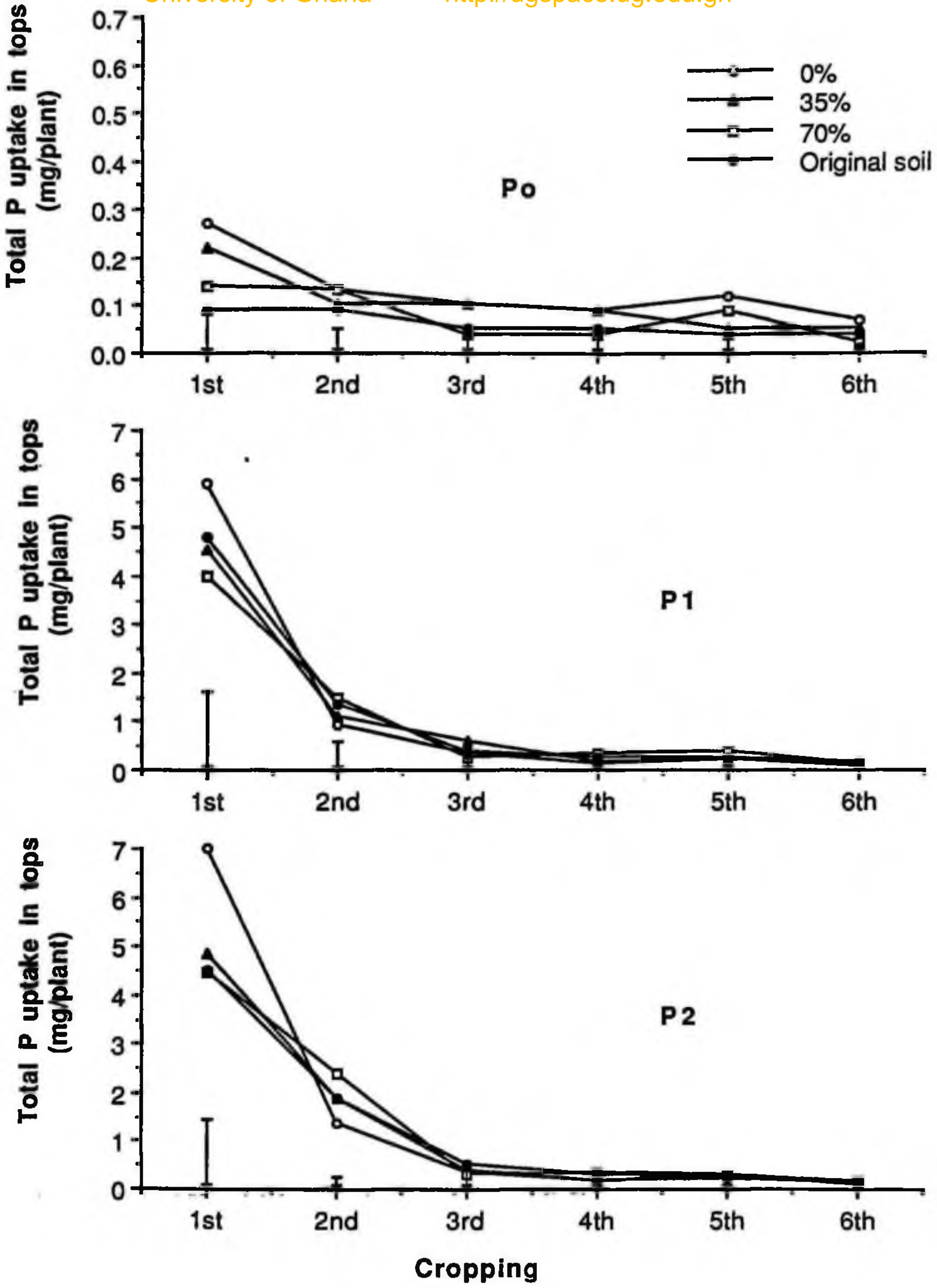

Figure 6. Total P uptake of millet grown on reconstituted soils containing 0, 35, and 70% concretions and original soil (error bars represent LSD at p=0.05).

Table 5. Budget of P added to both reconstituted and original soils.

% Concretions	P in soil mg/pot†	P removed†† by plant shoot mg/pot	P remaining in soil mg/pot	P removed by plant %	Desorbed P %
		1st cropping			1st extraction
0	122.2	56.2	66.0	46.0	67
	153.4	67.1	86.3	43.7	
35	176.0	43.3	132.7	24.6	58
	243.2	46.0	197.2	18.9	
70	308.0	38.2	269.8	12.4	45
	356.0	43.0	313.0	12.1	
Original soil	243.6	43.4	200.2	17.9	53
	289.5	46.9	242.6	16.2	
		2nd cropping			2nd extraction
0	66.0	8.2	57.8	12.4	46
	86.3	12.4	73.9	14.4	
35	132.7	10.0	122.7	7.5	32
	197.2	17.7	179.5	9.0	
70	269.8	13.6	256.2	5.0	16
	313.0	22.5	290.5	7.2	
Original soil	200.2	12.5	187.7	6.2	26
	242.6	17.7	224.9	7.3	
		3rd cropping			3rd extraction
0	57.8	2.2	55.6	3.8	42
	73.9	2.4	71.5	3.2	
35	122.7	4.9	117.8	4.0	24
	179.5	2.7	176.8	1.5	
70	256.2	2.1	254.1	0.8	9
	290.5	3.0	287.5	1.0	
Original soil	187.7	3.2	184.5	1.7	17
	224.9	4.6	220.3	2.0	

table continued on following page.

Table 5, continued.

% Concretions	P in soil mg/pot†	P removed†† by plant shoot mg/pot	P remaining in soil mg/pot	P removed by plant %	Desorbed P %
		4th cropping			4th extraction
0	55.6	0.5	55.2	0.8	44
	71.5	0.9	70.6	1.3	
35	117.8	1.7	116.2	1.4	19
	176.8	1.4	175.5	0.8	
70	254.1	4.7	249.5	1.8	7
	287.5	4.2	283.3	1.5	
Original soil	184.5	3.2	181.4	1.7	11
	220.3	3.7	216.6	1.7	
		5th cropping			5th extraction
0	55.2	1.7	53.8	2.5	59
	70.6	1.5	69.1	2.1	
35	116.2	2.6	113.9	2.2	18
	175.5	3.9	171.6	2.2	
70	249.5	4.2	245.3	1.7	5
	283.3	3.3	280.0	1.2	
Original soil	181.4	3.2	178.2	1.8	10
	216.6	3.2	213.4	1.5	
		6th cropping			6th extraction
0	53.8	1.1	52.7	2.0	35
	69.1	1.8	67.3	2.6	
35	113.9	1.7	112.2	1.4	18
	171.6	1.4	170.2	0.8	
70	245.3	2.0	243.0	0.8	6
	280.0	2.0	278.0	0.7	
Original soil	178.2	2.3	175.9	1.3	12
	213.4	2.4	211.0	1.1	

† shows the two levels of P.
†† P removed in fertilized soil minus P removed in unfertilized soil

six croppings dry matter yields of shoot on the original soil were similar to those obtained on the 70% concretionary soil.

4.2.2 Total dry matter yield of the six croppings and the phosphorus applied

Figure 7 shows that there is a response to P fertilization on all the soils. Mokwunye (1977) and Mokwunye et al. (1985) reported similar results of P response on soils of the Guinea savanna zone of Nigeria. These results are indicative of the low P status of the soils.

At the 0-P treatment dry matter yield was significantly higher in the soil fines than in the concretionary soils. With P fertilization there was no significant difference between dry matter yield at the two rates of P applied on any of the test soils (Fig. 7). It is possible that the rates of P applied were too high to show any significant differences. Again a paired t- test between the cumulative dry matter yields between 0% concretions which received 94 to 118 µg P/ g soil and 70% concretions that received a higher P fertilization of 154 to 178 µg P/ g soil did not show a significant difference in yields either.

4.2.3 The effect of exhaustive cropping and P fertilization on total P uptake

At 0-P level, P uptake on the soils follow the order: 0% concretion = 35% >70% = original soil and generally this pattern did not change with the exhaustive cropping. A possible explanation is that all the soils were deficient in P and were thriving on the little available P left. Phosphorus uptake was significantly higher in the soil fines than in the 70% concretions (figure 6). This may be due to higher P availability (table 4) or better root contact with the particles of the soil fines than in the concretionary soil samples.

At the first planting the total P uptake was relatively high on all the soils at both fertilized levels. This is in conformity with the solution desorption trend which indicates a

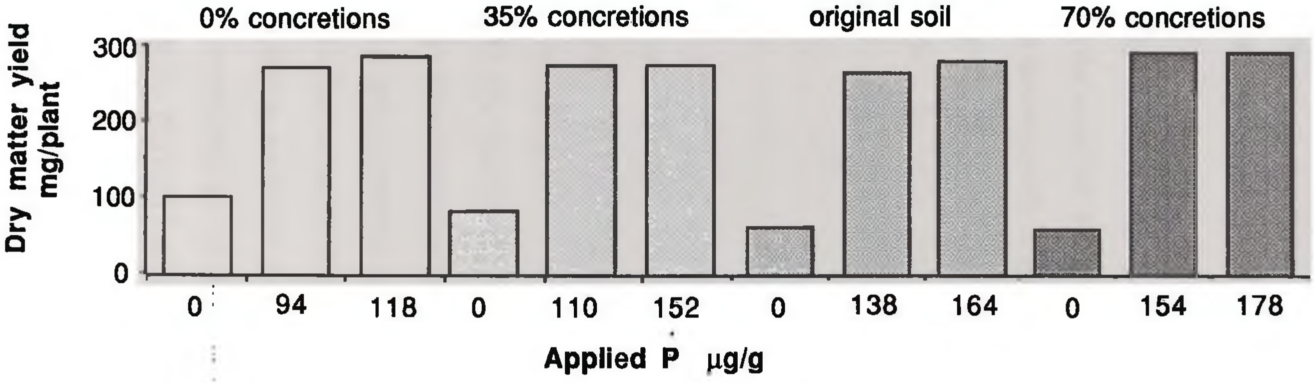

Figure 7. Histogram showing the mean cumulative dry matter yield of millet grown on reconstituted and original soils of the Tingoli / Tolon series of northern Ghana.

high P release from all the soils at the first extraction. Though the solution desorption predicted high P release at the first extraction the quantities of P desorbed were much higher than the amount of P removed by the plants in all the soil samples. In the soil fines the percent P desorbed by the 0.01M KCl extraction was 67% of that applied and P removed by the plants on the same soil was 43 to 46%. On the 70% concretionary soil sample the KCl extraction desorbed 45% of phosphorus applied and the plants removed 12% (Table 5). This means that at the high P saturation levels desorbable P exceeded plant demand, and the 0.01M KCl desorption overestimated the quantity of P and thus not representative of the plant P uptake. It is also possible that higher P released by the 0.01M KCl suspension may be due to disruption of aggregates due to vigorous shaking and the consequent release of more phosphorus into the solution.

Phosphorus uptake was highest in the soil fines at the first cropping and lowest in the concretionary soils on the fertilized soil samples, a trend which follows that of the dry matter yield of shoot (Figure 5). At the second cropping P uptake was highest in the 70% concretions and lowest in the soil fines. P uptake in the original soil was again close to that of the sample containing the 70% concretions. The sharp fall in P uptake in the soil fines at the fertilized levels could be because it received the lowest rate of P application (94 and 118 µg/g) and also because of an earlier exhaustion of P indicating that the buffering capacity of the soil fines is weak. In other words the ability of the soil fines to replenish the soil solution P when it diminishes as a result of plant withdrawal is low. Again percent P desorbed by KCl extraction was far in excess of the actual quantities of P removed by the plants in all the soils (Table 5). The high P uptake in the concretionary soils at the second cropping suggests that there was higher amount of phosphorus released by the concretionary soils during that period of cropping. Further croppings showed that P uptake continued to be higher in the fertilized concretionary soils than in the soil fines.

This trend may be due to the fact that the concretionary soils have a labile P pool equivalent to the soil fines but the soil fines tend to release P faster than the former.

There was a general increase in P uptake during the fifth cropping probably due to increased application of N and K and also to calcium.

4.2.4 Budget of phosphorus addition and plant uptake

Table 5 shows a budget of P added to the soil, P absorbed by the crop and the amount of phosphorus left in the soil. In the 0% concretions 122.2 and 153.4 mg P / pot were applied and at the end of the first cropping 56.2 and 67.1 mg P / pot were removed by the millet crop leaving 66.0 and 86.3 mg P / pot. The results show that when about 1.6 times the amount of P was added to the 70% concretionary soil sample only 38.2 and 43.0 mg P / pot were absorbed by the first crop. Though a higher P level was applied to the 70% concretionary soil only a small proportion had been made available to the crop signifying that the phosphorus had been tenaciously held by the concretions. This confirms the sorbing nature of the concretions. At the end of the first cropping the order of P removed by the plants grown on the soils was: 0% > 35% > original soil > 70% concretions.

The second and the third cropping followed the same pattern as the first though with gradual decrease in rate of P removal in all the soils by the millet crop, a pattern which agreed with the solution desorption isotherms. There was a slight increase in P uptake at the fourth cropping in the 70% concretionary soil possibly due to higher planting density.

At the end of the sixth cropping the total quantities of P removed by the crop in the soil fines were 69.9 and 86.1 mg / pot representing 56.1% to 57.2% of the applied P, and in the sample containing 70% concretions were 64.8 and 78.0 mg / pot, (21.0% to 21.9%). From these results it can be inferred that a large proportion of the phosphorus applied to the concretionary soils was not available to the crop at the end of the entire cropping period, but the differences in P released between the soil fines and the concretionary soils had narrowed with successive croppings.

At the end of the exhaustive cropping yields were low but between 43 and 80% of P was left in the soil (Table 6). It is possible that a greater proportion of the P left in the soil was in forms not readily available to the crop although the 0.01M KCl extraction predicted a higher P release in the soils. Middleton (1960) reported that over 90% of phosphorus applied either as superphosphate or rock phosphate was converted into not readily available forms to plants in some soils under rubber. Chemical extraction may remove forms of phosphorus that may not necessarily be available to plants (Muriuki and Barber 1983) and as stated by Olsen and Khasawneh (1980) only the plant can measure the amount of P that is available to it.

4.2.5 Percent concretions in soils and residual effect of the applied phosphorus

Table 6 indicates that there is no significant difference in cumulative total P uptake on all the soils fertilized at P_1 level. This is because although the concretions have high sorption capacity they do release about the same quantity of P as the soil fines. This was shown by the solution desorption data. At the P_2 level cumulative total P uptake in the 35% and 70% concretionary soil samples was lower than uptake in the soil fines. However, table 6 shows that when P uptake after the first cropping is considered according to Fixen and Ludwick's (1982) method, the 70% concretionary soil has released more phosphorus to the crop than the soil fines. Percent total P taken up by the crop from the original soil falls between samples containing 35% and 70% concretions (Table 6). The concretions seem to have the capacity to release P for crop uptake but at a slow rate. It is possible that P sorbed by the concretions is a potential reservoir of available phosphorus to crops as suggested by Tiessen et al. (1987).

Table 6. Summary of P budget in both reconstituted and original soils of Tingoli /Tolon series.

Concretion (%)	Total P taken up mg/pot	% Total P taken up	% P remaining in soil	Residual P† mg/pot
0	69.9	57.2	42.8	13.4
	86.1	56.1	43.9	18.3
35	64.6	36.7	63.3	20.8
	73.1	30.1	69.9	27.0
70	64.8	21.0	79.0	26.6
	78.0	21.9	78.1	35.0
Original soil	67.8	27.8	72.2	24.3
	78.6	27.2	72.8	31.2

†P uptake after the first cropping.

CHAPTER FIVE

5 SUMMARY AND CONCLUSION

Phosphorus status of soils of the semi-arid zone of northern Ghana is low. The low P status has been attributed to the advanced weathering process. Some of the soils of the region contain large quantities of lateritic concretions.

A study into P sorption by samples of a typical concretionary soil that has been reconstituted to form different levels of concretions showed that the concretions are the main sorbers of phosphorus in the soil. Crop production in semi-arid northern Ghana is affected by unreliable and scarce rainfall. Concretions in some of the soils constitute an additional limitation to agriculture in the area because they act as an effective sink for added P in competition with plants.

Desorption of added phosphate from soils of different levels of concretions using 0.01M KCl showed a lower percentage of P release from soils with concretions than in the soil fines but at the end of the extraction the amounts of P released from both the former and latter were similar. The reconstituted concretionary soils, however, contained an additional P that was not desorbed in the experiment. The fact that these concretionary samples released the same quantity of P as the soil fines suggests that though the concretions are sorbers of phosphorus they retain a " labile P pool " similar to the soil fines except that the rate of P release is slower in the former.

A test crop grown on the fertilized and unfertilized samples of both reconstituted and original soils indicated that the soils responded to P fertilization. On the fertilized soils, the sample containing 0% concretions gave the highest dry matter yield of shoot at first cropping in accordance with the results of solution desorption. Dry matter yield dropped in all the soils at the second cropping but the soil fines recorded the lowest yield indicating an earlier exhaustion of P. Dry matter yield continued to be highest on the concretionary soils after the second cropping, an indication that there had been a higher P release in the concretionary soils than in the soil fines.

Results of both desorption studies and pot experiment suggest that the concretionary samples do release part of the sorbed P but the major difference between them and the soil fines is that they are slower releasers of P. In general the original soil containing about 60% concretions behaved similarly to the sample containing 70% concretions. The high percentage of additional P in the concretions not desorbed in both experiments is an indication of accumulation of a large nonlabile P pool in the concretions that may be tapped when the labile pool is depleted. However, the slow release of P by the concretions suggest that the phosphorus constituting the nonlabile pool must be tenaciously held and difficult to desorb and therefore cannot be relied upon for adequate replenishment of the labile pool.

In order to increase agricultural production in soils containing large quantities of lateritic concretions in the northern region of Ghana the use of suitable cropping systems to avoid the risk of crop failure and eventual introduction of residue management as suggested by Tiessen (1988) will have to be considered. The results suggest that for concretionary soils a combination of P fertilization and fallow management may be desirable.

Future research considerations

Concretions contain a high quantity of sesquioxides which, from the study, are mainly dithionite-citrate extractable Fe and Al which are usually in the crystalline state (Parfitt and Childs 1988) yet they are highly sorptive. Perhaps the oxalate extraction was not effective enough to remove active Fe and Al oxides in the concretions. Future studies may have to look into the possibility of using a stronger oxalate solution as suggested by Parfitt (1989) for soils with high amounts of concretions.

The solution desorption of sorbed phosphorus was found to be unrepresentative of plant P uptake and it is suggested here that future desorption studies should employ anion exchange resins or better still a cation-exchange resin and anion-exchange resin mixture which has been found to correlate very well with plant P uptake (Dalal 1985).

Pot trials at lower P rates will be needed to recommend phosphorus fertilizer rates of the concretionary soil. Fertilizer P in the form of triple superphosphate as often used by farmers in Ghana is expensive so the need to use cheaper forms of P by the local farmers is highly anticipated. Research trials with slow release rock phosphate on the concretionary soil of semi-arid northern Ghana will be relevant. Field trials will be necessary to ascertain the reversibility of P sorbed by the concretions since results of pot trials may differ from field experiments owing to the controlled conditions under which pot experiments are conducted.

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