INFLUENCE OF SOIL PROPERTIES ON THE DISSOLUTION OF MINJINGU PHOSPHATE ROCK

FOR REFERENCE
ONLY

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ABSTRACT

Phosphorus is mostly supplied in the form of water soluble fertilisers which are very expensive. Thus resource poor farmers can not afford it. The price of Minjingu phosphate rock (MPR) is relatively lower and may substitute water soluble P fertilisers if found to be agronomically comparable to the traditional P sources. A study was conducted to investigate the extent of M'PR dissolution and extractability of P after dissolution of MPR and to determine soil factors controlling the dissolution of MPR and subsequent levels of extractable P in eleven Tanzanian soils. Also the adsorption characteristics of the experimental soils were determined.

P adsorption maxima of the experimental soils ranged from 375.4 to 4110.2 mg P/kg and were directly influenced by Al_2O_3. The amounts of P adsorbed at 0.2 μg P/ml ranged from 22 to 710 μg P/g. The soil with the highest P adsorption maximum had the highest P adsorbed at 0.2 μg P/ml. On the other hand, soils with substantial amount of P in equilibrium solution at zero added P had low P requirement. Some of the soils with high P adsorption maxima had low P requirement. The extent of MPR dissolution in the eleven soils tested ranged from 34 - 97 % of the applied P after 70 day (d) of incubation. High percentage (83%) of the variation in MPR dissolution was accounted for by three soil properties namely percent Ca saturation, OC and P retention capacity. Bray 1 P in the experimental soils ranged from 7.3 to 71.0 % of the dissolved P after 56 days of incubation, with an average of 29.6 %

suggesting a high degree of fixation. Bray 1 P was also significantly related to exchangeable Al, Al saturation, soil pH, soil pH buffering capacity and OC. However none of these soil properties accounted for > 50 % of the variation in Bray 1 P. This implies that none of the independent variables tested adequately predicted the dependent variable.

Results from this study indicate that MPR has high solubility in acid soils of pH ≤ 5.8 and should thus be evaluated for direct application under field conditions.

DECLARATION

I, John Mwakisimba, do hereby declare to the Senate of Sokoine University of Agriculture that the work presented in this dissertation is my own original work and has not been submitted for degree award in any other University.

Signature ------------------

Date 21.9.1999 ------------------------

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DEDICATION

To the late my father Masika Mwaipopo and my mother Fainess Kijabilwa who realised that, the best inheritance I could be given was to be sent to school.

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LIST OF ABBREVIATIONS AND SYMBOLS

*	significant
<	less than
>	greater than
%	percent
α	alfa
β	beta
μ	10^{-6}
AAS	Atomic absorption spectrophotometer
Al sat	Aluminium saturation
Al	Aluminium
Al_2O_3	Aluminium oxide
AOAC	Association of Official Analytical Chemists
b	adsorption maxima
C	clay
Ca -ER	Calcium exchange resin
Ca sat	Calcium saturation
Ca	Calcium
Ca- Ec	Calcium exchange capacity
$CaCl_2$	Calcium chloride

CEC	cation exchange capacity
CL	clay loam
cm	centimetre
d	day
DAP	Diammonium phosphate
DCB	Dithionite- citrate- bicarbonate
dm	decimeter
e.t.c	and so on
eq	equation
et al.	and others
Fe	iron
Fe_2O_3	Ferric oxide
Fig	figure
g	gramme
GPR	Gafsa phosphate rock
h	hour
H	hydrogen
ha	hectare
HCl	Hydrochloric acid
$HClO_4$	Perchloric acid
HNO_3	Nitric acid
HPR	Huila phosphate rock

i.e	that is
IITA	International Institute for Tropical Agriculture
JOPR	Jordan phosphate rock
JPR	Jbabua phosphate rock
k	constant related to bonding energy
KCl	Potassium chloride
kg	kilogramme
KH_2PO_4	Potassium phosphate
KOH	Potassium hydroxide
M	molar
MAP	Monoammonium phosphate
meq	milliequivalent
mg/kg	milligram per kilogramme
mg	milligramme
Mg	Magnesium
Mlingano(L)	Mlingano lower slope of the catenary sequence
Mlingano(U)	Mlingano upper slope of the catenary sequence
mm	millimetre
mmol	millimole
MPR	Minjingu phosphate rock
NaOH	Sodium hydroxide
N	Nitrogen

N	Normality
Na	Sodium
NCPR	North Carolina phosphate rock
Ng\`anda ^{1}	Soil sample from Mgeyekwa\`s farm one, Njombe district
Ng\`anda ^{2}	Soil sample from Mgeyekwa\`s farm two, Njombe district
NH_4F	Ammonium fluoride
ns	non significant
OC	organic carbon
P	phosphorus
pH	Negative logarithm of hydrogen ion concentration
PPR	Pesca phosphate rock
PR	phosphate rock
r	correlation coefficient
R^2	coefficient of determination
rpm	Revolution per minute
SAS	Statistical Analysis System
SC	sand clay
SCL	sand clay loam
SL	sand loam
SPR	Sechura phosphate rock
SSP	single superphosphate
SUA	Sokoine University of Agriculture

TSP	Triple superphosphate
UPR	Udaipur phosphate rock
USA	United State of America
USDA	United State Department of Agriculture
X	independent variable
Y	dependent variable

CHAPTER ONE

INTRODUCTION

Phosphorus deficiency is very common in highly weathered soils such as Oxisols and Ultisols and slightly weathered soils such as Andepts and Vertisols (Sanchez, 1976). The highly weathered soils which dominate much of the landscape of the humid tropics require relatively large inputs of P to optimize crop production.

Mnkeni (1988) concluded that, P was deficient in most areas where common grain crops are grown in Tanzania. He further concluded that the optimum rate of application was in the range of 20 to 40 kg P ha^{-1}, with 40 kg ha^{-1} being recommended in areas with long growing seasons and reliable rainfall. Phosphorus is mostly supplied in the form of water soluble fertilisers such as single superphosphate (SSP), triple superphosphate (TSP) and mono- and di-ammonium phosphates (MAP and DAP).

Resource poor farmers (who constitute the majority) do not afford to supply P to their crops, because the available fertiliser sources are expensive. However, they would benefit greatly by using less expensive alternative sources of P such as phosphate rocks (PR). Due to this, researchers in recent years have been searching for alternative means of supplying P for crop production in the world at large

(Tanzania inclusive).

In Tanzania mineral explorations have disclosed the presence of PR deposits in various parts of the country such as Minjingu located at Minjingu village near Lake Manyara in Arusha region (Harris, 1981) and Panda hill, Sukumawera, Songwe scarp, Mbalizi and Ngualla carbonatites all located in Mbeya region. Also there are small occurrences at Zizi near Kisaki in Morogoro region, Chali hills in Dodoma (Patel, 1975) and Buchuba and Ichwandini in Muleba district Kagera region (Mkamba, 1988).

Among these deposits Minjingu phosphate rock (MPR) has been intensively studied, while Panda hill phosphate rock has received less attention than MPR, but much more than the other PRs mentioned above. Minjingu phosphate rock is of sedimentary origin with total reserves estimated to be 10 million metric tonnes (Hammond *et al.*, 1986).

The Minjingu PR has been reported by several workers to have potential of releasing P in acidic soils. Thus it can be beneficial to crop production if applied both by direct application and as a partially acidulated product. Hence MPR can be used as an alternative means of supplying P for crop production.

However for any fertiliser material to be effective when applied in soil it should undergo dissolution. There are a number of factors that interactively influence the rate of chemical breakdown of apatite lattice at the rock surface. The susceptibility of apatite to proton attack is one factor reflected by the PR solubility (Lehr *et al.*, 1959; Anderson *et al.*, 1985). Because dissolution is a surface phenomenon particle size and specific surface area are also involved in the process (Khasawneh and Doll, 1978; Hammond *et al.*, 1986). Transport of reactant and product ions to and away from PR particle surface is another factor. This is a soil controlled process influencing the apparent rate of diffusion of specific ions (Anderson *et al.*, 1985). Properties of the PR itself, properties of soils and plants determine how well a water insoluble P source e.g PR will perform relative to convetional soluble fertilisers (Hammond *et al.*, 1986).

Many researchers in East Africa (Ikerra, 1986; Kimambo *et al.*, 1988; Mowo and Gama, 1988; Kaihura *et al.*, 1988; Ngatunga *et al.*, 1988; Semoka, 1988; Meda and Kulaya, 1988; Okalebo *et al.*, 1991; Budotela, 1995; Kimbi *et al.*, 1996; Tusekelege, 1997; Kitua, 1997) have reported results on the agronomic effectiveness of MPR in different soils. Generally, in acid soils low in P the performance of MPR applied to soil either directly or as a partially acidulated PR was more or less similar to that of convetional soluble fertilisers. However the agronomic effectiveness of PRs when used as fertiliser material is supported by the understanding of the physical and chemical processes that take place when the PR is incorporated into soils. These are reflected by its dissolution.

Dissolution of PR in soils is a necessary prerequisite for the P from PR to become available to plants. There are several soil factors which influence PR dissolution namely, soil pH, exchangeable Ca, soil organic matter content, levels of soil P, P retention capacity, soil pH buffering capacity, soil clay content, moisture content of soil, etc (Khasawneh and Doll, 1978; Kanabo and Gilkes, 1988; Wright *et al.*, 1992; Syers *et al.*, 1992). Mnkeni *et al.*(1992) reported that low pH and low exchangeable Ca enhanced MPR dissolution.

However, there is inadequate information concerning the influence of soil properties in Tanzanian soils on the dissolution of MPR. Previous studies did not evaluate the effectiveness of MPR under widely different agroecological zones, and only a few soil properties have been addressed in depth for some soils. Thus the knowledge of which soil properties most influence the dissolution of MPR is lacking.

Hence this study was carried out to investigate the influence of soil properties on the dissolution of MPR so as to provide guidelines for predicting conditions where Minjingu PR application would be successful. Therefore, the objectives of the study were as follows:

(i) To determine the extent of Minjingu PR dissolution in selected soils of Tanzania.

(ii) To relate the extent of MPR dissolution to soil properties.

(iii) To identify soil properties that control P availability to plants after dissolution.

CHAPTER TWO

LITERATURE REVIEW

2.1 Factors affecting PR dissolution

Dissolution of PRs is an important process which determines the effectiveness of PRs as fertiliser materials. It depends on different factors such as PR properties, plant factors and soil properties.

2.1.1 Properties of PR

The PR properties which influence dissolution include type of phosphate rock, mineralogical composition of the PR and particles size, which normally lead to variation of P released from different PRs.

2.1.1.2 Type of phosphate rock

There are three types of rocks, namely sedimentary, igneous and metamorphic (Khasawneh and Doll, 1978; Hammond *et al.*, 1986). Phosphate rocks are found in all these types of rocks.

Among these rocks, there is a great variation in the structural build up and chemistry. This leads to variation in the rate of dissolution. The igneous and metamorphic rocks have much lower solubility than the sedimentary rocks. This is because igneous and metamorphic rocks are coarsely crystalline and do not possess internal surfaces. Sedimentary rocks, on the other hand, are microcrystalline in nature and consist of fairly open, loosely consolidated aggregates of microcrystals with a relatively large specific surface area (Khasawneh and Doll, 1978). Thus the former release less P than the latter.

2.1.1.3 Mineralogical composition

Mineralogical composition of PR influences the dissolution of PR. PRs with high CO_3^{2-} and F^- substitution for PO_4^{3-} in their apatite crystal lattice have high rates of solubilization. Substitution of CO_4^{3-} for PO_4^{3-} decreases the crystal size and increases the specific surface area of the apatite aggregates. This results in increasing rate of dissolution (MacClellan and Lehr, 1969; Khasawneh and Doll, 1978; Marwaha and Kanwar, 1981).

2.1.1.4 Particle size

The particle size of PR has an influence on the dissolution of PRs. This is mediated by the surface area of the dissolving particle. Khasawneh and Doll (1978) and

Hammond *et al.* (1986) reported that the dissolution of PR increases with increase in fineness, but the degree of improvement rarely justify grinding PRs to sizes less than 100 mesh (150 µm). Economically feasible grinding has been reported to be that from which at least 80% of the material passes through 100 mesh screen (Hammond *et al.*, 1986).

2.1.2 Plant factors

Plants promote PR dissolution by different means. Sale and Mokwunye (1993) argued that actively growing plant roots stimulate PR dissolution by acidification of the rhizosphere. Thus H^+ resulting from the excess uptake of cations over anions acidifies the rhizosphere resulting in an increase of dissolution.

Plants can also promote dissolution of PR by producing high root density. Plants such as ryegrass, rape, cabbage, clover, wheat, barley and lettuce are efficient users of PR (Khasawneh and Doll, 1978). This is attributed to high rooting density. High rooting density stimulate dissolution of PR due to the lowering of concentration of Ca^{2+} and $H_2PO_4^-$ in the solution surrounding the surfaces of PR particles.

The difference in the promotion of PR dissolution by plant is caused by the demand pattern of Ca and P by plants (Khasawneh and Doll, 1978). Plants with high Ca and P demand will promote high PR dissolution and vice versa. This is attributed to the amount of Ca and P remaining in the soil solution after plant uptake (Khasawneh and Doll, 1978; Sale and Mokwunye, 1993).

2.1.3 Soil factors influencing PR dissolution

A number of soil factors that influence PR dissolution have been identified. These include soil pH, exchangeable Al, exchangeable Ca, soil P levels, soil pH buffering capacity, clay content of the soil, P fixing capacity, soil moisture, texture and soil organic matter (Khasawneh and Doll, 1978; Kanabo and Gilkes, 1988; Wright *et al.*, 1992; Syers *et al.*, 1992).

Khasawneh and Doll (1978) and Hammond *et al.* (1986) reported that among the list of soil factors that influence PR dissolution three factors namely soil pH, soil P levels and Ca in the soil, were the most dominant. Their role on PR dissolution is based on the following equation:

$Ca_{10}(PO_4)_6F_2 + 12H^+$--------------->$10\ Ca^{2+} + 6H_2PO_4^- + 2F^-$ ----(1).

From the law of mass action, the dissolution of PR in the soil will be favoured by low soil pH, low exchangeable Ca and low P concentration.

Combinations and interactions of soil factors have also been reported to influence PR dissolution. Some of the soil factors are reviewed hereunder.

2.1.3.1 Soil pH buffering capacity

Low soil pH with high pH buffering capacity and high rate of acid generation all contribute to enhanced PR dissolution (Sale and Mokwunye, 1993). This is governed by the law of mass action (eq. 1 pp. 9).

Soil pH is among the important soil factors which influence PR dissolution. The indicator is the supply of H^+ for dissolution reaction of apatite (eq. 1 pp. 9). Kanabo and Gilkes (1987) and Rajan *et al.* (1991) found that the concentration of H^+ in the soil solution is among the key factors that control PR dissolution in acid soils. Joos and Black (1955) reported that more P was released from PR in a soil with pH 4.6 and 5.6 than at pH 6.6. While the available P was reported to be higher at pH 5.6 than at pH 4.6. Shinde *et al.* (1978) found that soils with low pH caused greater dissolution of both North Carolina phosphate rock (NCPR) and Gafsa phosphate rock (GPR). The dissolution of North Carolina decreased from 41% at pH 5.4 to 30% at pH 5.9 and 5% at pH 6.4. While the dissolution of Gafsa PR decreased from 71% at pH 5.4, to 57% at pH 5.9 and 13% at pH 6.4. Gafsa PR (GPR) gave higher solubility than North Carolina PR (NCPR) at all pH values. Chaundhary and Mishra (1980) reported that more P was released from soils of pH below 6 than those of above 6 when Mussoorie, Jhabua, Kasiptatham, Udaipar (UPR) and Jordan (JOPR) PRs were incubated with the soils. pH alone accounted for 70.6% of the P released from PRs. Robinson and Syers (1990) reported the dissolution of GPR to be 60%

at 4.5 but decreased to 30% at pH 6.1 after 44 d of incubation. Wright *et al.* (1992) assessed the dissolution of NCPR in 32 soil with pH values ranging from 3.38 to 6.61. After 30 d of incubation they found that the extent of dissolution ranged from 2.8 - 71.5%. Anderson and Sale (1993) reported a decrease in the dissolution of NCPR with increase in pH from 4.8 to 6.3. The extent of dissolution decreased from 73 to 57.5%, respectively, after 194 d of incubation. When 1 mg P of PR/g soil was applied about 8% of P was dissolved, while when 0.1 mg P of PR/g soil was applied about 30% was dissolved (Hinsiger and Gilkes 1997). This indicates that the proportion of P dissolved relative to the amount applied is higher at low rates of PR application than at high rates of application.

However, Anderson *et al.* (1985) found that pH did not have a consistent influence on P release from the PRs they studied. This was in contrast with many reports in the literature. Thus they carried out a specific study on the influence of pH on PR dissolution. The soil pH was adjusted to 5.5 and 6.5 in Superior and Vacaria soil respectively. The NCPR, Sechura PR (SPR), Huila PR (HPR) and Pesca PR (PPR) released more P in soil at pH 5.5 than 6.5.

The capacity of a soil to supply H^+ is called the pH buffering capacity. A soil with low pH and high H^+ supply power tends to have high pH buffering capacity. Kanabo and Gilkes (1988) argued that if the initial pH of soils is the same, the difference in PR dissolution in such soils will be due to other factors such as soil pH buffering capacity. Kanabo and Gilkes (1988) and Sale and Mokwunye (1993) reported that PR dissolution increased with increase in soil pH buffering capacity. Syers *et al.* (1992) found that soil pH buffering capacities of 84.1, 24.6, 18.8, 17.2, 16.8, and 11.2 μmol OH^- $g.^{-1}$ resulted in GPR dissolutions of 350, 300, 200, 200, 155 and 100 mg P/kg, respectively. Thus, the dissolution of GPR increased with increase in soil pH buffering capacity. Wrights *et al.* (1992) found that dissolution of NCPR was high in soils with high soil pH buffering capacity. The range of titratable acidity was 17.4 to 137 μmol OH^- $g.^{-1}$

Anderson *et al.* (1985) stated that the importance of soil pH buffering capacity in controlling P release from the Huila PR was nearly twice that of any other parameter but it was only one half as important as P buffer power in P release from Pesca PR. While Kanabo and Gilkes (1988) reported that soil pH buffering capacity explained about 87 - 98% of the variation in NCPR dissolution.

2.1.3.2 Soil Calcium

Calcium concentration in the soil is among the important soil factors influencing PR dissolution. The extent of dissolution depends on the levels of Ca in the soil solution and the Ca sink of the soil.

Many workers (Henryk *et al.*, 1962; Khasawneh and Doll, 1978; Robinson and Syers, 1990; Robinson and Syers, 1991; Mnkeni *et al.*, 1992 and Sale and Mokwunye, 1993) have reported that low calcium concentration in the soil solution enhances PR dissolution. This is due to the law of mass action where low Ca in the soil solution favours release of P from PR. While poor P dissolution could be caused by the presence of high Ca concentration or free $CaCO_3$ in the soil. This has been described as being due to calcium "common ion" effect whereby high Ca levels in the soil solution depress dissolution of calcium from PR (Khasawneh and Doll, 1978). By using 30 different soils Mackay *et al.* (1986) found that the dissolution of SPR as measured by 0.5M NaOH increased as the exchangeable Ca decreased. Robinson and Syers (1991) reported that dissolution of GPR decreased with increase in exchangeable Ca.

Robinson and Syers (1991) further reported that when Ca-unoccupied sites were increased by adding a Ca exchange resin (Ca ER), the dissolution of GPR increased from 34.1 to 66.8 mmol/kg after 40d of incubation. Robinson and Syers, (1990) singled out a sink for Ca as the most important factor influencing the dissolution of Gafsa PR.

2.1.3.3 Soil P

Soil levels of soluble P play a great role in PR dissolution. Soil P is commonly expressed by the activity of $H_2PO_4^-$ or by the phosphate potential (Khasawneh and Doll, 1978). To ensure PR dissolution the soil should be low in P. If the soil is saturated with respect to a particular apatite the phosphate rock will not dissolve. Thus a number of workers have reported that for high PR dissolution, a soil in question should be low in $H_2PO_4^-$ (phosphate ions) (Peaslee *et al.*, 1962; Shinde *et al.*, 1978; Sale and Mokwunye, 1993).

It is generally accepted that high PR dissolution is limited to soils with low to medium phosphate ions while low dissolution occurs in soils with medium to high P status (Amberger, 1978).

P concentration of < 0.03 mmol dm^{-3} in soil is ranked very low and the extent of GPR dissolution in these soils was high (Robinson and Syers, 1991). Syers *et al.* (1992) found that as Olsen extractable P in soils increased in the order of 1.9, 3.5, 5.0 to 5.1 P mg /kg the dissolution of GPR decreased in the order of 71%, 38%, 22% and 54%, respectively. A sink for $H_2PO_4^-$ similarly favours PR dissolution (Khasawneh and Doll, 1978).

2.1.3.4 Soil constituents

Soil constituents of interest in the study were exchangeable Al and free oxides of Al and Fe. In acid soils dissolution of PR is favoured by high concentrations of Al and Fe and their oxides. When phosphate ion is considered as an example the following reactions may take place:

$H_2PO_4^- + 2OH^- + Al^{3+} \text{--->} Al(OH)_2H_2PO_4$ ---------------------- (2)

$H_2PO_4^- + 2OH^- + Fe^{3+} \text{---->} Fe(OH)_2H_2PO_4$ ------------------------------------ (3)

These reactions may also occur with oxides of Fe and Al (Chu *et al.*, 1962; Chaudhary and Mishra, 1980).

In soils rich in Al and Fe there is high dissolution of PRs (Chu *et al.*, 1962; Shinde *et al.*, 1978; Chien, *et al.*, 1980). This is attributed to removal of $H_2PO_4^-$ {eq (2) and (3)} dissolved from PR by Fe and Al and thus causing greater dissolution of PRs until the Al and Fe and their oxides are saturated.

Sharma and Shangrai (1993) reported that P released from UPR, Mussorie PR and Purulia PR increased with an increase in the soil exchangeable Fe and Al. Wright *et al.* (1992) found that exchangeable Al was the single soil property that was most closely related to PR dissolution with a correlation coefficient (r) value of 0.82. They attributed high correlations to the hydrolysis of Al^{3+} and hydroxyl species resulting in the release of H^+ which in turn stimulated PR dissolution.

However, Wright *et al.* (1992) found no significant relationship between the extent of dissolution of NCPR and free iron oxide in soils. Interestingly, free iron oxide was significantly and negatively related to extractable P (r = -0.34) implying that as free iron oxide increased extractable P decreased.

2.1.3.5 P retention capacity of soils

Phosphorus sorption capacity of soils is among the soil factors which influence PR dissolution. It is related to other soil factors which influence sorption such as: clay content, CEC, OC, Fe-oxides and exchangeable Al.

P adsorption is related to the specific surface area and reactivity of Fe and Al oxides than their total contents (Hsu, 1964; Carreira and Lajtha, 1997). Ghosh and Sarkar (1997) found that variations in clay content, CEC and OC are responsible for variations in the extent of adsorption of added P. They further reported that adsorption of added P was higher in soil with OC content of 2 g /kg, where about 76% of the applied P was adsorbed than in soil with OC content of 10.0 g/kg where about 46.7% of the applied was adsorbed.

Biswas and Tomar (1997) reported that the amount of added P sorbed varied with clay content, nature of clay, free oxide and hydroxides of Fe and exchangeable Al^{3+}. Clay content was the most important factor influencing the amount of sorbed P (Singh and Gilkes, 1991). Yuan and Lavkalich (1994) reported that in acid soils, the oxides, hydroxides and oxyhydroxides of Fe and Al do influence phosphate adsorption.

The dissolution of PR is also influenced by the P sorption capacity. Dissolution of PRs has been reported by many workers to increase with increase in soil P sorption capacity (Chu *et al.*, 1962; Chien *et al.*, 1980; Symth and Sanchez, 1982; Sale and Mokwunye, 1993; Hinsinger and Gilkes, 1997). Syers and Mackay, (1986) reported that the dissolution of SPR increased with increase in P sorption capacity. The extent of dissolution ranged from 22% of total P added to 48% in low and high sorbing capacity, respectively. Syers *et al.* (1992) reported that as P retention capacity increased from 19 - 64% and GPR dissolution increased 54 - 74%.

2.1.3.6 Soil organic matter

Soil organic matter is among soil properties which play a great role in dissolution of PRs. Soil organic matter upon hydrolysis supplies some functional groups or organic acids such as aliphatic acids, carboxylic acids, phenols, citrate and oxalate (Hammond *et al.*, 1986). The functional groups and anions produced can effectively chelate Ca^{2+}. This results in lowering the activity of Ca^{2+} in the soil solution thus generating a driving force for PR dissolution (Hammond *et al.*, 1986; Sale and Mokwunye, 1993). Lloyd *et al.* (1959) reported that acids produced during decomposition of organic matter enhance PR dissolution. Wright *et al.* (1992) studied 32 soil horizons and found that, organic carbon ranged from 2 to 201 g/kg soil. The organic carbon was significantly and positively correlated with the extent of PR dissolution ($r = 0.42$).

However, Chaudhary and Mishra (1980) reported that the transformation of Mussourie PR , Jhabua PR, Kasipatam PR, UPR and JOPR was not significantly influenced by soil organic matter.

2.1.3.7 Other soil factors

Soil texture indirectly incorporates the effect of soil clay on CEC - P relationship and the ability of soil to provide a sink for P. Light textured soils are not good sinks for P and Ca (Khasawneh and Doll, 1978) and thus cause low PR dissolution. Wright *et al.* (1992) reported that soil with high clay content had high dissolution of NCPR.

2. 2. Previous studies on Minjingu PR

Different workers have reported on the agronomic effectiveness of MPR in different soils. Some reports on MPR dissolution and type of the rock will be reviewed.

2 .2. 1 Type of the rock

Minjingu PR is of sedimentary origin (Mnkeni *et al.*, 1992). Many workers have reported that sedimentary rocks are more reactive than igneous and metamorphic rocks (Khasawneh and Doll, 1978). Minjingu PR is more reactive than Panda phosphate rock (Mnkeni *et al.*, 1992; Tusekelege, 1997). The average contents of P, Ca and Mg have been reported by Harris (1981) to be: MgO 3.4%, CaO 46.4% and total P_2O_5 of 8 - 28%.

2. 2. 2 Minjingu PR dissolution as influenced by soil properties

It has been reported that Minjingu PR has the potential of releasing P when incubated with soil or applied directly in acidic soils (Semoka, 1988; Mnkeni *et al.* 1992). Mnkeni *et al.* (1992) assessed P release from MPR in two soils namely Magadu1 (pH 6.2) and Magadu2 (pH 5.5). Magadu1 gave 300 mg P/kg after 30d of incubation as extracted by Bray 2 and the rate applied was 400 mg P/kg. Magadu2 gave about 15 mg P/kg after 30d of incubation as extracted by Bray 1 and the rate applied was 36 mg P/kg. They further repoted that the amount of P released increased up to 45 d of incubation period. These workers attributed the extent of MPR dissolution to low P, low Ca and acidic nature of the soils. Budotela (1995) assessed the dissolution of MPR in three soils from Dodoma district namely Msalato A, Msalato-Manispaa and Veyula - Makutupora. The extent of dissolution at 45 d of incubation was 62.1, 51.8 and 42.6% of applied P for Msalato A, Msalato Manispaa and Veyula Makutopora, respectively. Tusekelege (1997) assessed the dissolution of MPR in three soils namely Ihanda, Magadu and Sasanda. The extent of dissolution after 56 d of incubation was 65, 40 and 28.9 mg P/kg for Ihanda, Magadu and Sasanda respectively. However, all workers mentioned above did not relate the extent of dissolution to soil properties.

2. 2. 3 Indirect indicator of MPR dissolution and levels of extractable P

Crop response to MPR application can be used as an indirect indicator of PR dissolution since crops primarily absorb nutrients from the soil solution. This means that an insoluble compound must dissolve before nutrients contained in it can be absorbed. The dry matter yield of maize due to MPR application was reported by Kimbi *et al.* (1996) to be more than the control in all the soils tested. The soils used had pH values of 4.7, 4.9 and 5.8. Direct application of MPR to a soil with available P of 8 mg/kg and pH of 5.3 increased maize yield by in 67% above the control (Okalebo *et al.*, 1991). Mowo and Gama (1988) reported that the yield of cotton resulting from application of MPR was significantly higher than the control at all sites. This indicates that MPR dissolved to the extent that it released adequate P for cotton production. Soils used had pH which ranged from 4.4 to 5.8 and available P which ranged from 4.6 - 8.8 mg P/kg.

2. 3 Assessment of PR dissolution

The extent of PR dissolution has been measured indirectly by employing various techniques. Only the techniques used in this study are reviewed briefly hereunder: The dilute acids (0.025M HCl + 0.03M NH_4F (Bray and Kurtz, 1945)) and alkaline (0.5N NaOH) extraction techniques have been used by many workers (Peaslee *et al.*, 1962; Syers *et al.*, 1992; Wright *et al.*, 1992).

The 0.5 N NaOH extraction technique does not extract untreated PR, and the difference in extractable P between treated and untreated samples represent PR dissolution. Chang and Jackson (1957) have demonstrated that apatite group minerals have very limited solubility in NaOH. In addition NaOH has been shown to be an effective extractant of sorbed inorganic P (William *et al.*, 1967) and nonoccluded Fe and Al phosphate (Syers et al., 1972).

Bray 1 extractant estimates the amount of P which is available. Wright *et al.* (1992) reported that Bray 1 extracted more P from PR than the Olsen extractant in acid soils suggesting that there was partial dissolution of unreacted PR by the Bray 1 reagent. This means that the Bray 1 method may sometimes overestimate the available P level in PR treared soils. However, at any sampling time NaOH extractable P exceeds Bray 1 extractable P, indicating that Bray 1 extracts a fraction of NaOH extractable P (Wright *et al.*, 1992).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Soil sampling and preparation

Table 1 shows the parent materials and classification of the soils used in this study. Eleven soil samples from fields which had not been fertilised with phosphatic fertilisers were collected. Three {Magamba and Sasanda (virgin soils) and Ihanda (cultivated soil)} were from Mbeya region, two [Mlingano upper slope and Mlingano lower slope (Virgin soils) which will be referred to as Mlingano(U) and Mlingano (L)] were from a catenary sequence in Tanga region, three {Mzumbe , Gate (virgin soils) located near the SUA botanical garden and Magadu (virgin soil)} were from Morogoro region and three {Mhenye (virgin soil), Ng`anda$^1$ and Ng`anda^2 (cultivated soils)} from (Mr. Mgeyekwa`s fields) were from Njombe district in Iringa region. These soils were selected in order to make use of different soil properties from a wide range of agroecological zones.

A representative topsoil sample (to a depth of 20 cm) composed of 15 subsamples was taken from an area of about one hectare (ha) at each location. The subsamples were thoroughly mixed to get a composite sample. The soil samples were air dried and ground to pass through a 2 mm sieve.

Table 1. Parent materials and classification of soils used in the study.

Soil name	Parent material	Classification	Reference
Magamba	-	nc	-
Ihanda	Mafic rocks	Oxic Haplustalf	Van Straaten *et al.* (1992)
Sasanda	Gneiss	Dystropept	Van Straaten *et al.* (1992)
Mhenye	Phyllitic schist and slate	Hapludult (Rhodic Acrisols)	Msaky and Kilasara (1997)
Ng`anda 1	-	nc	-
Ng`anda 2	-	nc	-
Mzumbe	Hornblende gneiss	Typic Haplustox	Moberg (1981)
Gate	Plagioclase, quartz	Typic Rhodustult	Kaaya (1989)
Magadu	Colluvial from meta sediments of Uluguru mountain	Oxic Haplustox	Kaaya (1989)
Mlingano(U)		Rhodic Haplustox (Rhodic Ferralsols)	Ikerra and Kalumna (1991)
Mlingano (L)		Typic Haplustalf (Lixisols)	Ikerra and Kalumna (1991)

nc = not classified

3.2 Soil analyses

All the soil samples were analyzed for particle size distribution by using the hydrometer method (Days, 1965) and textural classes were determined using a modified United States Department of Agriculture (USDA) soil texture triangular diagram (Landon, 1991). Other selected chemical analyses were made as follows: soil pH was measured in 1 : 2.5 soil : water ratio (Mclean, 1982), extractable P was determined following the Bray 1 procedure (Bray and Kurtz, 1945) and phosphorus concentration in the extracts was measured using the ascorbic acid molybdate blue method of Murphy and Riley (1962). Cation exchange capacity (CEC) was determined by ammonium saturation method (Rhoades, 1982) while exchangeable bases (K, Na, Ca, and Mg) in the ammonium acetate leachate were determined by atomic absorption spectrophotometry. Organic carbon was determined by Walkley and Black method (Nelson and Sommers, 1982) while total N was estimated by the Kjeldahl digestion method (Bremner and Mulvaney, 1982). Exchangeable H and Al were extracted by the KCl method followed by titration with NaOH for exchangeable acidity and titration with HCl for exchangeable Al (Thomas, 1982).

Free iron and aluminium oxides were extracted by using dithionite citrate bicarbonate reagent (DCB) (IITA, 1979). The concentrations of Al and Fe in extracts were determined by AAS (Yuan and Breland, 1969) and the values used to calculate the oxides.

In addition, the soil pH buffering capacity for all soils was determined. The pH titration curves for the 11 soils were obtained as follows: batches of 1g subsamples of soil were shaken with 10 ml of 0.1 M KCl solution for 20 minutes. Then different concentrations of KOH ranging from 0-30 μmol OH^- g^{-1} soil were added and the subsamples were shaken for additional 20 minutes. The samples were left overnight and then the pH of the supernatant solutions was measured. The pH values were plotted against the concentration of OH^- added and the reciprocal of the slope of this plot (i.e. the amount of OH^- required to change the pH of one gramme of soil by one unit) was taken as the pH buffering capacity of the soil (Kanabo and Gilkes, 1988).

3.3. Adsorption studies

In this study the amount of phosphate adsorbed by soils at various concentrations of phosphate in equilibrating solutions was determined. The experiment was conducted by adding 30 ml of 0.01 M $CaCl_2$ containing different concentrations of KH_2PO_4 ranging from 0 - 400 mg P kg^{-1} to 3 g of air dried soil sample in 100 ml plastic bottles. Three drops of toluene were added to inhibit microbial activities. The bottles were shaken in a reciprocating shaker at a speed of 150 revolution per minute (rpm) for 30 minutes after every six hours for the period of 48 h. The equilibrating time (48h) was adopted from a previous study (Tusekelege, 1997) which showed that P adsorption by some of the soils approached equilibrium after 24 - 48 h. Equilibrated samples were filtered through Whatman No. 41 filter paper and P concentration in the filtrate was determined by the ascorbic acid molybdate blue method (Murphy and Riley, 1962). The amount of P adsorbed was calculated as the difference between P added in solution and that remaining in the equilibrium solution. The data obtained was used to determined adsorption parameters (bonding energy and adsorption maxima) using the linear form of the Langmuir equation

i.e. $C/x/m = 1/kb + C/b$.

Where:

C = Equilibrium P concentration(μg P/ ml)

x/m = amount of adsorbed P per unit weight of adsorbent (μg P/g)

k = constant related to the binding strength (mL/μg)

b = P adsorption maxima (μg P /g) or the maximum amount of P that can be adsorbed

The adsorption parameters were determined by plotting c/x/m versus C (Olsen and Watanabe, 1957; Patiram *et al.*, 1990). The phosphorus retention capacity at a certain level of added P was also determined. This was determined by taking the difference between the amount added and the amount remaining in equilibrium solution divided by amount added times 100. This parameter was determined for a P rate of 100 μg/ml.

3.4 Minjingu PR P content

The P content of ground and beneficiated MPR was determined as follows: One gramme of ground MPR was boiled gently with 25 ml of concentrated HNO_3 to oxidize easily oxidizable organic matter and 15 ml 70 - 72% $HClO_4$ were added after cooling. The solution was boiled gently until it was colourless and dense white fumes appeared in the beaker. The solution was then cooled slightly, distilled water (50 ml) was added and the mixture boiled for a few minutes. The solution was filtered, the filter paper was rinsed twice with 50 ml of distilled water and the filtrate was made up to 250 ml (AOAC, 1975). For total P determination, the filtrate was diluted 50 times. One ml was pipetted for colour development using ascorbic acid molybdate blue method (Murphy and Riley, 1962). The P content of MPR was 14.81 %.

3.5 Incubation studies

An incubation experiment was carried out to investigate the dissolution of MPR in different soils. Samples of 200 g of air dried soil were weighed into 500 ml containers, and Minjingu PR at the rate 500 mg P kg^{-1} was thoroughly mixed with the soil samples. A control soil sample without P was also weighed for each soil. Both treatments were duplicated, and all the samples were watered to approximately field capacity moisture content with distilled water and incubated at room temperature for 70 d. Moisture was maintained at field capacity by covering the containers.

Samples were withdrawn from the incubated soil samples at 0, 3, 7, 14, 28, 42, 56 and 70 d of incubation for P determination. For day 0, sampling was done before adding water to the mixture of soil and MPR. Phosphorus was extracted from the samples using Bray 1 (Bray and Kurtz, 1945) and NaOH (Syers and Mackay, 1986) extractants. For the Bray 1 method, a sample of moist soil which gave approximately 2.85 g after oven drying was used for extraction. Samples were put in plastic bottles, 20 ml of Bray 1 extracting solution was added to the bottles and the mixtures were shaken by hand for one minute. The suspension was filtered and the extract was used for P determination.

For the case of the NaOH extraction method, 0.5M NaOH was used. Sodium hydroxide is known to extract nonoccluded Al-P and Fe-P from soil (Syers *et al.*,1972) and it is also reported that it does not dissolve apatite to any significant extent (Chang and Jackson, 1957; Wright *et al.*, 1992). Therefore any increase in NaOH extractable P in the soil to which PR has been added should provide an estimate of the amount of P dissolved from the PR (Mackay *et al.*, 1986).

The procedure involved shaking a sample of moist soil, which gave approximately 2 g after oven drying, with 0.5 M NaOH at a soil: solution ratio of 1: 50 for 16 h after prewashing the samples with 1 M NaCl in order to remove free and exchangeable Ca. The prewashing with NaCl prior to extraction with NaOH prevents precipitation of $Ca(OH)_2$ and sorption of inorganic P (Syers *et al.*, 1972).

Phosphorus in the extracts from both methods was determined by the ascorbic acid molybdate blue method (Murphy and Riley, 1962). The extent of dissolution was taken as the difference in P content between the treated and untreated samples at a given sampling time.

3.6 Statistical analysis

The Statistical Analysis System (SAS 608) Programme was used to calculate simple correlation coefficients and estimate coefficients of determination (R^2) for both simple and multiple linear regressions between extent of MPR dissolution and selected soil properties. Multiple regression equations were considered necessary because combination of soil factors has been shown to predict PR dissolution better than single factors (Anderson *et al.*, 1985; Wright *et al.*, 1992). For multiple regressions, the stepwise procedure was used for the data analysis. The extent of MPR dissolution and Bray 1 P at 56 d of incubation (as dependent variables) were regressed separately against 13 soil properties (as independent variables). All the variables were entered in the model, but only variables which had a significant influence on either MPR dissolution or Bray 1 P appeared in the final model.

Variables which were not significant were eliminated in the final model. The general model was specified as described below:

$$\text{MPR dissolution/Bray 1 P} = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9x_9 + \beta_{10}x_{10} + \beta_{11}x_{11} + \beta_{12}x_{12} + \beta_{13}x_{13}.$$

Where:

Y = Extent of MPR dissolution in percent/ Bray 1 P in mg P/kg
α = intercept when X_1 - X_{10} are at zero
β_1 - β_{10} = partial regression coefficients
X_1 = Soil pH
X_2 = initial Bray 1 P levels (mg P/kg soil)
X_3 = exchangeable Ca levels (cmol(+)/kg soil)
X_4 = Organic carbon (%)
X_5 = Exchangeable Al (cmol(+)/kg soil)
X_6 = CEC (cmol(+)/kg soil)
X_7 = amount of free oxides of Fe (%)
X_8 = amount of free oxides of Al (%)
x_9 = P retention capacity (%)
x_{10} = pH buffer capacity (µg OH-/g soil per unit pH)
x_{11} = clay content (%)
X_{12} = Saturation Al (%)
X_{13} = Saturation Ca (%)

Initial Bray 1 P was excluded from the regression between Bray 1 P and soil properties because it has direct influence on Bray 1 P.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Properties of experimental soils

The eleven experimental soils were analyzed and their properties distributed into routine and specific analyses. Specific analyses included dithionite citrate bicarbonate extractable Fe and Al oxides, often referred to as free Fe and Al oxides, P adsorption characteristics and soil pH buffering capacity. These are shown in Tables 3, 4 and 5 respectively.

4.1.1 Routine analyses

The chemical properties considered under this heading are shown in Table 2. The pH in water ranged from 4.2 to 5.8. The exchangeable bases ranged from 0.4 to 4.8, 0.4 to 0.5, 0.4 to 1.8 and 0.5 to 5.1 cmole (+) /kg for Ca, Na, K, and Mg respectively. The exchangeable Al^{3+} ranged from 0 to 1.6 cmole (+) /kg. Exchangeable H^+ ranged from 0.1 to 0.7 cmole (+) /kg. The CEC ranged from 14 to 32 cmole (+) /kg, while Bray 1 extractable P ranged from 0.5 to 14.1 mg P/kg. Total N ranged from 0.3 to 0.4 % and OC ranged from 1.9 to 3.7 %.

Table 2. Some chemical properties of soils used in the study.

Property	Soils										
	Magamba	Ihanda	Sasanda	Mhenye	Ng'anda 1	Ng'anda 2	Mzumbe	Gate	Magadu	Mlingano(U)	Mlingano(L)
pH (H_2O)	5.7	5.3	5.1	4.5	5.2	4.8	5.3	5.2	4.2	5.3	5.8
OC (%)	1.9	3.0	3.5	3.7	3.7	3.3	1.7	1.7	1.6	1.8	2.4
Total N (%)	0.3	0.3	0.2	0.4	0.3	0.4	0.4	0.4	0.3	0.3	0.34
Bray 1 P (mg P/kg)	4.2	2.2	1.2	0.5	14.1	2.4	4.5	2.9	8.6	2.2	2.8
Exch.cations (cmol(+)/kg											
Ca^{2+}	2.8	2.1	0.7	0.4	3.2	1.4	1.8	2.5	1.2	1.1	4.8
Mg^{2+}	1.7	2.7	0.54	0.52	1.4	0.6	5.1	2.9	1.5	1.9	1.6
K^+	1.3	1.7	1.2	0.7	1.0	0.4	0.6	1.1	1.4	0.5	1.1
Na^+	0.5	0.4	0.5	0.4	0.5	0.4	0.5	0.46	0.4	0.5	0.5
Al^{3+}	0.0	0.1	0.7	1.2	0.1	0.4	0.1	0.0	1.6	0.0	0.0
H^+	0.2	0.2	0.3	0.7	0.1	0.4	0.4	0.3	0.7	0.1	0.1
CEC (cmol(+)/kg)	23	31	32	23	21	25	27	24	16	14	22
Ca Sat %	12.1	6.6	2.0	1.7	15	5.5	6.6	6.6	7.4	8.1	22
Al Sat %	0.0	1.6	2.1	5.1	0.2	1.7	0.2	0.0	10.2	0.0	0.0
Sand %	49.6	29.6	61.6	35.6	43.6	47.6	37.6	43.6	43.	33	43.0
Silt %	24.7	30.7	18.7	16.7	18.7	14.7	8.7	10.7	8.7	4.9	10.7
Clay %	24.7	39.7	19.7	47.7	37.7	37.7	57.7	45.7	47.5	61.5	45.7
Textural class	SCL	CL	SL	C	SC	SC	SC	SC	SC	C	C

According to Acres, (1983), pH values < 5 are rated as low while those from 5 to 7 are rated as medium. The exchangeable Ca values < 4 cmole (+) /kg are rated as low and 4 to 10 cmole(+)/kg are rated as medium. The exchangeable K values < 0.2 cmole(+)/kg are rated as low, from 0.2 to 0.6 cmole (+) /kg are rated as medium and > 0.6 cmole (+)/kg are rated as high. The exchangeable Mg < 0.5 cmole (+)/kg are rated as low and from 0.5 to 4 cmole (+)/kg are rated as medium and > 4 cmole (+)/kg are rated as high. The CEC values < 6 cmole (+)/kg are rated as low, from 6 to 25 cole (+)/kg are rate as medium and > 25 cmole (+)/kg are rated as high. The OC values < 1.5 % are rated as low and from 1.5 to 4.5% are rated as medium. The Bray 1 P less than 15 (mg P/kg) are rated as low. Total N values < 0.1% are rated as low, from 0.1 to 0.3% are rated as medium and more than 0.3% are rated as high.

Based on the above criteria the soil studied were ranked as following: Ihanda, Sasanda, Mhenye, Ng'anda^1, Ng'anda^2, Mzumbe, Gate, Mlingano(U) and Magadu were ranked as soils of low pH while Mligano(L) and Magamba were ranked as of medium soil pH. All soils had low P contents and medium OC. Magamba, Ng`anda$^1$, Ng`anda^2, Mzumbe, Gate, Mlingano(U), Mzumbe, Sasanda, Ihanda, Magadu and Mhenye were ranked as soils of low exchangeable Ca, while Mlingano(L) was ranked as of medium exchangeable Ca.

The data for particle size distribution are shown in Table 2. In general for all experimental soils clay content ranged from 19.7 to 61.7, silt ranged from 4.9 to 30.7

while sand ranged from 29.6 to 61.6. Table 2 also gives the textural classes based on the USDA textural class triangle (Landon, 1991) and these were : Sandy Clay Loam, Clay Loam, Sand Loam, Land Clay and Clay.

4.1.2 Specific analyses

4.1.2.1 Dithionite extractable Fe_20_3 and Al_20_3

The dithionite extractable Fe_2O_3 and Al_2O_3 are shown in Table 3. The dithionite extractable Al_20_3 ranged from 0.29 to 1.41 and dithionite extractable Fe_20_3 ranged from 3.2 to 7.2 %.

According to Acres (1983), dithionite extractable Fe_20_3 ranging from 1.0 to 5% are rated as medium and values above 7% are rated as high. Thus the experimental soils were ranked as follows: Magamba, Sasanda, Ng'anda^2 Mlingano(U), Mlingano(L) were soils of medium free Fe_20_3 while Ihanda, Mhenye, Ng'anda^1, Mzumbe and Magadu were soils of high free Fe_20_3. Substantial amounts of free Al_2O_3 were found in the studied soils.

Table 3. Dithionite citrate bicarbonate extractable Fe and Al oxides in the experimental soils.

Soil	Fe_2O_3	Al_2O_3
	------------ % ----------------	
Magamba	3.2	0.29
Ihanda	6.2	0.77
Sasanda	4.3	1.41
Mhenye	7.2	0.44
Ng'anda 1	6.5	0.86
Ng'anda 2	4.5	0.73
Mzumbe	6.1	0.80
Gate	5.5	0.52
Magadu	6.9	0.48
Mlingano (U)	3.0	0.41
Mlingano (L)	3.9	0.34

4.1.2.2 Soil pH buffering capacity

Data for pH buffering capacity of the soils together with their regression equations and correlation coefficients are shown in Table 4. Data used to draw linear relationships for the 11 soils are shown in Appendix 1, and examples of linear regressions used to determine the pH buffering capacity are shown in Fig. 1.

The correlation coefficients (r) between change in pH and the concentrations of OH^- ranged from 0.88 to 0.98. According to Anderson and Sclove (1970) r values ranging from 0.8 to 1 are ranked as strong associations. Thus there were strong associations between change in pH and added OH^-. The pH buffering capacity ranged from 21.8 to 52.6 μmol OH^- $g.^{-1}$ Sasanda soil had the highest pH buffering capacity (52.6 μmol OH^- $g.^{-1}$) and Magadu soil had the lowest (21.8 μmol OH^- $g.^{-1}$).

The pH buffering capacity was correlated with other soil properties. The pH buffering capacity was positively and significantly correlated with CEC (r = 0.69*) and was negatively and significantly correlated with clay content (r = -0.63*). These results indicate that pH buffering capacity increased with increase in CEC but it decreased with increase in clay content. The pH buffering capacity was also not significantly related ($P > 0.05$) to OC (r = 0.34), exchangeable Ca (r = 0.48), P retention

Table 4. Data for pH buffering capacity for the experimental soils together with corresponding regression equations and correlation coefficients.

Soil	Regression equation	Correlation coefficient (r)	Soil pH buffering capacity (μmol OH^-/ unit pH)
Magamba	$pH = 5.6 + 0.025\ OH^-$	0.88**	39.3
Ihanda	$pH = 5.4 + 0.021\ OH^-$	0.95***	47.1
Sasanda	$pH = 5.3 + 0.019\ OH^-$	0.98***	52.6
Mhenye	$pH = 4.6 + 0.036\ OH^-$	0.95***	27.6
Ng'anda 1	$pH = 5.0 + 0.022\ OH^-$	0.98***	45.2
Ng'anda 2	$pH = 5.1 + 0.025\ OH^-$	0.96***	39.9
Mzumbe	$pH = 5.4 + 0.029\ OH^-$	0.91**	33.7
Gate	$pH = 5.5 + 0.023\ OH^-$	0.89**	44.2
Magadu	$pH = 4.6 + 0.046\ OH^-$	0.93***	21.8
Mlingano (U)	$pH = 5.5 + 0.036\ OH^-$	0.92***	27.8
Mlingano (L)	$pH = 5.8 + 0.021\ OH^-$	0.97***	48.4

** ,*** significant at $P < 0.01$ and $P < 0.001$, respectively.

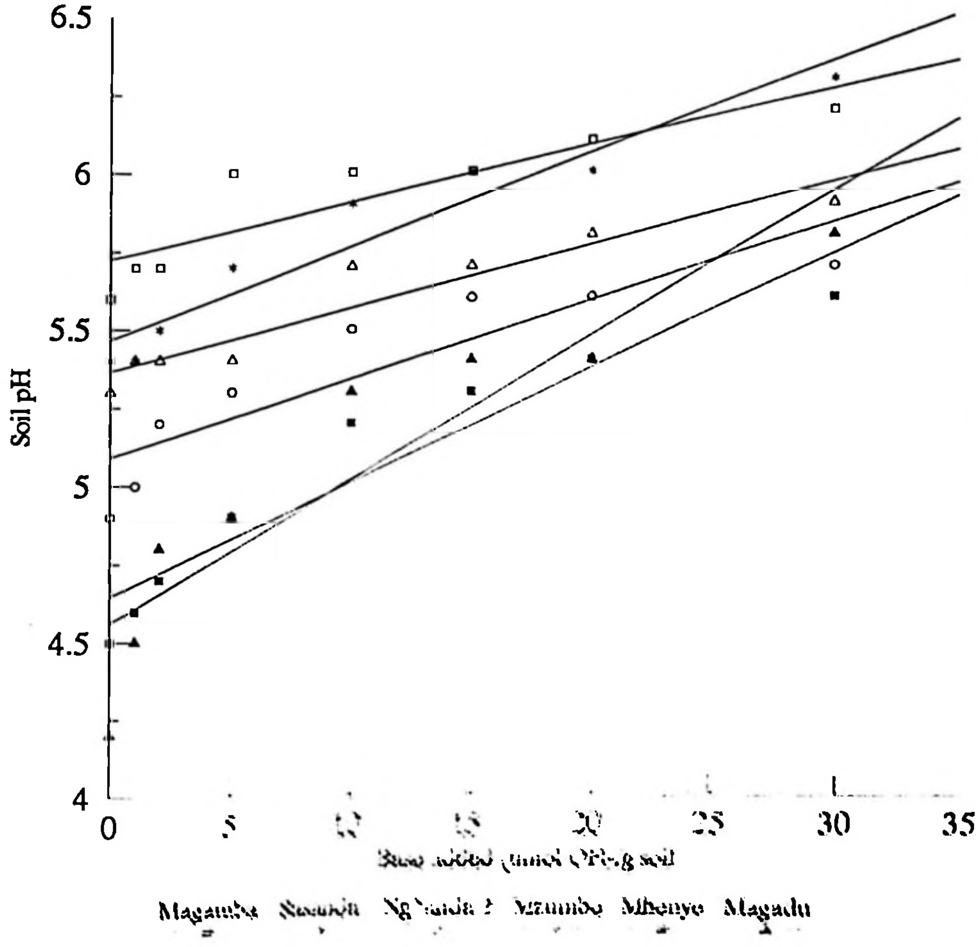

Fig. 1. Titratable acidity curves for six Tanzanian soils of the pH range 4.2 to 5.7

capacity (r = 0.19) or Al_2O_3 (r = 0.51). However the rlationships between pH buffering capacity and Fe_2O_3 and Al was negative with correlation coefficients of -0.32 and -0.55, respectively.

4.1.2.3 P adsorption

Table 5 shows regression equations relating equilibrium P concentration and adsorbed as well as P adsorption characteristics for the soils studied. Selected regression lines are given in Fig 2. (a & b) while data from the adsorption studies are given in Appendix 4.

The bonding energy (k) for 11 soils ranged from 0.35 to 13.4 ml/µg P, while P adsorption maxima of the experimental soils ranged from 375.4 to 4110.2 mg P/kg. The soils were grouped into four classes namely relatively low (375 to 450 mg P/kg), medium (450 to 1000 mg P/kg), high (1000 to 3000 mg P/kg) and very high > 3000 mg P/kg adsorption maxima. Most of the soils belonged to the groups of relatively low and medium P adsorption maxima except the Sasanda soil which had a very high adsorption P maximum (Table 5).

Table 5. Summary of Langmuir linear equations and adsorption parameters.

Soil	Regression equations	Correlation coefficient (r)	Adsorption maxima (μ g P/g)	Bonding energy (ml/μg P)	P adsorbed at 0.2 μ g P/ml in equ solution	P in equilibrium at 0 added P	Percent adsorbed P at 100 μ g P/ g added P
Magamba	$Y = 0.0045 + 0.0019x$	0.886	527.7	0.417	22	0.11	73
Ihanda	$Y = 0.0023 + 0.0008x$	0.755	1233.1	0.351	36	0.12	91
Sasanda	$Y = 0.0004 + 0.0002x$	0.979	4110.2	0.579	710	0.002	99
Mhenye	$Y = 0.0004 + 0.0005x$	0.821	2018.6	1.227	245	0.01	98
Ng'anda 1	$Y = 0.0026 + 0.0009x$	0.711	1164.6	0.331	34	0.03	92
Ng'anda 2	$Y = 0.0001 + 0.0007x$	0.941	1447.8	13.386	705	0.0	99
Mzumbe	$Y = 0.0003 + 0.0022x$	0.987	446.7	8.009	308	0.0	63
Gate	$Y = 0.0010 + 0.0024x$	0.987	407.7	2.443	130	0.0	60
Magadu	$Y = 0.0003 + 0.0021x$	0.985	466.4	8.579	218	0.0	68
Mlingano (U)	$Y = 0.0003 + 0.0023x$	0.988	436.8	6.959	218	0.0	59
Mlingano (L)	$Y = 0.0022 + 0.0027x$	0.984	375.4	1.223	128	0.01	47

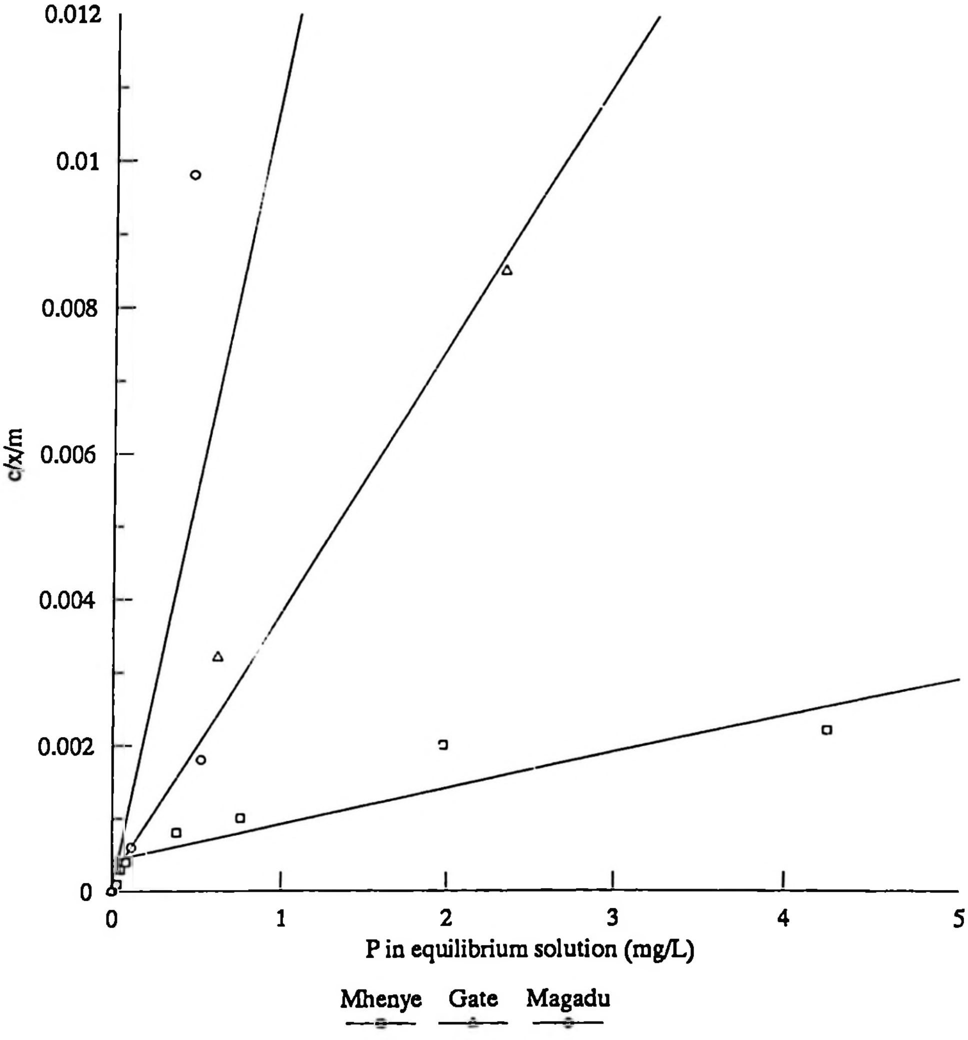

Fig. 2 (a) Langmuir adsorption of P by three Tanzanian soils.

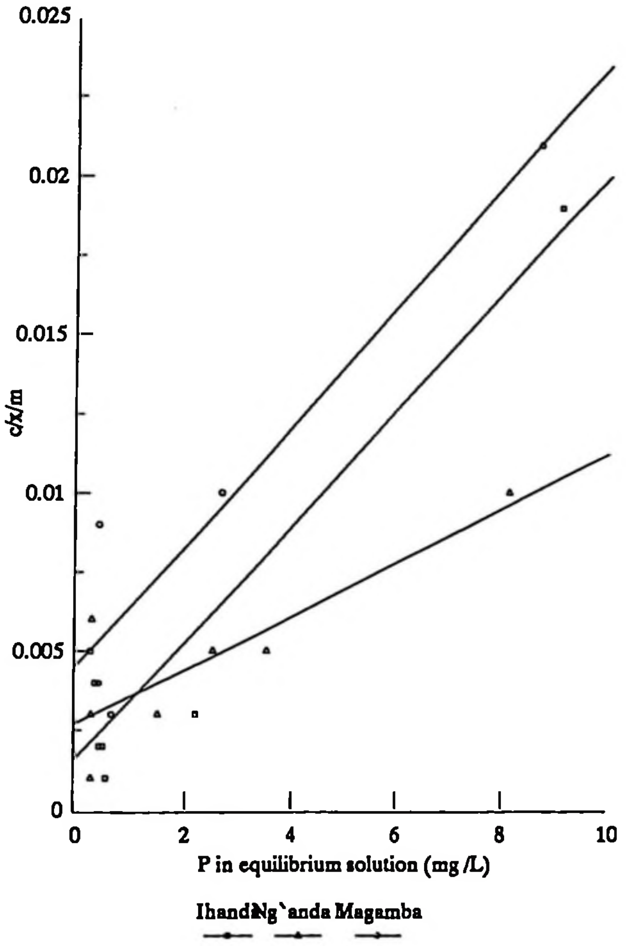

Fig. 2 (b) Langmuir adsorption of P by three Tanzanian soils.

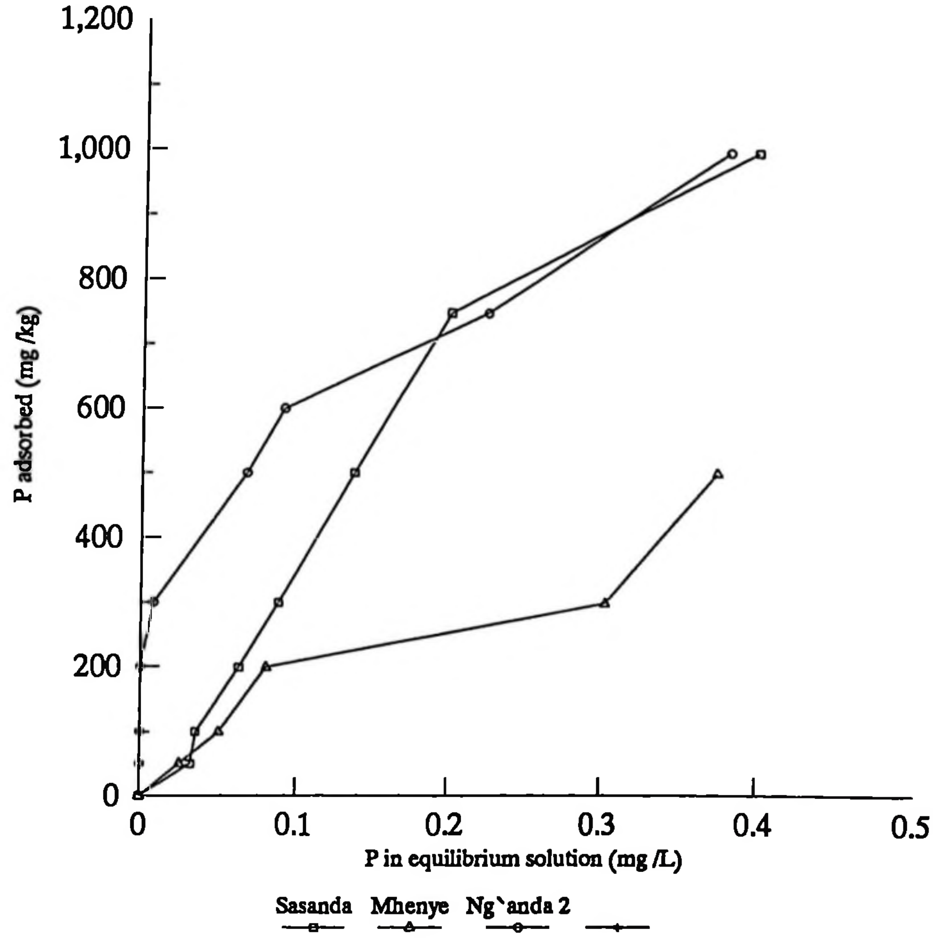

Fig. 3 (a) P adsorption isotherms for three Tanzanian soils.

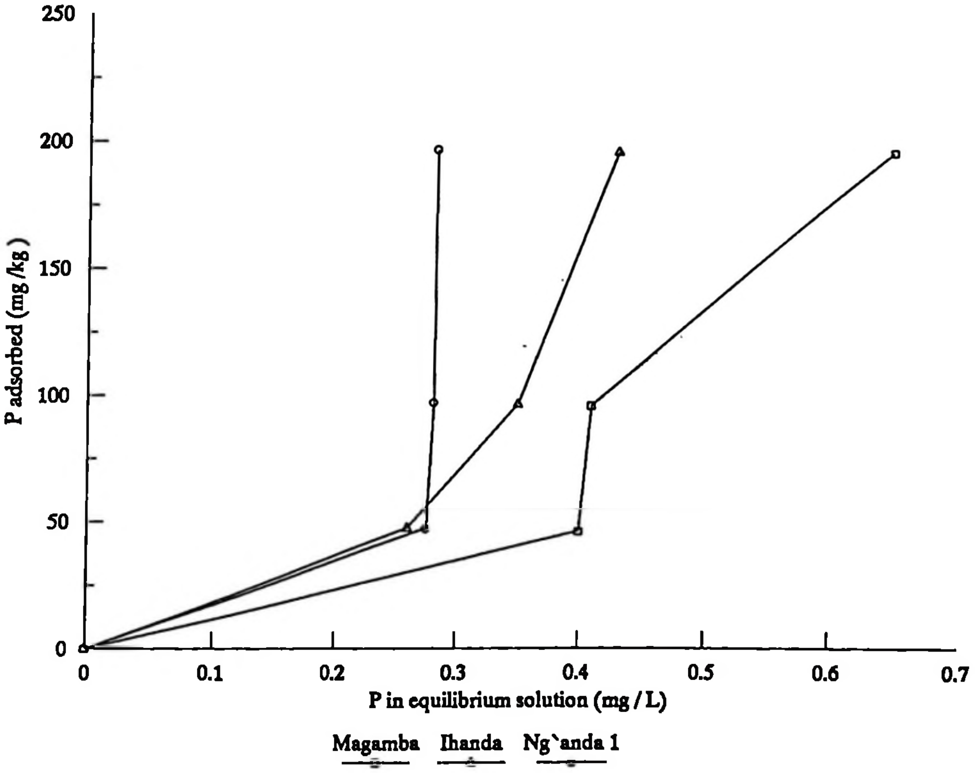

Fig. 3b P adsorption isotherms for three Tanzanian soils.

The lowest value was obtained in Mlingano (L) soil (375.4 mg P/kg) followed by Mlingano (U) soil (436.8 mg P/kg). Similar results were reported by Ikerra and Kalumna (1991) who reported adsorption maxima values of 386.4 mg P/kg and 477 mg P/kg for Mlingano(L) and Mlingano(U) soils respectively. Gate, Mzumbe and Magadu soils had 407, 446, and 466 mg P/kg respectively. Such results are similar to those reported by Mackenzie *et al.* (1997) for 10 soils from Morogoro district. The adsorption maxima for Ihanda, Sasanda and Magamba were 1233.1, 4110.1 and 527.7 mg P/kg, respectively. The results for Ihanda soil are similar to those reported by Tusekelege (1997) (1309 mg P/kg) and Van-Straaten *et al.* (1992) (1167 mg P/kg). However results for Sasanda soil are higher than those reported by Tusekelege (1997) (2850 mg P/kg) and Van-Straaten *et al.* (1992) (3058 mg P/kg). Mhenye, Ng'anda^1, and Ng`anda^2 had 2018.57 mg P/kg 1164.55 mg P/kg and 1447.81 mg P/kg. These are also soils with high P-fixing capacity. It was reported by Msaky and Kilasara (1997) that soils of Imalilo division (Njombe) have high P fixing capacity, Mhenye ridge being inclusive.

Phosphorus adsorbed when P was added at the rate of 100 mg P/kg and expressed as percent is also given in Table 5. The percent P adsorbed ranged from 47 - 99 %. The soils with < 50% of applied P adsorbed can be ranked as having low adsorption capacity and those with 50 to 60% as medium adsorption capacity while adsorption capacities > 60% can be ranked as high. Most of the experimental soils were in the medium to high categories except Mlingano (L) which was in the low P adsorption capacity.

P adsorption maxima were positively and significantly correlated with Al_2O_3 (r = 0.79**), but there was poor correlation (r = 0.04) between P adsorption maxima and Fe_2O_3. These results suggest that Al_2O_3 directly influenced P adsorption maxima while Fe_2O_3 had a negligible effect. These observations are in agreement with those reported by Hinga (1973), Patiram *et al.* (1990) and Agbenin and Tiessen (1994) who reported that Al_2O_3 was the best indicator of P sorption capacity and was more important than Fe_2O_3. There are many other reports in the literature indicating that Al_2O_3 contributes to P fixation (Mackenzie *et al.*, 1997; Parfitt, 1977; Biswas and Tomar, 1997; Ghosh and Sarkar, 1997; Yuan and Lavkalich, 1994). However, Biswas and Tomar (1997) demonstrated that P-adsorption maxima was more closely related to the specific surface area and reactivity of Fe-oxides than the total content. Yuan and Lavicalich (1994) suggested that the reactivity of different forms of Al and Fe contributed to P fixing capacity. Thus these aspects should be considered in future studies especially in view of poor correlation found with Fe oxides.

The amount of P remaining in the equilibrium solution at zero added P and the amount adsorbed at 0.2 µg P/ml equilibrium solution are shown in Table 5, Figs. 3 (a and b) and Appendices 4 and 5.

The concentration of P in the equilibrium solution when no P was added ranged from 0 to 0.12 µg P/ml. Ihanda and Magamba soils had relatively high value of P in equilibrium solution at zero added P. The amount adsorbed to give 0.2 µg P/ml of the experimental soils ranged from 22 to 710 µg P/g. The quantity of P adsorbed at 0.2 µg P/ml is reported to be the amount that will satisfy P requirement of many crops, and it is taken as the standard P requirement of soils (Beckwich, 1965; Fox and Kamprath, 1970; Agebnin and Tiessen, 1994). The amount of P adsorbed at 0.2 µg P/ml by the soils indicated that there were wide variations of P requirements among the soils.

The soils with relatively high concentration of solution P in equilibrium solution at zero added P (Magamba, Ihanda and Ng'anda^1) also gave low amounts of adsorbed P at 0.2 µg P/ml. This indicates that such soils require low additional P to reach the standard equilibrium solution of 0.2 µg P/ml. High amounts of additional P were required in Sasanda (710 µg P/g) and Ng'anda 2 (705 µg P/g) soils. This indicates that high rates of P will be required to satisfy crop requirements in these soils. Generally, the amount of adsorbed P at 0.2 µg P/ml of other soils ranged from 128 to 308 µg P/g [Table 5, Figs. 3 (a) and (b) and Appendix 5]. It can therefore be concluded that the soils showed a wide range of P requirements to satisfy crop requirements and that one may not have to saturate the P adsorption capacity to achieve satisfactory crop production. However, optimum P application rates will need to be confirmed by field experiments.

4.2 Extent of MPR dissolution

The NaOH extractable P data are shown in Table 6, Fig. 4, and Appendix 6. Generally, NaOH extractable P increased with sampling time for all eleven soils. These results are in agreement with those of Mnkeni *et al.* (1992) and Budotela (1995) on MPR dissolution studies, and also with those of Mackay and Syers (1986) on Sechura phosphate rock, Wright *et al.* (1992) on North Carolina PR and Syers *et al.* (1992) on Gafsa PR and Christmas phosphate rock (CPR).

The amounts dissolved at time zero ranged from 1.8% to 37.4%. High MPR dissolution values at zero time were found in the following soils: Ng'andal (37.4%), Sasanda (26.3%), Magadu (18.7%), Magamba (16.8%) and Ihanda (10.0%). In principle, NaOH is not expected to dissolve substantial amounts of PR (Syers, 1972) and thus this observation can not easily be accounted for. However, there are similar high values reported by other workers. Tusekelege (1997) reported a value of 12.6% in Sasanda soil while Wright *et al.* (1992) reported a value of 22.3% in one soil to which North Carolina PR was applied, Syers and Mackay (1986) reported values between 10 to 20% in some soils treated with Sechura PR.

In most of the soils the extent of dissolution was rapid during the first 7 d of incubation (Fig. 4). This suggests that most of the dissolution took place during the first 7d. The extent of MPR dissolution in this study approached equilibrium after about 28d of incubation except in the Mhenye soil where dissolution increased at a fast rate until 42d and thereafter slowed down. The variation in time of reaching equilibrium was attributed to different rates of removal of reaction products. Soils with small sinks for the dissolution products (Ca^{2+} and $H_2PO_4^-$) reach equilibrium in shorter periods than those with larger sinks (Syers *et al.*, 1992). The main sinks for $H_2PO_4^-$ are the Fe_2O_3 and Al_2O_3 (eq. 2 and 3 on p. 15). These results show that MPR dissolution was closely associated with soil pH, Ca status (i.e exchangeable Ca and Ca saturation). Soil with low pH and low Ca status caused greater dissolution of MPR (Table 7). Low soil exchangeable Ca and low pH have been reported by various workers to enhance PR dissolution (Hammond *et al.*, 1986; Robinson and Syers, 1991; Syers *et al.*, 1992). Low soil pH implies a high concentration of H^+ while Low soil exchangeable Ca implies ample sites for Ca adsorption, both of which are important factors in PR dissolution as shown on equation 1 above.

Three variables namely Ca saturation, OC and P retention capacity accounted for a high proportion of the variation in MPR dissolution. The Ca saturation alone explained about 45% of the variation in MPR dissolution in the tested soils while the combination of the three variables accounted for 83% of the variation in MPR dissolution. This means that MPR dissolution can be predicted by the following equation: $\text{MPR diss} = 73.3 - 23.3\ \text{OC} + 0.9\ \text{PRC} - 1.8\ \text{Ca sat.}$ ($R^2 = 0.83^{***}$) (eq. 4 p. 52).

Table 6. Change in NaOH - P with incubation time in eleven soils treated with MPR at the rate of 500 mg P/kg.

	Change in NaOH - P %							
	Sampling time (days)							
soil	0	3	7	14	28	42	56	70
Magamba	16.8	19.9	23.5	36.3	46.6	56.8	51.9	62.1
Ihanda	10.6	21.8	27.7	28.2	44.6	52.8	74.1	74.4
Sasanda	26.3	36.6	36.8	41.5	59.4	66.4	66.6	67.0
Mhenye	8.5	17.0	40.2	43.7	55.4	57.8	58.1	59.8
Ng'anda 1	37.4	43.6	47.0	44.8	47.8	47.8	48.2	55.0
Ng'anda 2	10.0	25.9	29.9	34.9	61.0	90.8	92.4	97.3
Mzumbe	5.8	23.5	25.9	32.0	54.3	76.9	77.0	78.1
Gate	10.0	16.8	21.1	25.3	64.7	73.1	73.6	74.6
Magadu	18.7	36.0	45.4	47.4	77.6	80.5	82.0	82.5
Mlingano (U)	3.0	18.4	24.4	25.0	57.5	64.7	66.7	75.7
Mlingano (L)	1.8	5.3	6.1	6.8	30.4	33.0	33.0	34.0

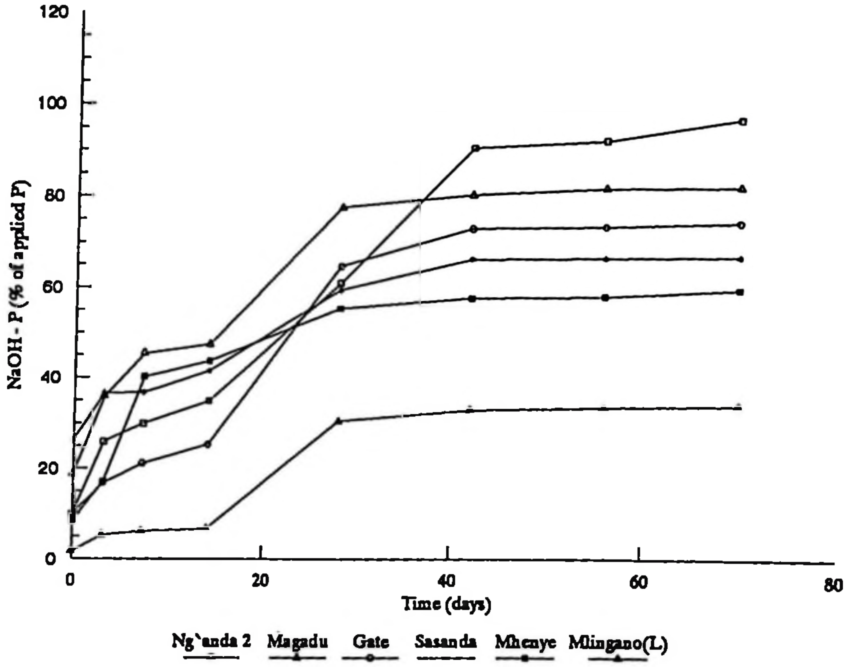

Fig. 4 Dissolution of MPR as a function of incubation time in six selected soils

Table 7. Correlation coefficients (r) relating dissolution of MPR after 56 days of incubation in 11 soils as estimated by NaOH method to soil properties.

Soil property	r
Soil pH	-0.53*
Bray 1- P(mg P kg^{-1})	-0.16ns
OC (%)	-0.15ns
Exchangeable Al (cmol(+) kg^{-1})	0.28ns
Al saturation (%)	0.32ns
Exchangeable Ca (cmol(+) kg^{-1})	-0.63*
Ca saturation (%)	-0.67*
CEC (cmol(+) kg^{-1})	0.14ns
Fe_2O_3 (%)	0.24ns
Al_2O_3 (%)	0.20ns
P- retention capacity (%)	0.27ns
pH buffering capacity (µmol OH/unit pH)	-0.33ns
Clay content (%)	0.05ns

* significant at $P < 0.05$
ns = not significant.

Table 8. Multiple regression equations between MPR dissolution and soil properties.

Regression equation	R^2
MPR diss = 83.2 - 1.9 Ca sat	0.45*
MPR diss = 112.3 - 8.9OC - 2.4 Ca sat	0.66**
MPR diss = 73.3 - 23.3 OC + 0.9PRC - 1.8 Ca sat	0.83***

MP diss= MPR dissolution
Ca sat = Ca saturation
PRC = P retention capacity (%)
*, ** and *** Significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively.

Many workers have shown that interaction of soil properties influence the extent of PR dissolution. Anderson *et al.* (1985) reported that the dissolution of about 69% was accounted for by the influence of soil pH, phosphate buffer, soil solution P concentration, soil solution calcium and soil moisture holding capacity and phosphate rock properties. Wright *et al.* (1992) reported that 85% of the dissolution of North Carolina phosphate rock was accounted for by the interaction of soil moisture, Ca saturation and exchangeable Al. Robinson and Syers (1990) reported that Gafsa PR dissolution was influenced by the combination of pH, calcium sink and P-sink. Anderson *et al.* (1985) further noted that the influence of soil pH on dissolution was greater on North Carolina PR than on Pesca PR. This suggests that results reported for one PR may not always hold for another PR and thus such results only provide a general guide when another PR is considered. In this study organic carbon, Ca saturation and P retention capacity were the three factors which had high power to account for the variation of MPR dissolution (eq. 4 p. 52). However, from this review (Anderson *et al.* 1985) some of the soil factors reported to influence to dissolution of North carolina PR, Pesca PR and Gafsa PR, did not appear to influence MPR. This indicates that factors which had high influence on one PR can either have low or show no influence on another PR.

4.3 Bray 1 extractable P

Bray 1 extractable P data are shown in Table 9, Fig. 5 and Appendix 7. Change in Bray 1extractable P was taken as the difference between the treated and untreated samples at any sampling time. Generally, change in Bray 1 P increased rapidly during the first 28d followed by a much lower rate of increase up to 56d. Similar trends were reported by Chien (1978), Mackay and Syers (1986), Mnkeni *et al.* (1992) and Wright *et al.* (1992).

Table 10 shows NaOH extractable P, Bray 1 extractable P and percent of Bray 1 P (Bray 1 P expressed as percent of NaOH-P) at 56d of incubation time. Bray 1 P at 56d of incubation time ranged from 24.4 mg P/kg in Sasanda soil to 291.4 mg P/kg in Magadu soil. Most of soils had > 50 mg P/kg at 56d of incubation time. In some soils up to 100 mg P/kg or > 100 mg P/kg Bray 1 P was found (Table 10). The amounts found in some soils were comparable to those obtained with North Carolina PR (112, 117 and 102 mg P/kg), in strongly acidic soils of the Appalachian region (Wright *et al*; 1992). This suggests that MPR is comparable to North Carolina PR in releasing P in acid soils.

The amounts of Bray 1 extractable P found at 56d of incubation time have a significant implications in terms of supplying P to plants. The critical P level for Morogoro soils is 25 mg P /kg (Singh *et al.*, 1977). The amounts of Bray 1 P at

56d of incubation time ranged from 24.4 to 291.4 mg P/kg (Table 10). This indicates that almost all the 11 soils studied released enough P for crop production from MPR. This also suggests that MPR can be used as a fertiliser material in acid soils. Good yield from direct application of MPR have been reported by many other wokers namely, Kaihura *et al.* (1988), Mowo and Gama (1988), Okalebo *et al.* (1991) and Kimbi *et al.* (1996).

The general pattern of Bray 1 P over time (Fig. 5, Appendix 7) was similar to that of MPR dissolution (Fig. 4 and Appendix 6). At any sampling time the amount extracted by NaOH exceeded that of Bray 1. This indicates that Bray 1 measures a fraction of NaOH extractable P. However, the soil with the highest extent of MPR dissolution at 56d of incubation (Table 10) did not have the highest level of extractable P (Table 10). When Bray 1 P was expressed as a percent of dissolved P (NaOH-P), the values obtained ranged from 7.3 to 71.0 %.

There were wide differences in Bray 1 extractable P between soils. The lowest amount was found in Sasanda soil where almost 92.7 % of the dissolved P from MPR was not extracted Bray 1 extractant. This indicates that 92.7% of dissolved P became fixed. This was attributed to the highest P adsorption maxima (Table 5) associated with relatively high Al_2O_3 (Table 3) in Sasanda soil. Magadu soil Bray 1 P constituted about 71.0 % of dissolved P impling that 29 % of the dissolved P became fixed. It worth noting that Magadu soil, has medium P adsorption maximum.

Table 9. Bray 1 extractable P from eleven soils treated with MPR at the rate of 500 mg P/ kg as a function of incubation time.

	Change in Bray 1 P (mg P /kg)							
	Sampling time (days)							
Soil	0	3	7	14	28	42	56	70
Magamba	21.7	27.5	17.4	27.3	79.0	79.4	93.3	93.3
Ihanda	10.5	43.9	42.0	47.1	65.5	66.6	71.9	71.7
Sasanda	1.7	1.0	12.9	10.0	21.4	23.4	24.2	24.4
Mhenye	5.8	14.9	42.2	45.8	51.3	57.1	58.8	59.8
Ng'anda 1	14.1	21.2	28.7	25.9	58.8	62.6	76.8	80
Ng'anda 2	12.9	33.0	46.4	46.8	84.0	99.7	102.3	102.8
Mzumbe	20.5	62.7	61.4	52.7	119	122.6	124.9	125.0
Gate	23.1	44.6	48.1	48.8	89.4	101.6	103.8	104.7
Magadu	54.8	107.7	115.4	112.1	214.8	221.9	291.4	292.6
Mlingano (U)	19.9	41.5	45.0	51.3	95.1	105.9	106.4	117.5
Mlingano (L)	4.3	5.3	21.4	24.4	37.1	51	51.2	51.4

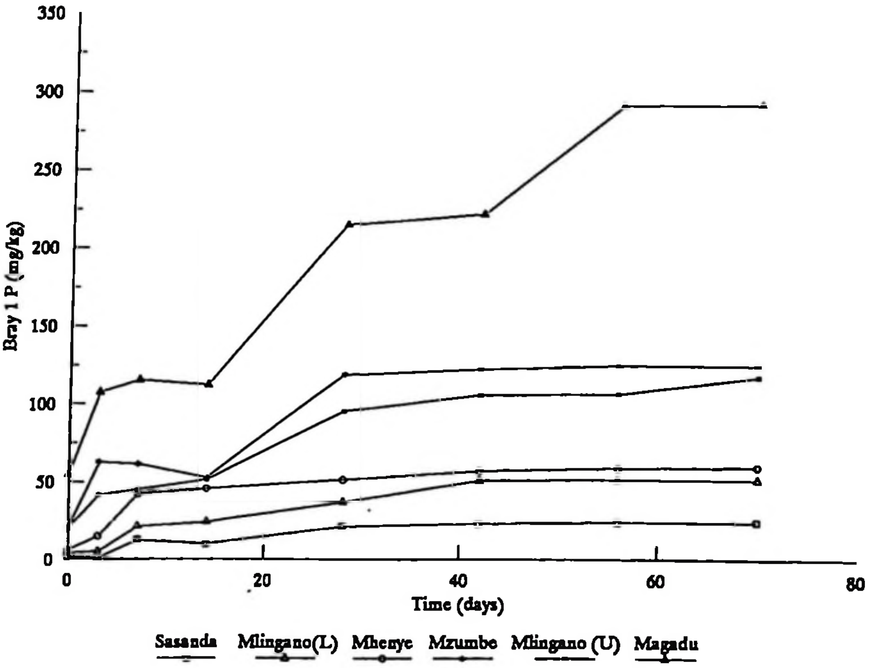

Fig 5. Change in Bray 1 extractable P over time in six of the experimental soils treated with 500mg P/kg of MPR.

Table 10. Changes in NaOH - P, Bray 1 extractable P at 56d of incubation and Bray 1 extractable P expressed as percent of NaOH - P in eleven Tanzanian soils.

Soil	NaOH - P	Bray 1 P	Bray 1 P
	-- mg P/kg	------	%
Magamba	309.6	93.3	30.1
Ihanda	370.3	71.9	19.4
Sasanda	333.1	24.2	7.3
Mhenye	290.3	58.8	20.3
Ng`anda 1	241.0	76.8	31.9
Ng`anda 2	462.0	102.3	22.1
Mzumbe	385.2	124.9	32.4
Gate	368.2	103.8	28.2
Magadu	410.1	291.4	71.0
Mlingano (U)	333.3	106.4	31.9
Mlingano (L)	167.1	51.2	30.6
Mean	333.3	100.5	29.6

These results are in agreement with those of Mackay and Syers (1986) and Syers *et al.* (1992) who reported that soils with high adsorption maxima had low available P from PRs. Other soils studied had more than 20 % of dissolved P which was made available for plant use except Ihanda soil (19.4 %) (Table 10). It can be concluded that most of the soils studied had substantial fractions of dissolved P which made remined available in the form.

The correlation coefficients for the relationship between Bray 1 P and different soil properties including extent of MPR dissolution are shown in Table 11. Bray 1 P was positively and significantly related ($P < 0.05$) to the extent of MPR dissolution. This indicated that extractable P increased with increase in extent of MPR dissolution. Bray 1 P had a positive and significant relationship with exchangeable Al ($P < 0.05$) and Al saturation ($P < 0.01$) while its relationship with pH, CEC, OC and pH buffering capacity was negative and significant. This suggests that the increase in Bray 1 P was associated with decreases in CEC, soil pH, pH buffering capacity and OC.

Soil pH and pH buffering capacity are associated with supply of H^+ ions which are important for PR dissolution (eq. 1, p. 8) and subsequent available P. However, high pH buffering capacity and low pH are associated with higher amounts Al_2O_3 and Fe_2O_3 while high pH and low pH buffering capacity are associated with lower amounts of Al_2O_3 and Fe_2O_3. Aluminium and Fe oxides are associated with P fixation. In this study Sasanda soil had the lowest Bray 1 P while Magadu soil had the highest. The lowest Bray 1 P in Sasanda soil was due to the high soil pH buffering capacity (Table 4 and Table 11) which was associated with relatively high Al_2O_3 (Table 3). Besides, Sasanda soil had the highest P retention capacity (Table 5) which was negatively related to Bray 1 P (Table 11). Therefore, high pH buffering capacity, which was associated with relatively high Al_2O_3 and the highest P retention capacity in Sasanda soil led to low Bray 1 P. This observation suggests that most of the dissolved P became fixed. This result was expected due to the fact that extractable P decreases with increase in P retention capacity (Syers *et al.* 1992; Sale and Mokwunye, 1993). These results are in agreement with those reported by Mackay and Syers (1986) and Syers *et al.* (1992). Bray 1 P was not significantly related to Fe_2O_3, exchangeable Ca, Ca saturation, P retention and Al_2O_3.

In an attempt to establish the combined effect of different soil properties, the stepwise multiple regression analysis was used. All soil properties shown in Table 11 were regressed against Bray 1 P . Only pH buffering capacity appeared to be an important factor in accounting for variations of Bray 1 extractable P. The results of the relationship are shown in the following equation: Bray 1 P = 29.5 - 4.9 pH buffering capacity ($R^2 = 0.49^*$) (eq - 5).

Table 11. Correlation coefficients (r) relating Bray 1 extractable P in 11 soils after 56 days of incubation to soil properties and extent of MPR dissolution.

Soil property	r
MPR dissolution (%)	0.49 *
Soil pH	- 0.61*
Exchangeable Al (cmol(+)kg^{-1})	0.53*
Al saturation (%)	0.69**
Exchangeable Ca (cmol(+)kg^{-1})	- 0.19
Ca saturation (%)	- 0.07ns
CEC (cmol(+)kg^{-1})	0.55*
Fe_2O_3 (%)	0.36ns
Al_2O_3 (%)	- 0.31ns
P-retention capacity (%)	- 0.30ns
pH buffering capacity (µmol OH$^-$/ pH)	-0.70**
OC (%)	-0.49*
Clay content (%)	0.37ns

* and ** significant at $P \leq 0.05$ and $P \leq 0.01$ respectively
ns = not significant

However, pH buffering capacity accounted for only 49% of the variation in Bray 1 P. Coefficients of determination of < 50% are ranked as low (Anderson and Sclove, 1970). This implies that none of the independent variables tested adequately predicted the dependent variable. This was not expected because Bray 1 extractable P was reported by Wright *et al.* (1992) to be controlled by organic matter, P sorption index and North Carolina PR dissolution. Further more they noted that factors which appeared to be associated with PR dissolution also appeared to be associated with Bray 1 extractable P.

It should be noted that most of the factors which were included in evaluating the North Carolina PR were also included in evaluating MPR. However, for a single factor to appear in accounting for < 50 % of the dependent variable is not surprising because most of the factors (Table 11) accounted for < 40 % of the variation in Bray 1 P from MPR. Further more, inclusion of the other factors into the regression equation did not improve the predictive value of the equation. Thus only pH buffering capacity reached the level of significance.

From these results it can be concluded that Bray I extractable P is just a fraction of NaOH extractable P. Thus for good evaluation of Bray 1 P, soil factors which favour dissolution should be taken into account.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

In view of the findings from this study it was concluded that MPR dissolution was high (> 50% of the applied P dissolved after 56 days of incubation) in most of the soils studied except in one soil where only 34% of applied P was dissolved. Most of the variation (83 %) in the amount of dissolved P was accounted for by a combination of three soil properties, namely Ca saturation, P retention capacity and organic carbon.

The average Bray 1 extractable P for the studied soils was 29.6% of the dissolved P, indicating that a high proportion of the dissolved P was fixed by soil constituents. Of the soil properties determined, only pH buffering capacity was well correlated with Bray 1 P, but even so this property accounted only for 49 % of the variation in Bray 1 P.

It is therefore recommended that further studies be undertaken in order to

(i). improve the ability of predicting the level of available P in soils treated with MPR.

(ii). minimize P fixation and hence increase the level of available P to plants.

(iii). optimize the equation for predicting the extent of MPR dissolution in soils

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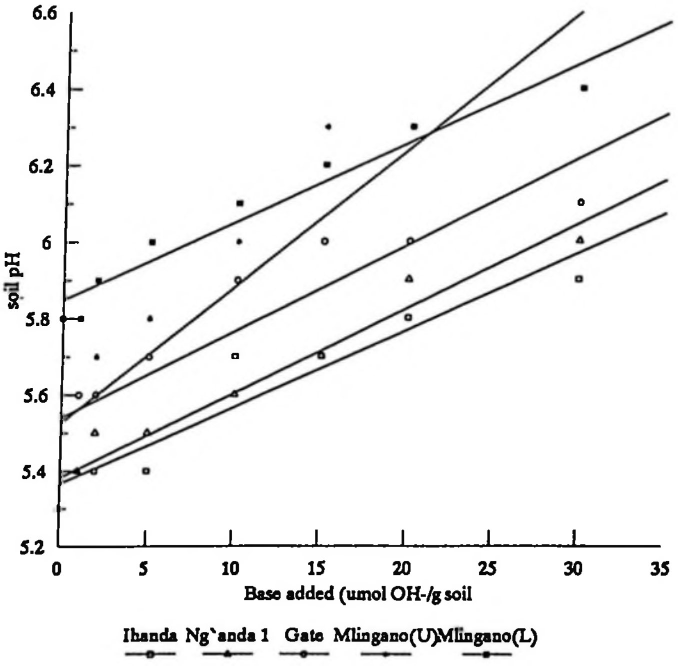
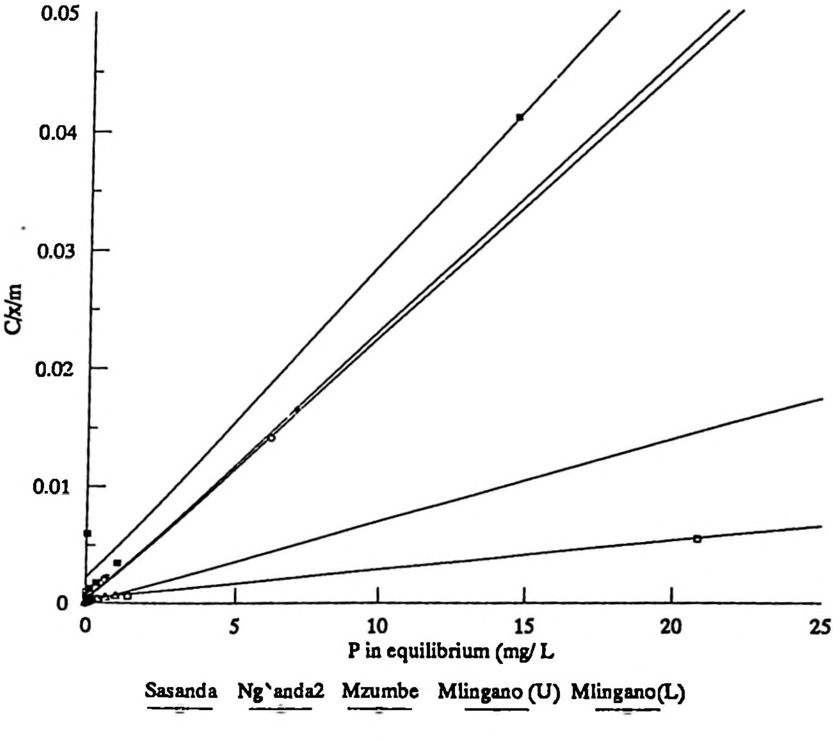
Appendix 1. Changes in pH following the addition of different amounts of KOH to eleven soil samples from different parts of Tanzania.

	Amount added OH^- µmol							
Soil \pH changes	0	1	2	5	10	15	20	30
Magamba	5.6	5.7	5.7	6.0	6.0	6.0	6.1	6.2
Ihanda	5.3	5.4	5.4	5.4	5.7	5.7	5.8	5.9
Sasanda	5.3	5.3	5.4	5.4	5.5	5.5	5.7	5.9
Mhenye	4.5	4.6	4.7	4.9	5.2	5.3	5.4	5.6
Ng‘anda1	5.3	5.4	5.5	5.5	5.6	5.7	5.9	6.0
Nga‘nda2	4.9	5.0	5.2	5.3	5.5	5.6	5.6	5.7
Mzumbe	5.4	5.4	5.5	5.7	5.9	6.0	6.0	6.3
Gate	5.3	5.6	5.6	5.7	5.9	6.0	6.0	6.1
Magadu	4.2	4.5	4.8	4.9	5.3	5.4	5.4	5.8
Mlingano(U)	5.3	5.4	5.7	5.8	6.0	6.3	6.3	6.4
Mlingano(L)	5.8	5.8	5.9	6.0	6.1	6.2	6.3	6.4



Appendix 2. Titratable acidity curves of five Tanzanian soils for the pH range 5.2 to 5.8



Appendix 3.Langmuir adsorption of P by five Tanzanian soils.

APPENDIX 4. Adsorption study data fitted to Langmuir regression equation

Soil name	Initial solution µg/ml (I)	Final solution µg/ml (C)	weight of soil g (M)	Total adsorbed P µg/ml (X)	weight of adsobateper unit weight adsorbent (X/M)	C/X/M
	0	0.11				
Magamba	5	0.4	3	138	46	0.009
	10	0.41	3	288	95.9	0.004
	20	0.65	3	581	196	0.003
	30	2.64	3	821	274	0.01
	50	8.7	3	1239	413	0.021
	75	14.8	3	1806	602	0.025
	100	27.4	3	2180	727	0.038
	200	112.0	3	2637	879	0.128
	0	0.12				
Ihanda	5	0.26	3	142	47.4	0.005
	10	0.35	3	290	96.5	0.004
	20	0.43	3	587	196	0.002
	30	0.49	3	885	295	0.002
	50	0.55	3	1484	495	0.001
	75	2.19	3	2184	728	0.003
	100	9.1	3	2727	909	0.01
	200	31.35	3	5060	1687	0.019
	0	0.002				
Sasanda	5	0.032	3	149	49.7	0.001
	10	0.0352	3	299	99.6	0.00064
	20	0.0625	3	598	199	0.00035
	30	0.0875	3	897	299	0.00029
	50	0.1375	3	1496	499	0.00028
	75	0.2	2	2244	748	0.00027
	100	0.4	3	2988	996	0.0004
	200	1.375	3	5959	1986	0.00069
	400	20.875	3	11937	39791	0.00551

Appendix 4 continued

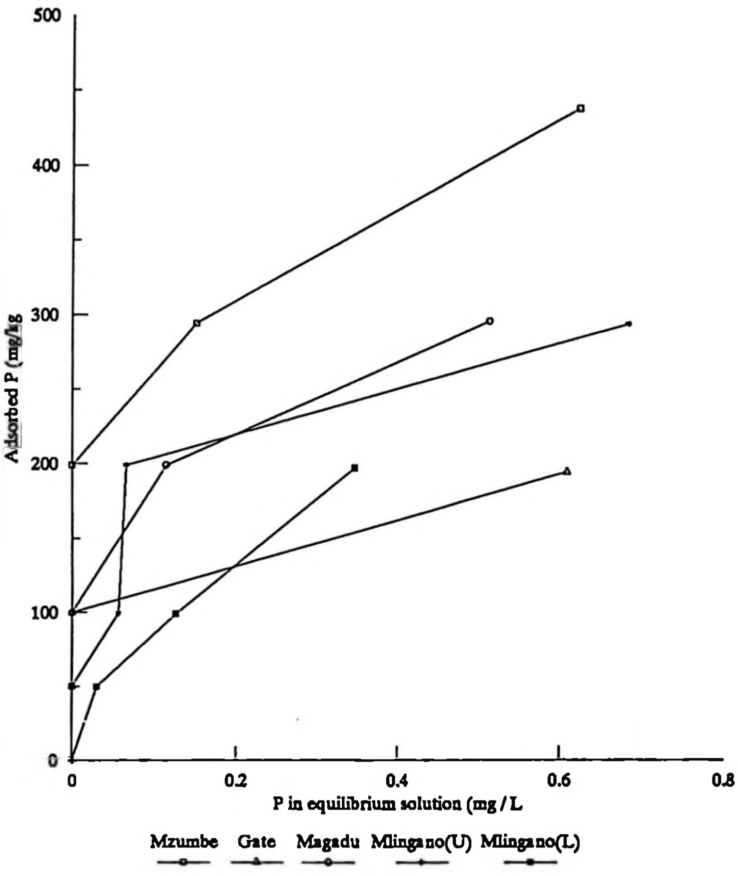
Mhenyc	0	0.01				
	5	0.025	3	149	49.8	0.0003
	10	0.05	3	299	99.5	0.0003
	20	0.08	3	598	199	0.0004
	30	0.303	3	891	297	0.0001
	50	0.375	3	1489	497	0.0008
	75	0.75	3	2228	743	0.0010
	100	1.975	3	2941	980	0.002
	200	4.25	3	5873	1958	0.0022
	0	0.03				
Ng`anda1	5	0.275	3	142	47.3	0.006
	10	0.281	3	292	97.2	0.003
	20	0.282	3	592	197	0.001
	30	1.00	3	870	290	0.003
	50	1.5	3	1455	485	0.003
	75	3.5	3	2145	715	0.005
	100	8.13	3	2756	919	0.009
	200	20.75	3	5378	1792	0.012
Ng`anda2	0	0				
	5	0.00.	3	150	50	0
	10	0.00	3	300	100	0.00
	20	0.00	3	600	200	0.00
	30	0.0078	3	899.76	299.92	0.00003
	50	0.06658	3	1498.0	499.33	0.00013
	60	0.09009	3	1798.0	599.10	0.00015
	75	0.22456	3	2243.3	747.75	0.00030
	100	0.38123	3	2988.6	996.19	0.00038
	125	0.64238	3	3730.7	1243.6	0.00052
	150	0.96613	3	4471.0	1490.3	0.000065

Appendix 4 Continued.

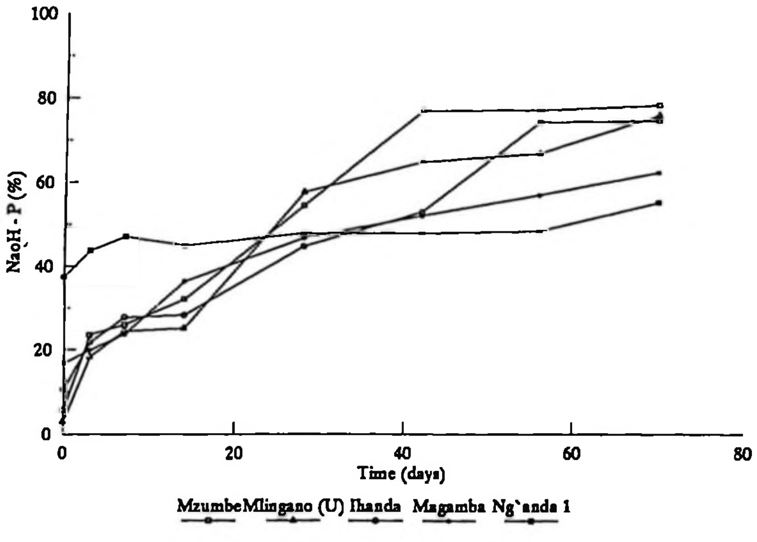
	0	0				
Mzumbe	5	0.00	3	150	50	0.00
	10	0.00	3	300	100	0.00
	20	0.15	3	596	199	0.0008
	30	0.625	3	881	294	0.0021
	50	6.195	3	1314	438	0.0141
	75	18.2	3	1704	568	0.032
	100	37.125	3	1886	629	0.0591
	200	108.65	3	2741	914	0.119
Gate	0	0				
	5	0.00	3	150	50	0.00
	10	0.00	3	300	100	0.00
	20	0.61	3	582	194	0.0032
	30	2.34	3	830	277	0.0085
	50	10.09	3	1197	399	0.0253
	75	24.225	3	1523	508	0.0477
	100	40.5	3	1785	595	0.0681
	200	122.95	3	2312	771	0.1596
Magadu	0	0				
	5	0.00	3	150	50	0.00
	10	0.00	3	300	100	0.00
	20	0.113	3	597	199	0.0006
	30	0.515	3	885	295	0.0018
	50	4.48	3	1366	455	0.0098
	75	15.02	3	1799	600	0.025
	100	32	3	2042	681	0.0469
	200	108	3	2768	923	0.1168

Appendix 4 continued.

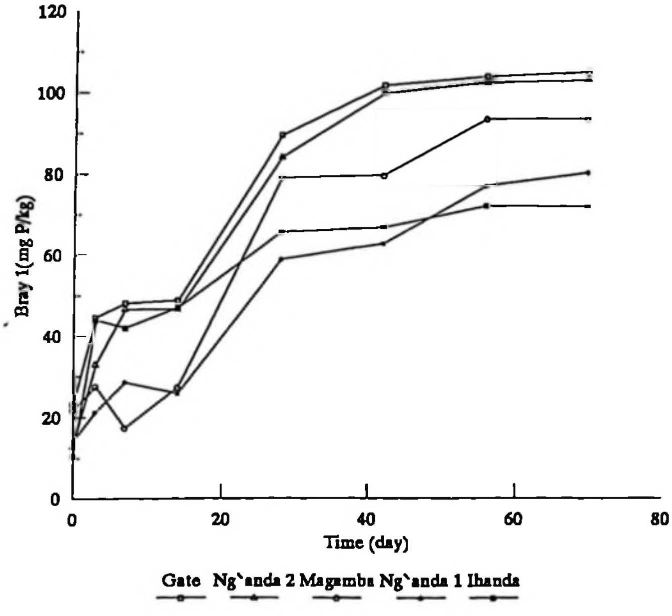
	0	0				
Mlingano (U)	5	0.00	3	150	50	0.00
	10	0.056	3	298	99.4	0.0006
	20	0.065	3	598	199	0.0003
	30	0.685	3	879	293	0.0023
	50	7.08	3	1288	429	0.0165
	75	21.55	3	1604	535	0.0403
	100	41.05	3	1769	590	0.0696
	200	126.0	3	2220	740	0.1703
	0	0.01				
Mlingano(L)	5	0.03	3	149	49.7	0.006
	10	0.125	3	296	98.8	0.0013
	20	0.3475	3	590	197	0.0018
	30	1.005	3	870	290	0.0035
	50	14.563	3	1063	354	0.0411
	75	34.5	3	1215	405	0.0852
	100	52.7	3	1421	474	0.1112
	200	141.5	3	1755	585	0.24219



Appendix 5. P adsorption isotherms for five Tanzanian soils.



Appendix 6. Dissolution of MPR as a function of incubation time in five Tanzanian soils.



Appendix 7. Change in Bray 1 extractable P over time in five of the experimenta soils treated with 500mg P/ kg of MPR.