EVALUATION OF BANDING METHODS AND ORGANIC MATTER ADDITION FOR IMPROVING DISSOLUTION AND AVAILABILITY OF PHOSPHORUS FROM MINJINGU PHOSPHATE ROCK IN TWO SOILS OI CONTRASTING CHARACTERISTICS

BY

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ABSTRACT

A study was conducted under pot and field conditions to evaluate the effects of Minjingu Phosphate Rock (MPR) banding and some manipulations within the band, on maize yields. The treatments were: varying depth of incorporating MPR, and organic materials (plant residues). They were evaluated for their effects on enhancement of dissolution and consequently availability of P from banded MPR in two soils with contrasting characteristics. The treatments tested were 20-cm MPR + O.M band, incorporated down to the 10 or 20cm depth, 20-cm MPR alone band, incorporated to the 10 or 20cm depth, 2-5cm width strip banded MPR, broadcasting MPR (only for field) and control, giving seven treatments for field and six treatments for pot experiment. The experiment was laid using Randomized Complete Block Design with four replications. Extractable P in soils, DM yields, plant P concentration, P uptake and grain yields were used to assess the effects of these treatments. The results of this study showed that some banding treatments significantly (P=0.05) increased dissolution and availability of P from MPR. For example, in the pot experiment, Minjingu PR plus organic matter increased DM yields from 3.17 to 56.32 g/pot and 7.13 to 76.24 g/pot, and P uptake from 2.75 to 83.24 mg/pot and 4.72 to 118.40 mg/pot for Sasanda and Magadu soil, respectively. Under field conditions, MPR + O.M treatments increased extractable P in the soil from 4.0 to 18.45 mg/kg and 5.39 to 79.84 mg/kg, and grain yields from 0.16 to 2.27 t/ha and 0.32 to 2.59 t/ha for Sasanda and Magadu sites, respectively. This study shows that banding of MPR can be a good method of MPR application in acid and high P fixing soils, especially when MPR is incorporated together with organic residues.

DECLARATION

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

Signature:.....

Date:12/05/2023

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DEDICATION

This dissertation is dedicated to the Lord God who is the source of life and the pioneer of Science. I also dedicate this work to my beloved parents who laid the foundation of my education.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
<	Less than
>	Greater than
AA	Available Alkalinity
Al	Aluminium
ANOVA	Analysis of Variance
BS	Base saturation
C	Carbon
C: N	Carbon to nitrogen ratio
Ca	Calcium
CEC	Cation exchange capacity
Cl	Chloride
cmol (+)/kg	Centimole (cation) per kilogram
CV	Coefficient of variation
DM	Dry matter
DMRT	Duncan multiple range test
DSS	Department of Soil Science
e.g.	for example
et al	and others
FAO	Food and Agriculture Organisation (of the United Nations)
g/pot	gram per pot
H^+	Hydrogen ion

H_2O	Water
H_2O_2	Hydrogen peroxide
ha	Hectare
HNO_3	Nitric acid
i.e.	such as
K	Potassium
KCl	Potassium chloride
LSD	Least Significant Difference
masl	metres above sea level
Mg	Magnesium
MPR	Minjingu Phosphate Rock
mg	milligram
mg/kg	milligram per kilogram
mmol	millimole
N	Nitrogen
Na	Sodium
OC	Organic carbon
O.M	Organic matter
OH^-	Hydroxide ion
P	Phosphorus
S	Sulphur
SUA	Sokoine University of Agriculture
t/ha	tonnes per hectare
WRB	World Reference Base

CHAPTER ONE

1.0 INTRODUCTION

Phosphorus (P) is indispensable for all forms of life because it is a constituent of nucleic acids and is involved in energy transfer, via adenosine triphosphate. In the soil, P has on many occasions been a limiting element due to its low availability. The prevalence of Al, Fe, or Ca, which bind P in highly insoluble compounds, exacerbates this unavailability (Engelstad and Terman, 1980).

Sanchez (1976) pointed out that P was known to be the second most limiting nutrient element after nitrogen (N) in crop production in tropical soils, particularly the highly weathered soils. It is, therefore, of greater importance to apply P fertiliser materials, which will ameliorate the problem of insufficient P in such soils. Usually, most P fertilisers applied to agricultural land contain water-soluble components. The common sources of water-soluble phosphate fertilisers applied to field crops are triple super phosphate (TSP), single super phosphate (SSP), and mono or di-ammonium phosphate (MAP or DAP).

However, these water-soluble fertilisers are expensive to resource poor farmers and their supply is often inadequate (Kimbi *et al.*, 1996). Resource poor farmers who can rarely afford these inputs would benefit greatly by less expensive but equally effective alternative P sources such as phosphate rock (PR) (Hammond *et al.*, 1986). During the past two decades, there has been renewed research interest on the use of

PR as an alternative to the more expensive water-soluble fertilisers (Khasawneh and Doll, 1978).

Some PR's are sufficiently soluble in acid soils to be useful fertilisers for some crops (Le-Mare, 1991). Around 40% of the land surface in the tropics consists of highly weathered, acidic soils mainly of the orders Oxisol and Ultisol while 50% of the land surface is occupied by acid soils of the order Alfisol and Entisol (Sale and Mokwunye, 1993). These are soils in which PR is potentially effective. Direct application of PR is a vital option in P fertilisation in Tanzania, because there are extensive areas with acid soils, low in P and in Ca (Singh and Uriyo, 1978). In general, results of experiments conducted in Tanzania have shown that the use of the Minjingu Phosphate Rock (MPR) was most effective when soils were acidic and deficient in P (Mnkeni *et al.*, 1986).

High dissolution of PR materials in soils is a prerequisite for the P to become available to plants (Gregg *et al.*, 1989). Several researchers have reported factors affecting dissolution of PR (Hammond *et al.*, 1986; Le-mare, 1991; Mnkeni *et al.*, 1992), including soil factors, properties of PR, and some plant factors. Among soil factors, soil organic matter is known to influence dissolution of PR. Organic matter is thought to form complexes with soil calcium, thereby diminishing the Ca concentration and thus enhancing dissolution of PR (Chien and Hammond, 1989). Mixing organic matter with PR has been found to increase PR dissolution by Ikerra (1986) and Ikerra *et al.* (1994). Ikerra *et al.* (1994), working with an Ultisol, reported the release of 58 mg P/kg soil when MPR was combined with farmyard manure and

only 45 mg P/kg soil when MPR was applied alone, after 60 days of incubation. Beside those factors, fertiliser placement methods have been reported to substantially affect PR utilisation by crops. The reason behind this concept is the extent of contact between PR and soil (Kanabo and Gilkes, 1987). Among the fertiliser placement methods, broadcasting and banding are usually used.

Broadcasting has been the easiest, commonest and most preferred method in the past. Khasawneh and Doll (1978) have reported broadcasting of finely ground PR followed by incorporation into the soil to be an appropriate placement method. Also it was reported that dissolution of PR was improved in broadcasting, probably due to increased contact between the PR and soil particles (Bolland and Gilkes, 1989).

Nevertheless, fertiliser applied by broadcasting came into contact with a large volume of soil and, thus, there was a high risk of the nutrients so dissolved being fixed in the soil (Forth, 1990). Kanabo and Gilkes (1987) found that for equal amounts of PR a higher proportion of dissolved P was available to plants if the PR was banded than broadcast. However, there is a lower level of dissolution in the banded PR. A further drawback of broadcasting is that it requires high rates of PR application to satisfy the P fixing capacity of a soil (Bolland and Gilkes, 1989). It is laborious in the sense that it requires a second "tilling" of the land to incorporate the broadcast PR. Resource-poor farmers who are mainly dependent on the family labour to meet various farm activities (i.e. cultivation, weeding and harvesting) would not afford to supply labour repeatedly for "tilling" of the same land. Thus, broadcasting, which requires high rate of PR application and high labour, becomes very expensive

and will not be popular with resource-poor farmers. Also, the broadcast PR, if in powder form, is subjected to wind drift losses during application.

An alternative to broadcasting is banding. It has been reported by several researchers (Ozanne, 1980; Kanabo and Gilkes, 1987; Ngatunga *et al.*, 1988) that banding PR resulted in more efficient use of the fertiliser by plants than broadcasting. Economically, banding can use lower rates of phosphate fertiliser than broadcasting and also labour requirements will be low because only the banded soil, i.e. a hand-hoe width, will require the second "tilling", thus making it relatively cheaper and affordable to resource-poor farmers.

Inferior dissolution of PR on the banded PR has been reported (Sale and Mokwunye, 1993). Also, Kanabo and Gilkes (1987) observed lower dissolution of PR in banded application compared to broadcasting. In Tanzania, Kadogholo (2001) similarly observed lower yield of maize from Sasanda (Mbeya) volcanic soils where PR was banded than where it was broadcast, probably due to lower PR dissolution in the former. An explanation to less PR dissolution within a band may be due to a temporarily limited supply of H^+ ions for dissolution, coupled with a temporary accumulation of the products of dissolution (Ca^{2+}, P) which would then reduce further dissolution due to the common ion effect (Bolland and Gilkes, 1989; Bolan and Hedley, 1990).

However, the little amount of P dissolved in band application should be readily available for plant uptake, as it is less exposed to the binding or fixing effect of the

soil. Thus, improving dissolution within the band may increase availability of P, resulting in better crop performance. However, there is insufficient knowledge about practices or amendments that can be applied within the band that will enhance dissolution, and consequently availability of P from banded PR in different type of soils.

This scenario calls for a need to search for some manipulations within the band, which will enhance dissolution and, consequently, availability of P from banded PR in soils with contrasting characteristics. The soil of Sasanda and SUA-farm are the case in point. The Sasanda soil has high P fixing capacity while Magadu (SUA farm) has medium P fixing capacity. Thus, the present studies were conducted using these two soils, with the following objectives:

1. To evaluate the effect of varying depth of incorporating MPR in soil on dissolution and availability of P from banded MPR.
2. To evaluate the effect of organic materials (plant residues) mixed with MPR on dissolution and availability of P from banded MPR.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Role of phosphorus in agriculture

Phosphorus is one of the major elements required for plant growth, development and reproduction. Phosphorus is a vital component of DNA and is involved in energy transfer, via adenosine triphosphate and it influences both yields and quality of crops (Engelstad and Terman, 1980; Marschner, 1990). The element is amongst the most limiting nutrients in many soils. Some specific growth effects that have been associated with phosphorus are: stimulated root development, increased stalk and stem strength, improved flower formation and seed production, more uniform and earlier crop maturity, and improvement in crop quality (Johnson and Steen, 1997). Tandon (1987) reported the effect of P in enhancing plant cell division, growth and lengthening of roots, seed and fruit development, and early ripening. In cereal crops, phosphorus strengthened structural tissues such as straw and stalks (Brady and Weil, 1990). Mullins (1993) reported that the addition of phosphorus in the form of monocalcium phosphate through band application showed positive response on strengthening maize, wheat and soybean roots. All of these effects eventually result in increased crop yields where phosphorus supply is sufficient, and the vice versa.

Thus, research has revealed increased maize grain yields following use of phosphorus fertiliser as compared to P controlled treatments. For example Semoka *et al.* (1992) reported an increase in maize grain yields from 0.29 t/ha from a P control to 3.8 t/ha from treatments that received P from MPR fertiliser. The effects of P are

not only associated with crop yields but also with crop quality. Drycott (1972), for example, reported that P played a key role in increasing sugar content in sugar cane. Therefore, in order to maximize these positive effects of P, it should be supplied as fertiliser to P deficient soils.

2.2 Chemistry of soil phosphorus

The chemistry of phosphorus in the soil is complex because the phosphorus is associated with many different compounds to which it is bound with a range of bonding energies or strengths. Soil phosphorus occurs in different forms within the soil. The vast majority of soil P is present in organic and inorganic forms that are unavailable to plants (Barber, 1984). Phosphorus is a constituent of primary minerals (Smeck, 1973). Primary apatite minerals gradually undergo hydrolysis and inorganic P becomes labile. Newly released P is either taken up by organisms, thus entering the organic P pool (P_o), or sorbed onto positively charged colloidal sites of secondary minerals, especially hydroxides of aluminium (Al) and iron (Fe). Both the organic P and inorganic P (P_i) pools increase in size as the apatite pool feeding them are solubilized. Once the apatite pool is diminished, P_o and secondary P_i pools also begin to decline as P is lost from the soil system in leaching, erosion and in crops harvests (Crews, 1996). Initially a large percentage of soil P_o and surface bound P_i are labile, but with time P_o compounds resistant to microbial breakdown begin to dominate the pool (Stewart and Tiessen, 1987). Meanwhile, P_i becomes occluded in amorphous or crystalline oxides (Al-P, Fe-P, and Ca-P), rendering the vast majority of soil P to be unavailable to the plants (Crews, 1996). According to Loganathan and Sutton (1987)

highly weathered acidic soils of the humid tropics are known to present problems in their management for P fertility. These soils are actually low in total and available P and are expected to fix large quantities of available P. This justifies the need for addition of P fertilisers in these soils for plant use.

However, when phosphate fertilisers are added to soil, only a fraction of the phosphorus is taken up by the plant roots. The major forms taken up by plants from soil solution are $H_2PO_4^-$ or HPO_4^{2-}. A large proportion of the added phosphate becomes adsorbed (attached to the surface) on soil particles. Where the attachment is weak, the phosphorus can easily be brought back into the soil solution. After the first release of P into soil solution further reactions lead to assimilation, which means that the bond is stronger and the phosphorus becomes less readily available. The speed of these reactions and, therefore, the extend of deficiency of phosphorus depends on the type and size of the adsorbing mineral particles, the presence of other minerals such as those of aluminium, iron or calcium, intensity of soil acidity, and content of organic matter. The concentration of P in solution is normally low, with 0.3 mg/l being necessary for normal plant growth. Of the P associated with the soil solid phase, approximately 50% is in the organic phase and 50% in the inorganic phase (Barber *et al.*, 1963; Ozanne and Shaw, 1967).

Sample (1972) reported that calcium carbonate and hydrous oxides of Fe and Al played key roles in P retention in soil. High concentrations of Al, Fe or Ca led to precipitation of a range of compounds such as $FePO_4.2H_2O$, $AlPO_4.2H_2O$ or $Ca_8H_2(PO_4)\ 6.5H_2O$, which made P temporarily unavailable to plants (Engelstad and

Terman, 1980). Sanchez (1976) pointed out that P was the second most limiting nutrient element after nitrogen in crop production in tropical soils. This was so particularly in highly weathered soils, due to their high concentrations of Al and Fe hydrous oxides. To ameliorate the problem of insufficient P in these soils, use of P fertilisers is a prerequisite. Because highly processed P fertilisers are expensive for resource-poor farmers, many researchers (Mnkeni *et al.*, 1991; Bashir, 1999; Kimbi *et al.*, 1996) have recommended the use of PR as the relatively inexpensive alternative. But to be as effective as the processed P fertilisers, the PR has to be solubilized in the soil.

Several factors influence the dissolution of PR in soil. The level of soil P plays great role in PR dissolution. To ensure high PR dissolution, the soil should be low in P (Khasawneh and Doll, 1978). Sale and Mokwunye (1993) reported that for high PR dissolution, a soil should be low in $H_2PO_4^-$. A P concentration of <0.03 mmol/dm^{-3} in soil solution was ranked as being very low and the extent of PR dissolution in these soil was high (Robison and Syers, 1991). Syers *et al.* (1992) found that as the level of Olsen extractable P in soil increased in the order 1.9, 3.5, 5.0 to 5.1 mg P/kg, the dissolution of PR decreased in the order of 72%, 54%, 38% and 22%.

2.3 Factors affecting dissolution of phosphate rocks

Dissolution of PR materials in soil is prerequisite for the P to become available to plants (Gregg *et al.*, 1989). The dissolution of PR in acid soil may be represented by

the following reactions (Dong and Li, 1992; Hu *et al.*, 1995; Khasawneh and Doll, 1978; Sanya and De Datta, 1991):

$$\underbrace{Ca_{10}(PO_4)\,6F_2}_{\text{Phosphate rock}} + \underbrace{12H^+}_{\text{protons}} = \underbrace{10Ca_2^{+} + 6H_2PO_4^{-} + 2F^{-}}_{\text{reaction products}}$$

$$H_2PO_4^{-} + OH^{-}soil = H_2PO_4^{-}soil + OH^{-}$$

$$F^{-} + HO\text{-}soil = F^{-}soil + OH^{+}.$$

These reactions indicate that the rate of dissolution is governed by the concentration of protons (H^+) and the concentration of the reaction products, Ca^+ and H_2PO_4, in the solution immediately surrounding the PR being solubilized. A number of factors have been reported to affect the dissolution, hence agronomic effectiveness, of PR on its direct application to soil (Hammond *et al.*, 1986; Khasawneh and Doll, 1978). These factors include soil factors, plant factors and type and reaction of the PR.

It has been reported that the reactivity of PR is a function of the degree of substitution of CO_3^{2-} for PO_4^{3-} in the apatite structure. The higher the substitution the higher the reactivity (Khasawneh and Doll, 1978; Chien, 1977). Reactivity of PR also depends on the particle size used, which influences the surface area of the PR particles. Hammond *et al.* (1986) noted that grinding of PR was economic and effective when at least 80 percent of material passed through the 0.15mm (100 mesh) screen.

Soil pH is another factor, which influence dissolution of PR. Many workers (Hammond *et al.*, 1986; Mnkeni *et al.*, 1992; Kanabo and Gilkes, 1987; Hu *et al.*,

1997) found that PR dissolved more when soil was acidic than when it was neutral or alkali. Laboratory incubation experiment with a single soil adjusted to various pH levels showed that PR dissolution increased linearly with decreasing pH. Generally, PR has been found to be an effective fertiliser at pH < 6.0 (Khasawneh and Doll, 1978).

Another soil factor influencing PR dissolution is the Ca concentration. Mackay *et al.* (1986), Sale and Mokwunye (1993) and Welte (1978) reported that high Ca concentration in soil solution reduced PR dissolution. Among other soil factors, P concentration has been reported to influence PR dissolution, with better dissolution attained in soil with low available P (Le-Mare, 1991; Mnkeni *et al.*, 1992).

Organic matter is another factor known to influence dissolution of PR. Organic matter was thought to form complexes with soil calcium, thereby diminishing Ca concentration and consequently enhancing dissolution of PR (Chien and Hammond, 1989). Organic matter mixed with PR has been found by Ikerra (1986) and Ikerra *et al.* (1994) to increase PR dissolution. Ikerra *et al.* (1994) working with an Ultisol, reported release of 58 mg P/kg soil when MPR was combined with farmyard manure and 45 mg P/kg soil when MPR was applied alone, following 60 days of incubation.

Alexander (1977) reported that the addition of fresh dried plant residues resulted in release of more P from PR. He further noted that the increased availability of P from PR as a result of organic matter addition has been attributed to improved water holding capacity and soil nutrients, leading to increased microbial activities. Dhar

and Singh (1982) working with wheat (*Triticum spp*) reported higher yield in all plots receiving compost in combination with PR. Jaggi (1986) and Le-Mare (1991) noted that soils with high organic matter were suitable for PR dissolution. They further noted that phenols, aliphatic acids, carboxylic acids, amino acids, complex humic and fluvic acids and mineral acid ions produced during decomposition of compost enhanced the dissolution of PR.

2.4 Agronomic effectiveness of PR relative to water-soluble phosphate fertilisers

The use of indigenous PR has recently received tremendous interest as an alternative to processed mineral P fertilisers that usually are imported, high priced and often unavailable when needed (Kimbi *et al.*, 1996; Bashir, 1999). Some benefits of PR over processed mineral fertilisers include: (a) Cheap source of P for crops (b) PR can become an export commodity, there by strengthening national economies and regional trade linkages, and (c) PR exploitation generates employment opportunities (Bashir, 1999). A number of studies have highlighted the suitability of Minjingu Phosphate Rock (MPR) as P source for crops in acid and P deficient soils. Mnkeni *et al.* (1991), working with four different soils, observed varied effects of MPR on maize yield. In their experiment the rates of 80 kg and 240 kg P/ha significantly increased maize yields on Magadu and Mzumbe soils, both of which had <6.5 mg P/kg and pH < 5.2. Semoka *et al.* (1992) observed that at the application rate of 40 mg P/kg, MPR was as effective as TSP, with Relative Agronomic Effectiveness (RAE) values of 92% and 111% in an Utisol and Oxisol, respectively. Ikerra *et al.*

(1994) found MPR to be a good substitute to TSP for maize production especially when combined with organic materials (compost manure).

The superior agronomic effectiveness of PR over TSP was also emphasised by Hu *et al.* (1997). He noted that properties of soil (Ultisol) changed as follows, upon application of PR for six seasons, changed as follows: (1) pH of soil increased from 4.82 to 4.9-5.3, (2) The content of labile Ca increased from 693 microgram/gram to 800-1060 microgram/gram. (3) The content of exchangeable Ca increased from 1 194 microgram/gram to 1 300-2 100 microgram/gram. (4) The content of exchangeable Mg increased from 330 microgram/gram to 350-400 microgram/gram. (5) The content of available P increased from 4.3 microgram/gram to 4.7-6.5 microgram/gram. Although the TSP treatment could supply the Ultisol with more available P than the PR could, PR was superior to TSP for supplying Ca and Mg, and in raising pH. Also PR was more effective than TSP in reducing active Al species. This suggests that the potential of PR to reduce soil Al toxicity might be greater than that of TSP.

Anderson (1970) and Scaife (1968) compared MPR with double super phosphate using; maize, groundnuts, cotton and pasture as test crops. In most cases MPR was inferior to double superphosphate in the first year but when assessed over a longer period of three to six years it was found to be equal or more effective than double superphosphate. In another experiment, beneficiated MPR applied at 0.16 g/pot significantly increased sorghum dry matter yield on Mlama, Magadu and University Gate soil (Kimbi, 1991). Kimbi (1991) further observed that TSP applied at the same

rate increased the dry matter yields significantly only on an Oxisol and an Ultisol and this dry matter yield was compared to that produced by MPR. Kimbi *et al.* (1996) conducted pot and field experiments on three different acid and P deficient soils with beneficiated and partially acidulated MPR. From this experiment the beneficiated MPR applied at the rate of 80 kg P/ha significantly increased maize grain yields and was as effective as TSP with RAE of 77% and 67% in an Oxisol and an Ultisol, respectively. Moreover, results indicated a significant interaction between P source and soil type suggesting that efficiency of MPR was dependent on soil properties.

In a long-term field experiment conducted on acid sandy loam soils of Naliendele in Southeast Tanzania, Ngatunga *et al.* (1988) found MPR to be as effective as TSP in supplying P to sorghum. Nyaki *et al.* (1985) on the other hand, found no beneficial effect of applying MPR to wheat in Hanang district, Tanzania, in a soil of pH close to neutral while TSP applied at 20 kg P/ha was found to be more effective on increasing wheat yield. The evaluation of MPR for agronomic effectiveness has not been limited to Tanzania only but has been carried out in other countries as well. Okalebo *et al.* (1991) in Kenya reported a positive response of maize to MPR on a Luvisol of pH 5.3 and low available P. Banded MPR at 20 kg P/ha doubled maize grain yields from 668 to 1 337 kg/ha. The net P released from MPR indicated that this PR had good potential for direct application as a P fertiliser (Okalebo *et al.*, 1991).

2.5 Factors affecting availability of P from PR in the soil

The extent of PR dissolution in soil may not necessarily reflect availability of the P to plants (Bolan and Hedley, 1990; Syers and Mackay, 1986) because some other soil factors may intervene. Among others, P adsorption capacity is the major factor, which controls plant available phosphate in soil. Soil factors, which are known to influence phosphate adsorption, include clay mineral, hydrous oxide of Fe and Al, soil pH and organic matter content. Highly weathered soils such as Oxisols and Ultisols are known to retain large amount of phosphate added to such soil as fertiliser. This is because Oxisols and Ultisols contain large amounts of 1:1 clay minerals and Al and Fe hydrous oxides, which have high affinities for phosphate (Kuo, 1990). Aluminium and Fe oxides and their hydrous oxides can occur as discrete particles in soils or as coatings or films on the surfaces of other soil particles (Chen and Barber, 1990). Moshi *et al.* (1974) noted that hydrous oxides of Fe and Al contributed to P sorption when P fertiliser was applied to the soil and, consequently, decrease the amount of plant available P. Rivera *et al.* (1993) reported that three fractions, namely Ca-P, Fe-P and Al-P, were among the factors, which controlled available P in soil. Phosphorus availability from these three fractions increased in the order Ca-P>Fe-P>Al-P.

Soil pH is also an important factor controlling P availability. Bolan and Hedley (1990) demonstrated that for soils dominated with pH dependent charge, the extent of dissolution of PR increased with increasing soil acidity, but the proportion of dissolved P becoming plant available probably decreased due to increase in phosphate adsorption of the phosphate at lower soil pH. Syers and Mackay (1986)

and Rajan and Ghani (1997) observed the same. They found a decrease of available P with increasing P sorption capacity from both TSP and senchuri PR. For soil incubated with PR for 90 days the extractable P at the end of incubation period were 26 mg P/kg in a soil with low P-fixing capacity and 2 mg P/kg in a soil with high P-fixing capacity. Rajan and Ghani (1997) further observed a decrease of available P due to decrease in pH from 6.5 to 5.0.

Organic matter has also been reported to affect the reaction of P in the soil. Moreno *et al.* (1960), Bolland and Gilkes (1989) and Ikerra *et al.* (1994) showed that organic matter complexed Ca ions and thus increased P concentration in soil solution from Ca phosphates. Nagarajah *et al.* (1970) found that organic acids were capable of reducing the amount of P that was adsorbed by kaolinite, gibbsite and goethite. They generally suggest that organic acids could be adsorbed by ligand exchange on the mineral surface, thus competing with P for adsorption sites, thereby releasing more P into soil solution.

2.6. Effects of method of phosphate fertiliser placement on PR dissolution and availability of P

The above review has discussed the chemistry and interactions of phosphorus with different constituents of soil, and has surveyed the different factors affecting P dissolution and availability. All these aspect discussed will be affected by the method adopted of placing the P in the soil. Methods of fertiliser placement have been shown (Forth, 1990; Kanabo and Gilkes, 1987; Hammond *et al.*, 1986; Wendt and Jones,

1997) to influence dissolution and plant available P in soil. Among the different fertiliser placement methods, broadcasting and banding are the most commonly used. Several studies showed that banding of phosphate leads to more efficient use of fertiliser by plants than broadcasting dose (Ozanne, 1980; Sleight *et al.*, 1984). It is agreed that banding application reduces soil-phosphate contact, resulting in less phosphate fixation in the soil than what would occur with broadcasting (Sobulo *et al.*, 1978; Sleight *et al.*, 1984). Moreover, banding may decrease the distance from fertiliser to plant roots, and the distance influences P up-take by plants in that it may increase the probability of the plant root to come in contact with applied fertiliser. As the distance decreased from the origin of the root system the more were the root that come in contact with fertiliser hence increasing phosphate uptake, and vice versa (Sobulo *et al.*, 1978).

Application of P fertiliser through broadcasting leads to low nutrient concentration in the soil solution due to the fact that the applied nutrient is mixed with large volume of soil (Forth, 1990). However, application of phosphate fertilisers by broadcasting has been recommended in soil with low P adsorption capacities (Sanchez, 1976). Several studies reported good yields when PR's are applied by broadcasting, followed by thorough mixing with soil (Ensiminger *et al.*, 1967; Khasawneh and Doll, 1978; Hammond *et al.*, 1986). The good results are attributed to high dissolution due to the fact that the surface area of contact between PR materials and soil is increased. Wendt and Jones (1997) supported the contention that broadcasting worked better in soils of low P fixing capacity, and showed the superiority of broadcasting over banding of PR

in an Oxic Haplustalf and Ustic Tropept. They reported maize yields of 5 050 kg/ha and 4 710 kg/ha when PR was broadcasted and banded, respectively.

Banding PR has been reported to decrease PR dissolution in some soil (Sale and Mokwunye, 1993). This was because of build up of the dissolution products at the soil PR interface, thus limiting further dissolution due to small area of contact between the PR and soil. Uriyo *et al.* (1977) reported higher maize yield with banded TSP than broadcasted TSP in an Oxisol in Morogoro. Broadcasted MPR gave slightly higher maize yield (3.8 t/ha) than banded TSP (3.4 t/ha) both applied at rate of 40 kg P/ha on an Ultisol in Morogoro (Semoka *et al.*, 1992). Van Straten *et al.* (1992) tested different rates of TSP applied by banding on a Dystropept soil at Sasanda, Mbeya region in Tanzania and obtained maize yield of 6.82 t/ha at the rate of 120 kg P/ha while a study by Mwasha *et al.* (1995) at the same rates of TSP and site but applied by broadcasting gave a yield of 1.9 t/ha. Semoka *et al.* (1999) reported maize yield comparable to those reported by Mwasha *et al.* (1995) with both TSP and MPR applied at 120 kg P/ha by broadcasting. These studies indicate that broadcasting decreased the efficiency of the P source in this soil with high P fixing capacity, implying that some form of banding could be better.

Wendt and Jones (1997) compared banding with broadcasting of Tunduru PR in acid soil (Ustic Tropept) of pH < 6 and with low to medium available P. The results showed that banding gave higher maize dry matter yields of 7 690 kg/ha than broadcasting, which resulted in 4 010 kg/ha. Yost *et al.* (1979) using maize as a test crop in Typic Haplustox soil compared rates of 70, 140 and 280 kg P/ha applied by

broadcasting to half of these rates applied by banding. Under these conditions broadcasted TSP gave higher grain yields than banded TSP probably because of the difference in rates of application attained between banding and broadcasting. However, when the rate of 280 kg P/ha was applied using both methods, banding caused more P uptake and yields of 7.96 t/ha where as yield from broadcasting was 4.76 t/ha.

Many studies have revealed that despite the higher dissolution of PR in broadcasting, efficient use of P by plants from the fertiliser applied was achieved with banding. This was due to the fact that the fertiliser applied by broadcasting came into contact with a large volume of soil resulting in a high risk of the nutrients so dissolved being fixed in the soil (Forth, 1990). Kanabo and Gilkes (1987) similarly observed that for equal amounts of PR applied, a high proportion of the P solubilized was available to plants if PR was banded than when broadcast, despite a lower level of dissolution in the banded PR. Thus improving PR dissolution in the band may increase the extent of availability of the P and better crop performance. This could be achieved by increasing the volume of soil which is in contact with the PR. Addition of organic matter within the band may further improve dissolution.

A further drawback of broadcasting was that it required high rates of PR application to satisfy the P fixing capacity of a soil (Bolland and Gilkes, 1989). Moreover, broadcasting is laborious in the sense that it requires a second "tilling" of the land to incorporate the broadcast PR. Also during application, broadcast PR may be subjected to wind drift, thereby losing some of the PR as well as contaminating the

atmosphere when the PR is in dust form. An alternative to broadcasting placement is banding. As recommended by several researchers (Ozanne, 1980; Kanabo and Gilkes, 1987; Ngatunga *et al.*, 1988) banding PR resulted in more efficient use of fertiliser by plants than broadcasting. Economically, banding may require overall lower rates of phosphate fertiliser than broadcasting.

Inferior dissolution of PR on banded application has been reported (Sale and Mokwunye, 1993). Also Kanabo and Gilkes (1987) noted a lower dissolution of PR in banded application compared to the same amount in broadcasting. An explanation to less PR dissolution within a band is due to temporarily limited supply of H^+ ions for dissolution and with temporary accumulation of dissolved products (Ca^{2+}, P), which would reduce dissolution due to common ion effect (Bolland and Gilkes, 1989; Bolan and Hedley, 1990). However, the little amount of P dissolved in band application can be readily available for plant uptake as it is less exposed to the binding or fixing effect of the soil.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Pot and field experiment were conducted to assess the effect of various ways of applying MPR on improvement of dissolution and availability of P from banded MPR in two soils with contrasting characteristics. Two soils which have not been treated with any phosphate fertiliser for past ten years or more and which have contrasting characteristics were selected. These soils were from Magadu, Morogoro district, classified as Oxic Haplustult by Kaaya (1989), and from Sasanda, Mbozi district, classified as Drystropept by Van straaten *et al.* (1992). The soil from Magadu (adsorption maximum of 466 mg P/kg) and Sasanda (adsorption maximum of 4110 mg P/kg) are known to have medium and high P fixing capacity, respectively (Mwakisimba, 1999). Maize(*Zea mays* L.) varieties UH 615 and TMV1 were used as test crop in both pot and field experiments for soil of Sasanda and Magadu, respectively.

3.1 Soil sampling and analysis

Representative topsoil (0-20cm) was sampled from each site, air-dried and ground to pass through a three-millimeter sieve for the pot experiment and two-millimeter sieve for routine soil analysis.

Particle size distribution determination was determined by hydrometer method (Gee and Bauder, 1986). A 50 g air-dried soil sample was weighed into a 250ml plastic bottle. Fifty ml of 4% sodium pyrophosphate ($Na_4P_2O_7$) were added, followed by

200ml of distilled water. The mixture was shaken at 150 revolutions per minute (rpm) overnight on a shaker. It was then transferred to a one-litre sedimentation cylinder. Distilled water was added to the mixture to bring it to the mark. The mixture was stirred for one minute and left to stand. Hydrometer readings were taken after five minutes and three hours and the relative proportions of the soil particles (i.e. sand, silt and clay) were calculated. The texture was determined using the USDA textural class triangle.

Soil pH was determined in 1: 2.5 soil: water using a pH meter (McLean, 1982). Ten gram of soil sample was weighed into 100ml plastic bottles and 25mls of water were added. The mixture was shaken for half an hour on a reciprocating shaker and pH determined electronically using a pH meter.

Organic carbon was determined by Walkley and Black method (Nelson and Sommer, 1982). One gram of soil sample was weighed into 500ml Erlenmeyer flasks. To the sample 10mls of potassium dichromate solution were added and the flask shaken for about five seconds. Then 20mls of conc. H_2SO_4 were added. The flask was carefully swirled for one minute and allowed to stand for 30 minutes. Then 200ml of distilled water, 10ml of conc. H_3PO_4 and 2ml of diphenyalamine indicator were added. The mixture was titrated with (0.5M) ferrous sulphate to the end point (brilliant green). Two blanks (only the reagents but no soil) were also treated in the same way for the purpose of standardising the ferrous sulphate solution. The volume of ferrous sulphate was used for calculating the percentage organic carbon content.

Total N was determined by macro-Kjeldahl digestion followed by distillation (Bremner and Mulvaney, 1982). One gram of soil sample was digested with 10ml of conc. H_2SO_4 in the presence of K_2SO_4, $CuSO_4$) and selenium powder as catalyst, in a digestion tube. Then tubes were placed in the digestion block and digested at about 360°C until the digest was pale green. Tubes were then removed from the digestion block and allowed to cool, followed by addition of 50ml of distilled water, while swirling. Twenty ml of 4% boric acid indicator solution were measured into conical flasks and placed under the condenser tube tip. The digest was distilled after adding about 50ml of 40% NaOH. The ammonia liberated was collected in 4% boric acid-mixed indicator and the distillate was titrated with standard 0.01M H_2SO_4 until the colour changed from green to pink. One blank was also treated in the same way for each batch. The titre was used to calculate the total N of the soil sample.

Extractable P was determined according to the Bray 1 method (Bray and Kurtz, 1945) and colour development by the ascorbic acid method of Murphy and Riley (1962). Three gram of air-dried soil sample were weighed into a 50ml plastic bottle. Twenty ml of extracting solution containing 0.03M NH_4F + 0.025M HCl were added, shaken (by hand) for one minute and immediately the suspension was filtered. Five ml of extract was transferred into a 50ml volumetric flask; 30ml of distilled water and 4ml of phosphate reagent were added and mixed. Then it was made to mark with distilled water and mixed, and after 15-20 minutes Atomic Absorption Spectrophotometer (AAS) measured absorbence at 884nm wavelength. The absorbency was then used to calculate percentage P.

The cation exchange capacity (CEC) was determined by the ammonium acetate saturation method (Rhodes, 1982). Five gram of air-dried soil sample were weighed into a beaker, and 35ml of ammonium acetate (1.0M NH_4Ac) solution were added, stirred and left over night. Using a filter paper, filtrate was collected in a 100ml plastic bottle. The filtrate was reserved for determination of exchangeable cations. Soil samples on the filter paper were washed with ethanol and NH_4 ions were leached with acidified 1.0M potassium chloride and the filtrate collected in 100ml volumetric flask and made to volume with KCl solution. Twenty ml of two percent boric acid with mixed indicator were used in distillation process, with 25ml of the potassium chloride filtrate pipetted into 250ml distillation tubes. Then using a dispenser 20ml of 32 % NaOH were added to the distillation tube and the mixture distilled for seven minutes when boric acid turned green. Then sample and blank were titrated with standardised 0.02N H_2SO_4 until the colour changed from green to light red and CEC was calculated using volume of H_2SO_4 used.

From the NH_4Ac filtrate under the CEC procedure, exchangeable Ca and Mg from ammonium acetate leachate were determined by atomic absorption spectrophotometer at wavelength of 422.5nm and 285nm, respectively. Exchangeable K and Na were determined by flame spectrophotometer fitted with a filter usually at wavelength of 768 and 589nm, respectively.

Exchangeable Al was determined by the KCl method described by McLean (1982). Thirty grams of soil sample were extracted by 75ml 1M KCl and the suspension shaken for 15 minutes and filtered. Ten ml 40% NaF-solution + phenolphthalein-

indicator were added to 25ml of filtrate. Then filtrates were titrated with 0.02M NaOH until a pale red colour appeared. The solutions were then titrated with 0.02M HCl until the pale red colour just disappears. Titre volumes were used to calculate extractable acidity and Al, respectively.

DTPA extractable Zn and Cu were determined by atomic absorption spectrometry (Lindsay and Norvell, 1978). A 20 gram of soil sample was weighed into 100ml plastic bottle, and 40ml of buffered DTPA extraction solution were added. The suspension was shaken for two hours and immediately filtered using dry filter paper. The extracts were used to measure the contents of Cu and Zn using AAS at the wavelengths 324.8nm and 213.9nm, respectively.

3.2 Brief description of some chemical and physical properties of experimental soils

Some of the chemical and physical characteristics of Magadu (Oxic Haplustox) and Sasanda (Dystropept) soils are shown in Table 1. The texture of the soils was sand clay and sandy loam for Magadu and Sasanda, respectively. All experimental soils contained low extractable P. Soil pH (in water) for both Magadu and Sasanda experimental soils were medium. Organic carbon and total N in Magadu soil were very low and low, respectively, while in Sasanda soil organic carbon was low and total N was medium. The exchangeable Ca level were low in both Magadu and Sasanda soils. All the rankings quoted here are those published by Landon (1996).

Table 1. Some physical and chemical characteristics of the experimental soils

Parameters	Soil sampled	Area
	Magadu	Sasanda
pH in water	5.10	5.68
Organic carbon	1.35	3.66
Extractable P (mg/kg)	4.42	2.16
Total N %	0.07	0.23
CEC {cmol (+)/kg}	9.8	29.8
Exchangeable Ca {cmol (+)/kg}	1.66	0.93
Exchangeable Mg {cmol (+)/kg}	1.42	0.27
Exchangeable K {cmol (+)/kg}	0.76	1.03
Exchangeable Na {cmol (+)/kg}	0.15	0.07
Exchangeable Al {cmol (+)/kg}	1.15	0.7
Base saturation (%)	41	11
Extractable Cu (mg/kg)	1.10	1.03
Extractable Zn (mg/kg)	0.30	0.20
Particle size analysis		
%Sand	51	63
%Silt	3	18
%Clay	46	19
Textural class	Sandy clay	Sandy loam

The lower concentrations of extractable P and exchangeable Ca^{2+} in both soils, and the acidic nature of these soils, imply that these soils should offer conditions favourable for high dissolution of MPR, eventually leading to increased absorption by plants and increased crop yields.

3.3 Pot experiment

A pot experiment was conducted in a glasshouse at SUA. Four kg portions of soil sieved through 3mm sieve were weighed into five-litre pots. Six treatment combinations were tested using the two soils. The treatments were as shown below:

-Control (no MPR added)

-Strip banded MPR at 2-3cm depth of soil along the diameter of the pot

-MPR applied to 10cm depth of soil in the pot

-MPR applied to 20cm depth of soil in the pot

-MPR + O.M both applied to 10cm depth

-MPR + O.M both applied to 20cm.

Application of MPR alone and MPR + O.M. at 20cm depth were achieved by mixing thoroughly the fertiliser materials with four kg of soil before filling the pot which had a depth of 20cm. In the case of the 10cm depth placement, the pots were first filled with untreated soil, leaving space for overlaying a layer of soil mixed with fertiliser materials to fill the 10cm depth. In the strip banded MPR, pots were filled with 4kg of soil and then a strip of 2-3cm-width of surface soil was mixed with MPR to a depth of 2-3 cm. The pots were arranged in randomized complete block design with four replications. The organic materials used in this study were plant residues

indigenous in each particular area. *Ageratum conyzoides* (Goat weed) was used for Sasanda soil, whereby *Pycnanthemum tenuifolium* (Mountain mint) and *Hyperenia sp.* (Elephant grass) were used for the soil from Magadu.

The rate of MPR application was 160 mg P/kg soil. Zinc (as $ZnSO_4.H_2O$) and copper (as $CuSo4.5H_2O$) fertilisers, each at the rate of 5 mg /kg soil, and magnesium [$Mg(NO_3)_2.6H_2O$] for Sasanda soil at the rate of 50 mg Mg/kg soil were also applied. Nitrogen (as ammonium sulphate) at the rate of 100 kg/ha was applied. Organic materials were applied at the rate equivalent to 2 tons per hectare (6 g O.M./kg of soil). The application of Zn, Cu and N was done to ensure that these nutrients do not limit plant growth since previous results and the present soil analysis suggest that the levels of these nutrients in these soils are marginal.

Four maize seeds, varieties UH 615 and TMV1, were planted in the pot for Sasanda and Magadu experimental soils, respectively. Thinning was done to two plants per pot one week after emergence. Plants were watered frequently before any signs of water stress occurred, by adding sufficient distilled water to bring the soil water content to approximately field capacity. Two splits of nitrogenous fertiliser, as ammonium sulphate, were applied two weeks after seedling emergence and again four weeks after seedling emergence at the rate of 100 mg N/kg per split, giving a total of 200 mg N/kg. Plant shoots were harvested 42 days after planting, by cutting at about 1cm above the soil surface, for dry matter yield determination and plant tissue analysis. The plant samples were rinsed clean and oven dried at 65^0C to

constant weight. Then the samples were cut to small pieces and ground to pass through 0.5 mm sieve for nutrient analysis.

3.4 Field experiment

3.4.1 Location of the study sites

The field experiment was conducted at Sasanda and Magadu sites. The Magadu site is located within the SUA farm in Morogoro municipality. The site is located at latitude 6.85^0S and longitude 37.64^0E and at an elevation of 568masl. The Sasanda site is located at latitude 9.16^0S and longitude 33.03^0E, at an elevation of 1650masl.

3.4.2 Experimental design, treatments and cultural practices

Seven treatments were tested at each site, as follows:

-Control (no MPR added)

-MPR broadcasted and ploughed in to a 5-10 cm depth

-MPR banded in a strip of 4-5 cm band and covered with soil

-MPR applied as a 20 cm band and ploughed down to 10 cm depth

-MPR applied as a 20 cm band and ploughed down to 20 cm depth

-MPR + O.M. banded and ploughed to 10 cm depth

-MPR + O.M banded and ploughed to 20 cm depth.

The treatments were replicated four times and arranged in randomized complete block design, giving a total of 28 plots at each site. The plot size was 5m X 5m. Seeds were sown at a spacing of 75cm X 30cm. The inter plot and inter block spacing were 0.5 m and 1m, respectively, while a 2 m pathway was maintained

around the experimental area. Broadcasting of MPR was done by spreading the fertiliser materials on the soil surface followed by a second "tilling" to ensure thorough mixing into the soil. Banding MPR alone and MPR + O.M. and ploughed in to the 10 cm and 20 cm depths was done by opening a hoe-width furrow (20 cm) of the corresponding depth, followed by thorough incorporation of fertiliser materials within these furrow depths. In the strip banded MPR treatment, a strip of MPR was placed on soil surface in rows and covered with a small amount of soil. The rate of application of P was 80 kg P/ha, which is equivalent to 611 kg MPR/ha, and that of O.M. was 2 tons per hectare. In addition to P, Zn and Cu fertilisers were applied at the rates of 5 kg /ha and Mg fertiliser at the rate of 25 kg Mg/ha for Sasanda soil. For the Magadu soil, only Zn fertiliser was applied in addition to P. These fertilisers were applied during planting time. The organic materials used were the same as those used in the pot experiments.

Planting was done in early December 2001 and early March 2002 at Sasanda and Magadu sites, respectively. The maize varieties used were UH 615 and TMV1 for Sasanda and Magadu sites, respectively. Two seeds were sown per hole and seedlings were then thinned to one plant per hill two weeks after seedling emergence. At the Magadu field, nitrogen fertiliser at the rate of 80 kg N/ha was applied in three splits. The first split (30 kg N/ha) was applied immediately after thinning, the second split (30 kg N/ha) on the 6^{th} week from sowing and the last split (20 kg N/ha) was applied at the onset of tasseling. At Sasanda the rate of N application was 100 kg N/ha, applied in three splits. The first application (40 kg N/ha) was done three weeks after planting, the second split (40 kg N/ha) at the 9^{th} weeks after planting and the

third split (20 kg N/ha) at 15 weeks after planting. Weeding was done to maintain the experimental plots almost free from weeds for most of the plant growth period. At both experimental sites maize was harvested at maturity, from five inner rows of each plot, covering an area of 20.21m^2. Cobs were shelled, grain weighed and moisture content of the grain determined using an electronic moisture meter. The yield data was reported in t/ha at 12.5% moisture.

3.5 Plant sampling and analysis

Maize shoots from each pot were harvested 42 days after planting. The whole plant was cut 1cm above the soil surface, rinsed clean with deionized water and oven dried at 65^{0}C to constant weight for dry matter and nutrient concentration determination. In the field experiments, plant sampling was done by randomly taking three ear leaves from each of the inner five rows, giving a total of 15 leaves per plot. These plant samples were taken when almost 50% of maize plants had tasselled. The samples were oven dried at 65^{0}C to constant weight. Then the samples for nutrient concentration determination were cut to small pieces and ground to pass through 0.5 mm sieve, and analysed for N, P, K, Mg, Ca and Zn as per procedure for each element as described below.

Half gram of dried plant samples ground to pass through 0.5mm sieve were weighed and placed in digestion tubes. They were digested by using a mixture of HNO_3 and H_2O_2 as outline by Jones and Case (1990) and modified by Moberg (2000). 5mls of 68% HNO_3 were added to each tube using an automatic dispenser and the mixture

left to stand over- night. The tubes were then placed in a digestion block and digested at a temperature of 125^{0}C for one hour and cooled. Five ml of H_2O_2 were then added into each tube and heated at 70^{0}C on the digestion block until the reaction stopped. This treatment was repeated until the digest was colourless. The digest was then heated on a digestion block at 180 ^{0}C to near dryness. After cooling 10mls of 10% HNO_3 were added and the dissolved digest residues transferred quantitatively to a 100ml volumetric flask and filled to the mark with distilled water. The content of P in the digest was determined spectrophotometically after colour development using the ascorbic acid-molybdate blue method (Moberg, 2000). Calcium, Mg and Zn from the digest were determined using an atomic absorption spectrophotometer while K was determined by using a flame spectrophotometer. Analysis of total N was done using the macro-Kjeldahl method following the procedure given for total N for soils in section 3:1.

3.6 Data analysis

Analysis of variance was performed on plant P, Ca, K, Mg and N concentration, and on dry matter and grain yields. Duncan's New Multiple Range Test was used for separation of means. The statistical model used for data analysis was as described by Snedecor and Cochran (1989):

$Yij = U + Ti + Bj + Eij$

Where: Yij = Response

U = General effect

Ti = Treatment effect

Bj = Block effect

Eij = Random error

i = 1, 2, ...t

j = 1, 2, ...b

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Pot experiment

4.1.1 Maize dry matter yields

The dry matter yields are shown in Table 2. Both in high P fixing Sasanda soil and low P fixing Magadu soil, the dry matter yields were significantly (P=0.05) increased in response to various ways of banding MPR. The dry matter yields obtained ranged from 3.17 g to 56.32 g and 7.13 g to 76.24 g for Sasanda and Magadu soils, respectively. For both soils the control treatment had lowest yields. The strip banding treatment had lower DM yields than other MPR treatments. In both soils, incorporating MPR to a soil depth of 20 cm increased DM yields over incorporation to a depth of 10 cm. When organic matter was also incorporated in addition to MPR, the 20 cm depth of incorporation resulted in significantly (P=0.05) higher dry matter yields than the 10 cm depth in Sasanda soil, but not in Magadu soil.

The lowest DM yields in the control treatment probably was due to deficiency of phosphorus as no source of P was applied in this treatment. The relatively lower DM yields when MPR was strip-banded compared to other treatments may be due to low dissolution of MPR in this treatment. This might have been caused by limited contact between the soil and MPR. This means that there was limited supply of H^+ from soil for dissolution of the MPR, due to this limited contact with the soil (Bolland and Gilkes, 1989). Thus, there was P deficiency in the strip-band treatment also.

Table 2. Dry matter yields as influenced by various manipulations on banded MPR in two experimental soils

Treatment	Maize dry matter yields	
	Sasanda soil	Magadu soil
	.....g/pot.....	
Control	3.17e	7.13c
Strip banded MPR	26.68d	55.19b
20-cm MPR Band, incorporated 10cm deep	41.33c	61.50b
20-cm MPR Band, incorporated 20cm deep	51.02b	74.62a
20-cm MPR Band + O.M, incorporated 10cm deep	49.48b	71.40a
20-cm MPR Band +O.M, incorporated 20cm deep	56.32a	76.24a
CV, %	8.6	9.6

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

The progressively higher dry matter yields from the treatments where MPR was incorporated to 20 cm depth, with or without organic matter, was due to increased contact between the MPR and soil, thereby leading to increased dissolution of the MPR and increased uptake of P, Mg and Ca by the plants. These results agree with those reported by Hammond *et al.* (1986) that PR dissolved more to release P, Ca and Mg into soil solution when it was mixed with relatively large volume of soil. The MPR upon dissolution and release of Ca also contributed a liming effect to the soil, hence providing favourable pH environment for plant performance. Hue, *et al.* (1997) reported the liming effect of PR in soil. In the Magadu soil, the lack of a significant difference in DM yields in the treatment that received organic matter at 10 cm or 20 cm depth of incorporation may be was due to the slightly high inherent soil P (Table 1) compared to that of Sasanda soil. The relatively higher soil P in Magadu may have also contributed to the relatively higher DM yields from that soil.

The high dry matter yields in the MPR + O.M. treatments may be due to improved dissolution of MPR and increased availability of P as a result of presence and decomposition of organic matter. These results conform to those obtained by Ikerra *et al.* (1994) and Le Mare (1991) who noted that dissolution of PR was improved when it was incorporated together with organic materials. They further noted that availability of P to plants was improved when soil was supplied with organic matter as this reduced P sorption by the soil. The lower DM yields when the MPR was in contact with small volume of soil, as in the present strip-band treatment, may be due not only to low dissolution of MPR but also due to a temporal accumulation of

dissolution products (Ca^{2+}, P) which would prevent further dissolution of MPR due to the common ion effect (Bolland and Gilkes, 1989).

4.1.2 Effect of MPR placement on phosphorus uptake by maize

The P uptake as influenced by the various MPR treatments is presented in Table 3. Plant P uptake ranged from 2.75-83.24 mg/pot and 4.72-118.90 mg/pot for Sasanda and Magadu soils, respectively. The control treatment had the lowest P uptake. All other treatments, which received MPR, had significantly (P=0.05) higher P uptake by maize plants compared to the control treatment. Strip banded MPR had the lowest P uptake by maize plants compared to the other treatments that received MPR. In both soils, the MPR incorporated to the depth of 20 cm resulted in significantly (P=0.05) higher P uptake than that from MPR at 10 cm depth. However, the MPR+O.M. incorporated down to the 20 cm depth resulted in significantly (P=0.05) higher P uptake than that from MPR + O.M. incorporated down to 10 cm depth in the Sasanda but not in the Magadu soil. There was generally a higher uptake of P from Magadu soil as compared to the Sasanda soil.

The lowest P uptake observed in control treatment is thought to be due to low levels of phosphorus in these soils, because these soils have low inherent P (Table 1) coupled with high P fixing capacity (Mwakisimba, 1999). These results are consistent with the data on dry matter yields reported in section 4:1:1, and also with P concentration trends in the plant material (Table 4).

Table 3. Effect of various manipulations on banded MPR on plant P uptake in two experimental soils

Treatment	Phosphorus uptake by maize plant	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	2.75d	4.72c
Strip banded MPR	35.87c	44.63b
20-cm MPR Band, incorporated 10cm deep	41.41c	50.15b
20-cm MPR Band, incorporated 20cm deep	69.03b	107.30a
20-cm MPR Band + O.M, incorporated 10cm deep	67.88b	118.90a
20-cm MPR Band +O.M, incorporated 20cm deep	83.24a	118.4a
CV, %	15.1	11.5

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test

Table 4. Phosphorus concentration in maize plant shoots as influenced by the various MPR treatments

Treatments	Phosphorus concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	0.088c	0.067d
Strip banded MPR	0.094c	0.082d
20-cm MPR Band, incorporated 10cm deep	0.136b	0.143c
20-cm MPR Band, incorporated 20cm deep	0.15b	0.155ab
20-cm MPR Band + O.M, incorporated 10cm deep	0.137b	0.166ab
20-cm MPR Band +O.M, incorporated 20cm deep	0.184a	0.180a
CV, %	11.4	10.9

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

In both experimental soils the lower P uptake observed with strip banded MPR and MPR incorporated down to the 10 cm as compared to other treatments suggests that there was limited dissolution of MPR in these treatments because the MPR was more localized. This may be due to small volume of contact between soil and MPR materials as already discussed in section 4.1.1. The higher P uptake when MPR was incorporated down to 20 cm depth compared to 10 cm depth implies that when the volume of contact between soil and MPR materials is increased, more P is dissolved from MPR leading to higher P uptake and, ultimately, to higher DM yields as discussed in section 4.1.1.

The superior P uptake in treatments received MPR + O.M. incorporated down to 10cm or 20cm suggests that organic matter contributed to higher dissolution of MPR in those treatments, and the organic matter also reduced considerably the extent of P fixation in the soil. Thus, more of the dissolved P was available for plant uptake. This is in agreement with Iyamuremye and Dick (1996) who reported that organic acids produced during the decomposition of organic matter temporally reduced P fixation by the soil, by binding to the oxide and hydroxide of the surfaces of clay particles, thereby increasing the P available for plant uptake. This is because organic anions formed during decomposition of organic inputs competed with P for the same sorption sites, thus freeing the P.

However, in the Magadu soil, the lack of a significant difference between the MPR + O.M. incorporated down to both 20 cm or 10 cm depth and the MPR incorporated down to 20cm was probably due to a relatively slightly higher inherent P status of

this soil compared to that of Sasanda. Mwakisimba (1999) reported that Sasanda soil has high P fixing capacity than the Magadu soil. Therefore, the small amount of P dissolved from MPR was more available in soil solution due to the lower P fixing capacity of the Magadu soil.

4.1.3 The concentration of other plant nutrients as influenced by various MPR treatments

4.1.3.1 Nitrogen

The concentration of nitrogen in maize shoots as influenced by the MPR treatments is presented in Table 5. Nitrogen concentration ranged from 0.33-1.94 % and 0.68-1.53 % for Sasanda and Magadu soils, respectively. Higher nitrogen concentrations were associated with all MPR treatments relative to the control. The MPR treatment associated with O.M. addition gave the highest nitrogen concentrations in maize shoots.

Generally, the concentrations of N in plant shoots for Sasanda were higher compared to those for Magadu soil. The relative higher concentration of nitrogen in maize shoots from the MPR +O.M. treatments generally coincided with increased or high supply of P in those treatments as depicted by P uptake (section 4.1.2). This may serve to illustrate the principle of better utilization of nitrogen when phosphorus is adequate in soil, and the vice versa.

Table 5. The concentration of nitrogen in maize plant shoots as influenced by various MPR treatments

Treatment	Concentration of nitrogen in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	0.33c	0.68d
Strip banded MPR	1.47b	0.98c
20-cm MPR Band, incorporated 10cm deep	1.73ab	0.99c
20-cm MPR Band, incorporated 20cm deep	1.55b	1.30b
20-cm MPR Band + O.M, incorporated 10cm deep	1.76ab	1.33b
20-cm MPR Band +O.M, incorporated 20cm deep	1.94a	1.53a
CV, %	15.8	10.8

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

Chapman (1965) set the following guidelines for nitrogen content of plants: N values of <1.8% were ranked as deficient, and those between 1.8-3.5% were ranked as low, while those >3.5% were ranked as adequate for maize growth for samples taken between 30-45 days after planting. Thus, the concentrations of nitrogen in the present experiment were, with one exception (MPR + O.M. incorporated to 20 cm in Sasanda soil), in the deficiency range. The low content of nitrogen in the plant materials, in the deficiency range, may be related to complex dynamics of nutrients, including nitrogen, under pot experimental conditions. The restricted volume in the pots may have interfered with root proliferation and, subsequently, resulted in reduced nutrient uptake (Tisdale *et al.*, 1990).

4.1.3.2 Potassium

The effects of various MPR treatments on K concentration in maize plant shoots are presented in Table 6. The K concentration ranged from 2.29-4.51% and 1.4-3.83% for Sasanda and Magadu soil, respectively. In both soils, the MPR treatments significantly (P=0.05) reduced K concentration in maize shoots. Probably, increased P supplies in treatment, which received MPR, and the resultant high DM yields caused a dilution effect of K in the high yielding plants. Marschner (1990) reported that increased yields of DM cause dilution of nutrients within the plant tissues. According to Tandon (1995) maize plants have sufficient K if its concentration is in the range of 2.5-4.0%. This was generally attained in the Sasanda soil, but to a much less extent in the Magadu soil.

Table 6. The concentration of K in maize plant shoots as influenced by various way of banding MPR in two soils

Treatment	Concentration of potassium in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	4.51a	3.84a
Strip banded MPR	3.72b	2.90b
20-cm MPR Band, incorporated 10cm deep	2.63cd	2.26c
20-cm MPR Band, incorporated 20cm deep	2.96c	2.23c
20-cm MPR Band + O.M, incorporated 10cm deep	2.68cd	1.87c
20-cm MPR Band +O.M, incorporated 20cm deep	2.29d	1.40d
CV, %	10.4	12.9

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

4.1.3.3 Zinc

The effects of the various MPR treatments on zinc concentration in maize plant shoots are shown in Table 7. The Zn concentrations ranged from 12.58-27.55 mg/kg and 14.33-27.16 mg/kg for Sasanda and Magadu soils, respectively. The control and strip banded MPR treatments contained higher Zn concentrations, while Zn concentrations were significantly (P=0.05) lower in other treatments. Tandon (1987) noted that increased supply of P in soil (solution) induced low level of Zn in plants due to an antagonistic effect. This may have been the case in the present studies, as well as a possible depressing effect due to unfavourable dynamics of nutrients under pot experimental conditions.

According to Tandon (1995) zinc concentration values of <20 mg/kg were ranked as being low and those value between 20-60 mg/kg as sufficient for maize plant growth. Thus, only the plants from control and strip-banded MPR treatments had sufficient levels of Zn while the same were deficient in the rest of the MPR treatments.

4.1.3.4 Magnesium

The concentrations of Mg in maize plant shoots are shown in Table 8. The Mg concentration ranged from 0.15-0.30% and 0.13-0.29% for Sasanda and Magadu soils, respectively. In both experimental soils MPR treatments significantly (P=0.05) increased Mg concentration in plants shoots. Tandon (1995) provided the critical range of Mg concentrations in maize shoot to be 0.15-0.45%. According to this rating in both experimental soils the Mg concentration value for all treatments are

Table 7. Effects of various ways of banding MPR on Zn concentration in maize plant shoots in two soils

Treatment	Concentration of zinc in maize plant shoots	
	Sasanda soil	Magadu soil
	.....mg/kg.....	
Control	27.55a	27.16a
Strip banded MPR	21.92b	21.38b
20-cm MPR Band, incorporated 10cm deep	16.93c	18.47c
20-cm MPR Band, incorporated 20cm deep	14.98cd	17.47c
20-cm MPR Band + O.M, incorporated 10cm deep	13.53d	16.44cd
20-cm MPR Band +O.M, incorporated 20cm deep	12.58d	14.33d
CV, %	9.4	10.1

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test

Table 8. The concentration of Mg in plant shoots as influenced by various manipulations on banded MPR in two soils

Treatment	Concentration of magnesium in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	0.15c	0.13c
Strip banded MPR	0.17c	0.15c
20-cm MPR Band, incorporated 10cm deep	0.18bc	0.13c
20-cm MPR Band, incorporated 20cm deep	0.16c	0.21b
20-cm MPR Band + O.M, incorporated 10cm deep	0.23b	0.21b
20-cm MPR Band +O.M, incorporated 20cm deep	0.30a	0.29a
CV, %	13.5	15.7

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

within the critical range, hence not limiting, except for the absolute control and the MPR alone incorporated down to 10cm depth in the Magadu soil.

4.1.3.5 Calcium

The effect of the various MPR treatments on the calcium concentrations in plant shoots from the two soil are shown in Table 9. The calcium concentration ranged from 0.063-0.271% and 0.056-0.288% for Sasanda and Magadu soils, respectively. Jones and Eck (1973) established the critical range of Ca in maize plant shoots to be 0.21-1.0%. According to this criterion, only those treatments received MPR + O.M. resulted in sufficient Ca in the maize shoots in both experimental soils. The rest of the treatments resulted in Ca contents below the critical range.

The sufficient Ca level in the MPR + O.M. treatments may be due to improved dissolution of MPR and consequently increased availability and plant absorption of P and Ca in those soils that received the organic residues. Hu et al. (1997) reported that the supply of Ca in soil increased upon dissolution of MPR in the soil since Ca is a constituent of MPR. Miller et al. (1972) found mutual Ca and P synergism, which in the present case may have resulted in increased plant absorption of both nutrients

The result of this study illustrated (section 4.1.3.1) that better utilization of nitrogen was achieved when phosphorus was adequately supplied in the soil. Further more, the trend of Mg and Ca concentration in plant leaves suggested the synergistic

Table 9. Influence of the various MPR treatments on plant Ca concentration in maize plant shoots in two soils

Treatment	Concentration of calcium in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	0.063e	0.056d
Strip banded MPR	0.090de	0.065d
20-cm MPR Band, incorporated 10cm deep	0.136cd	0.127c
20-cm MPR Band, incorporated 20cm deep	0.187bc	0.176b
20-cm MPR Band + O.M, incorporated 10cm deep	0.220ab	0.221b
20-cm MPR Band +O.M, incorporated 20cm deep	0.271a	0.288a
CV, %	27.4	17.2

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

interaction with P. However, P had antagonistic interaction with Zn as discussed in section 4.1.3.3.

4.2. Field experiment

A study was conducted under field condition as a follow-up of the pot studies, to further evaluate the effects of various ways of banding MPR on its dissolution and availability of P from MPR. This experiment was carried out using the two soils employed in the pot study, that is Magadu and Sasanda soils.

4.2.1 Maize grain yields

The maize grain yields are given in Table 10. The maize grain yields for Sasanda and Magadu ranged from 0.16-2.27 t/ha and 0.32-2.59 t/ha, respectively. The control treatment had the lowest maize grain yields. The strip banded MPR treatment had the lower maize grain yields compared to the other treatments that received MPR. In both soils broadcasted MPR resulted in maize grain yields statistically similar to those from the banding treatments, which also received organic matter. For the Sasanda soil, depth of MPR incorporation, with or without O.M., did not result in any significant (P=0.05) difference in maize yields. However, in Magadu soil, MPR + O.M. incorporated down to 20 cm depth resulted in higher (P=0.05) yields compared to the other banding treatments.

Table 10. Maize grain yields as influenced by different ways of MPR application in two experimental sites

Treatment	Maize grain yields	
	Sasanda site	Magadu site
	.....kg/ha.....	
Control	162.9d	318e
Broadcasting MPR	1 802ab	2 296ab
Strip banded MPR	1 155c	1 209d
20-cm MPR Band, incorporated 10cm deep	1 631bc	1 789c
20-cm MPR Band, incorporated 20cm deep	1 682b	1 805c
20-cm MPR Band + O.M, incorporated 10cm deep	1 759ab	2 121bc
20-cm MPR Band +O.M, incorporated 20cm deep	2 271a	2 596a
CV, %	22.7	17.3

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

The inferior maize grain yields observed for the control treatment for both experimental sites were probably due to deficiency of P. Upon addition of P in the other treatments, yields were increased. This assertion is consistent with the low Bray 1 P levels of these soils (Table 1). Semoka (1999) and Kadogholo (2001) also reported increased maize grain yields upon application of MPR at these sites. The lower maize grain yields from strip banded MPR compared to other MPR placement treatments suggests that there was poor dissolution of MPR in strip band and, consequently, low amount of P was released into soil solution for plants uptake, as discussed in section 4.1.1. The higher maize grain yields obtained with broadcasting MPR treatment are due to higher MPR dissolution associated with greater volume of contact between soil and MPR when the MPR was thoroughly mixed into the soil. Greater dissolution resulted in larger quantities of P that subsequently became absorbed by the plants.

In both experimental sites, the maximum grain yields were obtained with treatments received O.M. in addition to MPR, and when incorporated down to the 20 cm depth. This may be associated with higher dissolution of MPR as reflected by higher levels of Bray 1 in the soil (section 4.2.3). These results are supported by several other researchers (Ikerra *et al.*, 1994; Chien and Hammond, 1989; Jaggi, 1986; Le-Mare, 1991) who reported that organic matter enhanced PR dissolution. Although the yields under MPR + O.M. (20 cm depth) were not statistically different from those in the broadcast treatment, they were nevertheless somewhat higher. Moreover, this MPR + O.M. treatment also has a practical advantage relative to broadcasting from the standpoint of saving labour on the part of farmer. The broadcast MPR treatment

needs incorporating the MPR into soil, which is like a second "tilling" of the land. This require more labour input which the resource-poor farmers, who are mainly dependent on the family labour to meet various farm activities (i.e. cultivation, weeding, sowing), may not have or may not be willing to use on repeatedly "tilling" of the same land. However, incorporating MPR to 20 cm depth only at the position where the raw of maize will be established (on banded MPR) would take a comparatively lower labour input, which the farmer may willingly invest.

4.2.2 Effect of MPR on P concentration in maize plants

The plant P concentrations as influenced by the various MPR treatments are presented in Table 11. The P concentrations in the flag leaves ranged from 0.070-0.195% and 0.140-0.227% for Sasanda and Magadu sites, respectively. The control treatment and strip banding of MPR had the lowest P concentration. The strip banded MPR treatment had the lowest P concentration as compared to the other treatments that received MPR fertiliser. Broadcasting of MPR, and that banded together with O.M. and incorporated to the 20 cm depth, resulted in the highest P concentration in plant leaves. The plant P concentrations from the other banding treatments were not statistically different (P=0.05).

The low but similar P concentrations in flag leaves of control and strip banded treatments implies that MPR in the strip band did not dissolve much to release sufficient P in soil solution for plants uptake. This is consistent with the low Bray 1 extractable P and the low maize grain yields from these treatments.

Table 11. Influence of various MPR treatments on P concentration in maize flag leaves for two sites soil

Treatment	Concentration of phosphorus in maize plant leaves	
	Sasanda site	Magadu site
	.....%	
Control	0.071c	0.140e
Broadcasting MPR	0.178a	0.209ab
Strip banded MPR	0.070c	0.168de
20-cm MPR Band, incorporated 10cm deep	0.141b	0.181bcd
20-cm MPR Band, incorporated 20cm deep	0.135b	0.172cde
20-cm MPR Band + O.M, incorporated 10cm deep	0.145b	0.205abc
20-cm MPR Band +O.M, incorporated 20cm deep	0.195a	0.227a
CV, %	14.5	11.8

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

The relatively higher plant P in the broadcast treatment was due to greater dissolution of the broadcasted MPR in both sites, due to increased surface area of contact between soil and MPR as explained in section 4.2.1. The similar P concentrations in flag leaves of the MPR+O.M. incorporated down to the 20 cm depth as in the broadcast treatment implies that a comparable degree of contact between soil and MPR particles was achieved. The relative lower P concentrations in the leaves from Sasanda are consistent with the lower levels of Bray 1 extractable P in those volcanic soils (section 4.2.3). The Sasanda soils are known for their much higher capacity for fixing P (Mwakisimba, 1999) as compared to the Magadu soil.

The relatively higher P concentration in maize flag leaves from Magadu soil was probably due to higher dissolution of MPR due to the lower pH of this soil (Table 1) and the lower P fixing capacity of the soil. Comparable results have been reported from previous studies in the same sites (Kadogholo, 2001; Mwakisimba, 1999; Babili, 1999).

4.2.3 Bray-1 Extractable phosphorus

Bray 1 extractable P as influenced by the various MPR treatments in field plots are presented in Table 12. Bray 1 extractable P values for Sasanda and Magadu soils ranged from 4.00- 18.45 mg/kg and 5.39-79.84 mg/kg, respectively. In both experimental sites the treatment control had the lowest Bray 1 extractable P. Strip banded MPR treatment had lower extractable P compared to the other MPR treatments. Broadcasted MPR resulted in significantly (P=0.05) higher extractable P

Table 12. Bray 1 extractable phosphorus as influenced by the various MPR treatments in two site soils

Treatment	Extractable Phosphorus in the soils	
	Sasanda site	Magadu site
	.....mg/kg.....	
Control	4.0e	5.39e
Broadcasting MPR	8.85d	46.90c
Strip banded MPR	6.31e	17.87d
20-cm MPR Band, incorporated 10cm deep	11.73c	44.67c
20-cm MPR Band, incorporated 20cm deep	14.33b	50.33c
20-cm MPR Band + O.M, incorporated 10cm deep	17.10a	70.75b
20-cm MPR Band +O.M, incorporated 20cm deep	18.45a	79.84a
CV, %	14.5	11

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test

compared to control and strip banding MPR treatments. However, it had lower extractable P compared to that of the other MPR treatments. Minjingu PR incorporated down to the 20 cm depth had significantly (P=0.05) higher Bray 1 extractable P compared to MPR incorporated down to the 10 cm depth for Sasanda soil, while in the Magadu soil the Bray 1 P values were similar between these treatments. Minjingu PR+O.M. incorporated down to the 20 cm depth had significantly (P=0.05) higher extractable P compared to MPR+O.M. incorporated down to the 10 cm depth for Magadu soil, while no difference was observed in the Sasanda soil. The MPR+O.M. incorporated to the 20 cm depth had significantly (P=0.05) higher extractable P than MPR alone incorporated to the 20 cm depth. Similarly, MPR+O.M. incorporated to the 10 cm depth had significantly (P=0.05) higher Bray 1 extractable P compared to MPR alone at the same depth of incorporation.

The lowest Bray 1 extractable P obtained with control treatment was probably due to the inherent low P status of the soil (Table 1) coupled with high P fixing capacity of these soils (Mwakisimba, 1999), especially the Sasanda soil. This indicated that in both soils there was severe deficiency of P, and this was consistent with the poor performance of maize and P concentration in maize plants in this treatment (sections 4.2.1 and 4.2.2), suggesting a great demand for P supplementation for good crop growth and production. The low amount of extractable P observed where MPR was strip banded might be due to poor dissolution of MPR as discussed in section 4.1.1. The low extractable P in the broadcasted MPR treatment as compared to banded

MPR + O.M. treatment or MPR incorporated down to 20 cm may be due to fixation of the solubilized P as discussed in section 4.2.2.

According to the P fertility categories given by Landon (1996), extractable P values of <15 mg/kg are ranked as low, those between 15-50 mg/kg are ranked as medium and those >50 mg/kg are ranked as high. In the Sasanda soil the values for extractable P are ranked as low for all treatments except for those MPR treatments that received organic matter, which can be ranked as medium. The medium value of extractable P obtained when organic matter was incorporated together with MPR implies that organic matter enhanced dissolution of MPR and/or reduced P sorption by the soil, consequently, increasing the amount of plant available P in the soil solution. Likewise, in Magadu experimental site, the highest value (79.84 mg/kg) of extractable P was obtained when MPR was incorporated together with organic matter. The higher extractable P observed in these studies corresponded to higher dry matter yields, higher P uptake by plants and higher grain yields (sections 4.1.1, 4.1.2, and 4.2.1). This confirms that P was deficient in these soils such that addition of P was necessary for increased yields. These findings agree with Mnkeni *et al.* (1991) who found a decrease in P sorption in soil resulting from addition of plant residues or farmyard manure. Similarly, Ikerra *et al.* (1994) reported increase in extractable P, maize dry matter yields and P uptake by plant from soil treated with MPR plus manure.

Generally, the levels of extractable P in Magadu soil were slightly higher than those for Sasanda soil. This was probably due to the medium P fixing capacity of the soil at

Magadu site (Mwakisimba, 1999) and a relatively higher dissolution of MPR because Magadu soil was more acidic (Table 1). In contrast, the Sasanda soil had a very high capacity for P fixation (Mwakisimba, 1999) and its relatively higher pH would result in a relatively lower extent of dissolution of MPR.

4.2.4 The concentrations of other plant nutrients in maize plants as influenced by the various MPR treatments

4.2.4.1 Nitrogen

The concentration of nitrogen in maize flag leaves as influenced by the various MPR treatments is presented in Table 13. Nitrogen concentration ranged from 0.86-2.42% and 1.2-2.50% for Sasanda and Magadu sites, respectively. Higher nitrogen concentrations were associated with all MPR treatments relative to the control. In both sites, those treatments, which received organic matter in addition to MPR, resulted in slightly higher N concentrations in maize leaves. These results suggest that the improved supply of extractable P (Table 12) upon MPR use improved N absorption and utilization by maize plants.

However, the N concentrations were lower than the critical levels given by Tandon (1995) whereby nitrogen concentration values of <3.5% are ranked as low and those between 3.5-5% are ranked as high for maize growth. The lower N concentrations at Sasanda site may be due to leaching, despite the split N application regime adopted, since this site receives very high rainfalls of up to 1 000 mm or more annually (Kadogholo, 2001). In the Magadu site, the low plant N may be due to the prolonged

Table 13. Nitrogen concentration in maize flag leaves as influenced by the various MPR treatments in two experimental sites

Treatment	Nitrogen concentration in maize flag leaves	
	Sasanda site	Magadu site
	.....%	
Control	0.86c	1.20d
Broadcasting MPR	2.24ab	2.29bc
Strip banded MPR	2.07b	2.19c
20-cm MPR Band, incorporated 10cm deep	2.09b	2.32bc
20-cm MPR Band, incorporated 20cm deep	2.03b	2.32bc
20-cm MPR Band + O.M, incorporated 10cm deep	2.36a	2.45ab
20-cm MPR Band +O.M, incorporated 20cm deep	2.42a	2.50a
CV, %	7.8	5

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

moisture stress that affected the plants from tasselling to maturity, which may have caused little plant absorption and under utilisation of the N fertiliser applied in the second and third splits.

4.2.4.2 Magnesium

The Mg concentrations in maize plants are shown in Table 14. The range of Mg concentrations were 0.094-0.325% and 0.168-0.248 % for Sasanda and Magadu sites, respectively. The Mg concentration values were slightly higher at Sasanda site than at Magadu site. The trends of concentrations of Mg are consistent with plant performance (section 4.2.1). The higher Mg in plants from Sasanda may be because of the contribution from magnesium sulphate applied to the soil to correct a suspected Mg deficiency. Despite the slightly lower Mg concentrations in plant from the Magadu site, the Mg concentrations under treatments which received MPR were within the sufficiency range of 0.15-0.45% given by Tandon (1995).

4.2.4.3 Calcium

The calcium concentrations in maize flag leaves are presented in Table 15. The plant Ca concentrations for Sasanda and Magadu experimental soil ranged from 0.109-0.29% and 0.15-0.38%, respectively. The Ca concentration for the treatment control was the lowest for both experimental sites. This implies that MPR application significantly (P=0.05) increased Ca concentration in the soil and, thus, plant uptake. Similarly, Mnkeni *et al.* (1992) reported that application of MPR increased Ca

Table 14. Magnesium concentration in maize flag leaves as influenced by the various MPR treatments

Treatment	Magnesium concentrations	
	Sasanda site	Magadu site
	.....%.....	
Control	0.094d	0.168b
Broadcasting MPR	0.237bc	0.202ab
Strip banded MPR	0.190c	0.183b
20-cm MPR Band, incorporated 10cm deep	0.236bc	0.203ab
20-cm MPR Band, incorporated 20cm deep	0.252b	0.171b
20-cm MPR Band + O.M, incorporated 10cm deep	0.240bc	0.219ab
20-cm MPR Band +O.M, incorporated 20cm deep	0.325a	0.248a
CV, %	14.8	15.1

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

Table 15. Calcium concentration in maize flag leaves as influenced by the various MPR treatments

Treatment	Calcium concentration	
	Sasanda site	Magadu site
	.....%	
Control	0.109d	0.157e
Broadcasting MPR	0.232abc	0.312abc
Strip banded MPR	0.172cd	0.208de
20-cm MPR Band, incorporated 10cm deep	0.184bc	0.275bcd
20-cm MPR Band, incorporated 20cm deep	0.201abc	0.236cde
20-cm MPR Band + O.M, incorporated 10cm deep	0.263ab	0.328ab
20-cm MPR Band +O.M, incorporated 20cm deep	0.289a	0.381a
CV, %	27.9	19.3

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

uptake by the maize plant. The increased Ca concentration in the leaves following application of MPR is due to the fact that upon MPR dissolution, Ca was also released from the MPR. Thus, increased Ca in soil solution may lead to increase Ca uptake by the plants.

The trend of Ca concentrations in the leaves was consistent with yield trends obtained across the treatments. Maize flag leaves from strip banded and control treatments contained Ca concentration values which were below the critical values of 0.21-1.0% as given by Jones and Eck (1973) while plant Ca in the other treatments was within the sufficiency range.

4.2.4.4 Potassium

The K concentrations in maize flag leaves are shown in Table 16. The K concentrations in flag leaves ranged from 1.39-2.83% and 1.43-2.75% for Sasanda and Magadu sites, respectively. The MPR treatments resulted in significantly (P=0.05) lower concentrations of K in maize flag leaves as compared to controls. Probably, this was because of increased DM accumulation associated with increased supply of P, which caused a dilution effect. The MPR treatments decreased maize flag leaf K concentrations below the sufficiency range. According to Jones and Eck (1973) a range of 1.71-2.50% for K concentration in maize plant is rated as sufficient. Kadogholo (2001) also noted the decrease in K concentration of the maize plant following application of TSP or MPR at the same sites.

Table 16. Potassium concentration in maize plant leaves as influenced by the various MPR treatments

Treatment	Potassium concentration in maize plant leaves at two sites	
	Sasanda site	Magadu site
	.....%.....	
Control	2.83a	2.75a
Broadcasting MPR	1.63c	1.57d
Strip banded MPR	2.29b	2.23bc
20-cm MPR Band, incorporated 10cm deep	2.26b	2.32b
20-cm MPR Band, incorporated 20cm deep	2.11b	2.28bc
20-cm MPR Band + O.M, incorporated 10cm deep	1.59c	1.95c
20-cm MPR Band +O.M, incorporated 20cm deep	1.39c	1.43d
CV, %	12	10.2

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

4.2.4.5 Zinc

The plant zinc concentrations are shown in Table 17. Zinc concentration values ranged from 18.02-32.57 mg/kg and 20.15-38.51 mg/kg for Sasanda and Magadu sites, respectively. Treatments that received organic matter in addition to MPR in both sites seemed to result in decreased Zn concentrations in maize flag leaves. Nevertheless, Zn concentration values for all treatments were within or slightly below the sufficiency range of the 20-60 mg/kg as given by Tandon (1995). Therefore, the supply of Zn in these two experimental soils, achieved through a blanket application of Zn at planting, was sufficient.

Table 17. Zinc concentrations in maize flag leaves as influenced by the various MPR treatments

Treatment	Zinc concentration in maize flag leaves	
	Sasanda site	Magadu site
	.....mg/kg.....	
Control	18.02e	20.15f
Broadcasting MPR	19.95d	24.33de
Strip banded MPR	32.57a	38.51a
20-cm MPR Band, incorporated 10cm deep	30.38b	34.51b
20-cm MPR Band, incorporated 20cm deep	28.79b	30.69c
20-cm MPR Band + O.M, incorporated 10cm deep	23.40c	24.55d
20-cm MPR Band +O.M, incorporated 20cm deep	20.64d	22.61e
CV, %	4.4	4.5

Means in the same column followed by the same letter(s) are not significantly (P=0.05) different according to the Duncan's New Multiple Range Test.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and Conclusions

Based on the results of this study, it was concluded that various manipulations on the band on which MPR was placed improved significantly (P=0.05) the growth and yields of maize plants in both pot and field experiments. The manipulations included addition of organic materials and varying the volume of contact between soil and MPR through varying the depth of incorporation of the MPR.

Varying the volume of contact between soil and MPR materials significantly affected dissolution and availability of P from banded MPR. The results of this study indicated that MPR incorporated down to 20 cm significantly (P=0.05) improved dissolution of MPR and increased availability of P from banded MPR as was reflected by higher extractable P, P uptake by plants, plant P concentrations, and grain yields, relative to MPR incorporated to only 10 cm depth. The low extractable P, plant P concentrations and grain yields obtained with the strip banded MPR suggest that there was a poor dissolution and availability of P from the MPR in this treatment. It is concluded that this was due to limited supply of H^+ to effect the dissolution of MPR, coupled with accumulation of dissolution products (Ca^{2+}, P) within the environment surrounding the localized MPR, which brought about the common ion effect which depressed further dissolution of the MPR.

Incorporated organic materials were found to improve dissolution and availability of P from banded MPR. Banded MPR incorporated together with organic materials at both 10 cm and 20 cm depth gave higher Bray-1 extractable P than MPR alone incorporated at the same depths (without organic materials). This was consistent with increased plant P concentration, P uptake, and grain yields in the treatments that received organic matter. Organic materials, upon decomposition, produce organic acids, which play a role in solubilizing MPR. At the same time these acids may also be adsorbed to the soil colloid particles, thereby diminishing P sorption by the soil; hence more of the dissolved P may be made available in soil solution for plant uptake.

Broadcasted MPR comes to contact with a large volume of soil, resulting in more of the MPR to solubilize. Nevertheless, the P dissolved from MPR was not all available for plants uptake because some of it was adsorbed by soil colloids, as it was exposed to the fixing sites of the soil colloids. The results of this study showed that the MPR + O.M. was in most cases superior to broadcasted MPR in increasing the amounts of extractable P, P uptake by plant, plant P concentrations and grain yields. These results, therefore, suggests that banded MPR, incorporated together with organic matter, resulted in effective plant utilization of P from MPR and, hence, increased crop yields.

5.2 Recommendations

From the foregoing, the following recommendations are made:

1. Minjingu PR can be adopted as a P source for maize in these two soils when is banded and incorporated into soil together with organic residues, preferably to the 20 cm depth.
2. Banding of MPR should continue to be evaluated, as it is more economical in terms of labour.
3. Further studies on the rates of the present organic materials to be mixed with MPR should be undertaken.
4. Different organic materials and rates of their application should be evaluated to gain insight into their effects on dissolution and availability of P from banded PR.

REFERENCES

Alexander, M. (1977). *Introduction to soil microbiology*. 2nd edition. Wiley, New York. 253pp.

Anderson, G. D. (1970). Fertility studies on sandy loams in semi-arid Tanzania. II Effect of phosphorus, potassium and lime on yields on yields of groundnuts. *Experimental Agriculture* 6: 213 - 222.

Babili, H. I. (1999). Effect of combining Minjingu phosphate rock with selected plant biomass on phosphorus availability in two soils of contrasting properties. *M. Sc. Dissertation*. Sokoine University of Agriculture, Morogoro, Tanzania, 32 - 65.

Barber, S. A. (1984). *Soil Nutrient Biovailability*. 1. A mechanistic approach. Wiley, New York. 255pp.

Barber, S. A., Walker J. M. and Vasey, E. H. (1963). Mechanism for the movement of plant nutrient from the soil and fertiliser to the plant roots. *Journal of Agricultural and Food Chemistry* 11: 204 - 207.

Bashir, J. (1999). Phosphate application for rebuilding the productive capital of Africa soils: Experience from East Africa. *African Fertiliser Market*, Volume 12. Number 12. Special Issue on Soil Fertility.

Bolan, N. S. and Hedley, M. J. (1989). Dissolution of phosphate rocks in soils. 1. Evaluation of extraction methods for the measurement of phosphate rock dissolution. *Fertiliser Research* 19: 65 - 75.

Bolan, N. S. and Hedley, M. J. (1990). Dissolution of phosphorus rock in soils. 2. Effect of pH. On dissolution and plant availability of phosphate rock in soil with pH. Dependent charge. *Fertiliser Research* 24: 125 - 134.

Bolland M. D. A. and Gilkes R. J. (1989). Reactive rock phosphate fertilisers and soil testing for phosphorus: the effect of particle size of the rock phosphate. *Fertiliser Research* 20: 75 – 93.

Brady, N. C. and Weil, R. P. (1990). *The Nature and Properties of Soils*. 11th edition. Macmillan, USA. 740pp.

Bray, R. H. and Kurtz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science* 59: 39 - 45.

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: *Method of Soil Analysis Part 2. Agronomy Monograph No. 9 (Edited by Page, A.L., Miller, R.H. and Keeney, P. R).* American Society of Agronomy, Madison, Wisconsin. pp. 149 - 157.

Chapman, H. D. (1965). Appendix 1: Tissue analysis values useful in indicating nutrient status. In: *Diagnostic Criteria for Plants and Soils*. Quality Printing Company, Abilene, Texas. pp. 780 - 793.

Chen, J. H. and Barber, S. A. (1990). Soil pH and phosphate reaction. *Soil Science* 150: 844 - 850.

Chien, S. H. (1977). Dissolution rate of phosphate rocks. *Soil Science Society of America Journal* 41: 656 - 57.

Chien, S. H. and Hammond, L. L. (1989). Agronomic effectiveness of partially acidulated phosphate rock as influenced by soil phosphorus fixing capacity. *Plant and Soil* 120: 159 - 164.

Chien, S. H. (1997). Dissolution rate of phosphate rocks. *Soil Science Society of America Journal* 41: 656 - 57.

Crews, T. E. (1993). Phosphorus regulation of nitrogen fixation in traditional Mexican agroecosystem. *Biogeochemistry* 21: 141 - 166.

Dhar, N. R. and Singh, R. D. (1982). Use of Purulia rock phosphate in acid soils of west Bengal. Presented at a symposium on phosphate management of crops with special reference to use phosphate rock as a direct fertlizer. Sriniketan, West Benghal, India. 75pp.

Dong, Y. Y. and Li, X. Y. (1992). Application of phosphate rock to diminish the effect of simulated acid rain on soil properties. *Pedosphere* 2(2): 147 - 152.

Drycott, A. P. (1972). *Sugar Beet Nutrition.* Applied Science Publisher Ltd, London. 250pp.

Engelstad, O. P. and Terman, G. L. (1980). Agronomic effectiveness of phosphate fertilisers. In: *The Role of Phosphorus in Agriculture. (Edited by Khasawner, F.E., Sample F.C. and Kamprath, E.J.)* American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin USA. pp. 311 - 329

Ensminger, L. E., Peason, R. W. and Arminger, W. H. (1967). Effectiveness of rock phosphate as a source of phosphorus for plants. *Agriculture Research service*, United State department of Agriculture, Washington DC. 4: 56-123.

Forth, H. O. (1990). *Fundamentals of Soil Science.* 8th edition John Willey and Sons, New York. 360pp.

Gee, G. W. and Bauder, H. (1986). Particle size analysis. In: *Method of Soil Analysis Part 1. 2nd edition (Edited by Klute, A.)* Agronomy Monograph No. 9. Soil Science Society of America, Madison, Wisconsin. pp. 383 - 412.

Gregg, P. E. N., Bolan, N. S., Hedley, M. J. and White, R. E. (1989). Reactive phosphate rock-potential as a direct use fertiliser and as a component of other phosphorus fertilisers. In: *Phosphorus Symposium,* CSIR, Pretoria, South Africa. pp. 6 - 20

Hammond, L. L., Chien, S. H. and Mokwunye, A.U. (1986). Agronomic value of acidulated phosphate rock indigenous to the tropics. *Advances in Agronomy* 40: 89 - 140.

Hu Hongqing, Hung Qiaoyun and Li Xueyuan, (1995). The diminishing effect of phosphate rock application on aluminium toxicity in acid soil. *Scientia Agriculturae Sinica* 28(2): 51 - 57

Hu Hong-Qing; Li Xue-Yuan; Liu Jing-Fu; Xu Feng-Lin; Liu Jing and Liu Fan., (1997). The effect of direct application of phosphate rock on increasing crop yield and improving properties of red soil. *Nutrient Cycling in Agroecosystems* 46: 235 - 239.

Ikerra, T. W. D. (1986). Evaluation of minjingu phosphate rock as a source of phosphorus for maize apllied in combination with compost or farmyard manure. *MSc, Dissertation.* Sokoine university of agriculture, Morogoro, Tanzania, pp. 30 - 54.

Ikerra, T. W. D., Mnkeni, P. N. S., Singh, B. R. (1994). Effect of added compost and farmyard manure on phosphorus release from Minjingu phosphate rock and its uptake by maize. *Norwegian Journal of Agricultural Science* 8: 13 - 23.

Iyamuremye, F. and Dick, R. P. (1996). Organic amendments and phosphorus sorption by soil. *Advances in Agronomy* 56: 139 - 185.

Jaggi, T. N. (1986). Direct application of low grade phosphate rock in acidic soils its impact on economics In: *IMPHOS Seminar*. International fertiliser Development Center, Muscle. Schoals, Albama. pp. 176 - 190.

Johnston, A. E. and Steen, I. (1997). Understanding phosphorus use in agriculture. *European Fertiliser Manufacturers Association*, Avenue E.Van Nieuwenhuyse 4,B 1160. Brussels, Belgium. pp. 189 – 198.

Jones, B. J. J. R. and Case, V. W. (1990). Sampling, handling, and analysing plant tissue samples. In: *Soil Testing and Plant Analysis 3rd edition. (Edited by Westerman R. L.)*, Soil Science Society of America, Madison, Wisconsis. pp. 389 - 427.

Jones, J. B. and Eck, H. V. (1973). Plant analysis as an aid in fertilizing corn and grain sorghum. In: *Soil Fertility and Plant Analysis*. Revised edition. (Edited by Walsh, L. M. and Beaton, J. D.), Soil Science Society of America incorporation, Madison, Wisconsin. pp. 349 - 364.

Kaaya, A. (1989). Soil survey and land suitability evaluation of the central part of Sokoine University of Agriculture farm Morogoro. *M. Sc. Dissertation.* Sokoine University of Agriculture, Morogoro, Tanzania, pp. 36 – 68.

Kadogholo, E. M. (2001). Assessment of methods of Minjingu phosphate rock application on phosphorus availability in three soils with contrasting properties. *MSc. Dissertation.* Sokoine University of Agriculture, Morogoro, Tanzania, pp. 33 – 73.

Kanabo, I. A. K. and Gilkes, R. J. (1987). The role of pH in the dissolution of phosphate rock fertilisers. *Fertiliser Research* 12: 165 - 174.

Khasawneh, F. E. and Doll, D. E. (1978). The use of phosphate rock for direct application to soils. *Advances in Agronomy* 30: 159 - 204.

Kimbi, G. G. (1991). Evaluation of Minjingu phosphate rock products as a source of phosphorus for maize (*Zea mays*) in some Morogoro and Hai soils, Tanzania. *M. Sc. Dissertation*. Sokoine University of Agriculture, Morogoro, Tanzania, pp. 28 –65.

Kimbi, G. G., Mnkeni, P. N. S. and Singh, B. R. (1996). Effectiveness of partially acidulated and benefited Minjingu rock phosphate as a source of phosphorus for maize and sorghum in three acidic soils of Tanzania. *Norwegian Journal of Agricultural Science* 10: 301 - 308.

Kuo, S. (12990). Phosphate sorption implication on phosphate soil tests and uptake by corn. *Soil Science Society of America Journal* 54: 131 - 135.

Landon, J. R. (1996) Booker tropical soil manual. *A Hand Book for Soil Survey and Agricultural and Evaluation in the Tropics and Subtropics*. Longman, New York. 474pp.

Le-Mare, P. H. (1991). Rock phosphate in agriculture. *Experimental Agriculture* 27: 413 - 422.

Lindsay, W. L. and Novel, W. A. (1978). Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* 42: 421 - 428.

Loganathan, P. and Sutto, P. M. (1987). Phosphorus fractions and availability in soils formed on different geological deposits in the Niger Delta area of Nigeria. *Soil Science* 143: 17 - 25.

Mackay, A. D., Syres, J. K., Tillman, R. W. and Gregg, P. E. H. (1986). A simple model to describe the dissolution of phosphate rock in soils. *Soil Science Society of America Journal* 50: 291 - 296.

Marschner, H. (1990). *Mineral Nutrition for Higher Plants*. 4th edition. United State Edition Published by Academic Press INC, San Diego. 674pp.

McLean, E. O. (1982). Aluminium. In: *Method of Soil Analysis Part* 2. Agronomy Monograph No.9. (Edited by Page, A. L. Miller, R. H. and Keeney, P. R.), American Society of Agronomy, Madison, Wisconsin. pp. 221 - 223.

Miller, R. J., Peverly, J. H. and Koeppe, D. E. (1972). Calcium stimulated P accumulation by corn roots. *Agronomy Journal* 64: 262 – 266.

Mnkeni, P. N. S., Semoka, J. M. R. and Buganda, J. (1986). Evaluation of agronomic effectiveness of Minjingu phosphate rock for maize in four soils of Morogoro, Tanzania. In: *Proceedings of 8th Annual General Meeting of the Soil Science Society of East Africa*. (Edited by Magunda, M. K. and Fenster, W. E.). Kampala, Uganda. pp. 180 - 195.

Mnkeni, P. N. S., Semoka, J. M. R. and Buganda, J. (1991). Effectiveness of Minjingu phosphate rock as a source of phosphorus for maize in some soil of Morogoro, Tanzania. *Zimbabwe Journal of Agricultural Research* 29(1): 27 - 37.

Mnkeni, P. N. S., Semoka, J. M. R. and Mwanga, S. N. (1992). Dissolution of some Tanzania phosphate rocks of igneous and sedimentary origin. *Zimbabwe Journal of Agricultural Research* 30(1): 67 - 76.

Moberg, J. R. (1981). The mineralogy of clay, silt and sandy fractions of soil from various parts of Tanzania and its relation to soil forming factors and processes. Unpublished report, Danish Agency of International Development (DANIDA).

Moberg, J. R. (2000). *Soil and Plant Analysis Manual.* The Royal Veterinary and Agricultural University, Chemistry Department, Copenhagen, Denmark. pp. 133.

Moreno, E. C., Lindsay W. L. and Osborn, G. (1960). Reaction of dicalcium phosphate dehydrate in soils. *Soil Science* 90: 58 - 68.

Moshi, A. O., Wild, A. and Greenland, D. J. (1974). Effect of organic matter on charge and phosphate adsorption characteristics of Kikuyu red soils in Kenya. *Geoderma* 11: 275 - 285.

Mullins, G. L. (1993). Cotton root growth as affected by phosphorus placement method. *Fertiliser Research* 34: 23 - 26.

Murphy, J. and Rilley, J. P. (1962). A modified single solution method for determination of phosphate in natural water. *Analytica Chimica Acta* 27: 31 - 36.

Mwakisimba, J. (1999). Influence of soil properties on the dissolution of Minjingu phosphate rock. *MSc. Dissertation.* Sokoine University of Agriculture, Morogoro, Tanzania, pp. 32 – 70.

Mwasha, T. K., Yen, W. T., Kamasho, J. A., Pelley, C. W. and Mchihiyo, E. P. (1995). *Report on Small Scale Partial Acidulation of Phosphate Rock.* Project 91-1020-01 (1992-1995) December 1999. pp. 134.

Nagarajah, S., Posner, A. M. and Quirk, J. P. (1970). Competitive adsorption of phosphate with poldalacturonate and other organic anions on kaolinite and oxide surfaces. *Nature* 228:73 - 84.

Nelson, D. W. and Sommers, L. W. (1982). Organic carbon In: *Methods of Soil Analysis Part* 2. *Agronomy Monograph No. 9 (Edited by Page, A. L., Miller, R. H. and Keeney, P. R.)*, American Society of Agronomy, Madison, Wisconsin. pp. 561 - 573.

Ngatunga, E. L. N., Haule, K. L. and Deckers, E. (1988). Comparison of the effect of Minjingu phosphate rock and tripo superphosphate on the yield of sorghum on acid sand loam soil of Naliendele, Tanzania. In: *Proceeding of Phosphate Research Meeting* (Edited by Kaihura, F.B.S., Floor, J. and Ikerra, S.T.) Tanga, Tanzania. pp. 31 - 35.

Nyaki, A., Modestus W. and Loewen-Rudger, L. A. (1985). Phosphorus nutrition in wheat on the Hanang complex Tanzania. In: *Proceeding of The 7th annual General Meeting of the Soil Science of East Africa.* (Edited by Msumali, G.P. Semoka, J. M. R. and Sharma, A. K.). pp. 154 - 159.

Okalebo, J. K., Robert, M. E., Simpson, J. R. and Lekasi, J. K. (1991). Evaluation of different phosphate fertilisers prepared from phosphate rock for growth of maize in a phosphorus deficient soil. In: *Proceedings of The 11th Annual General Meeting of he Soil Science Society of East Africa.* (Edited by Zake, J. Y. K., Tumuhaire, J. K., Ochwoh, V., Tenywa, J., Nkwiine, C., Sessanga, S.

M., Hyuha, T. and Nsubuga D.), December 2nd-6th 1991, Mukono, Uganda. pp. 182 - 193.

Ozanne, P. G. (1980). Phosphate nutrition of plants. In: *The Role of Phosphorus in Agriculture. (Edited by Khasawner, F. E., Sample F. C. and Kamprath, E. J.).* American Society of Agronomy, Crop Science Society of America and Soil Science Society of America, Madson, Wisconsin, USA. pp. 559 - 585.

Ozanne, P. G. and Shaw, T. C. (1967). Phosphate sorption by soils as a measure of the phosphate requirement for pasture growth. *Australia Journal of Agricultural Research* 18: 601 - 612.

Porter, P. S. and Sanchez, C. A. (1992). The effect of Freundlich isotherm for phosphate sorption. *Journal of Soil Science* 26: 241 - 246.

Rajan, S. S. S. and Ghani, A. (1997). Differential influence of soil pH on the availability of partially sulphuric and phosphoric acidulated phosphate rock. II. Chemical and scanning electronmicroscopic studies. *Nutrient Cycling in Agroecosystems* 48: 171 - 178.

Rhoades, J. D. (1982). Cation exchange capacity In: *Method of Soil Analysis Part 2. Chemistry and mineralogical properties, Agronomy Monograph No. 9. (Edited by Page, A. L., Miller, R. H. and Keeney, P. R.)*, American Society of Agronomy, Madison, Wisconsin. pp. 149 - 169.

Rivera, R. O., Machodo-de-Armas, J. and Arzola, P. N. (1993). Factors affecting available phosphorus in a fersiallitic soil. *Centro-Azucar* 20(3): 11 - 19.

Robinson, J. S. and Syers, J. K. (1991). Effects of solution calcium concenration and calcium sink size on the dissolution of Gafsa phosphate rock in soils. *Journal of Soil Science* 41: 597 - 605.

Sale, P. W. G. and Mokwunyc, A. U. (1993). Use of phosphatc rocks in tropics. *Fertiliser Research* 35: 33 - 45.

Sample, E. C. (1982). Factors affecting phosphate retention parameter derived using the Langmuir adsorption equation. *PhD. Thesis*. North Carolina State University. pp. 38 - 60.

Sanchez, P. A. (1976). *Properties and Management of Soils in Tropics*. John Wiley, New York. 618pp.

Sanya, S. K and De Datta S. K. (1991). Chemistry of phosphorus transformation in soil. *Advances in Soil Science* 16: 37 - 55.

Scaife, M. A. (1968). Maize fertiliser experiments in western Tanzania. *Journal of Agricultural Science*. 70: 207 - 222.

Semoka, J. M. R. (1999). *Research in Rock Phosphate Utilisation, Progress Report Number 3*. January-June 1999. Department of Soil Science, SUA, Morogoro, pp. 7.

Semoka, J. M. R., Mnkeni, N. P. S. and Ringo, H. D. (1992). Effectiveness of Tanzanian phosphate rocks of igneous and sedimentary origin as source of phosphorus for maize. *Zimbabwe Journal of Agricultural Research* 30(2): 127 - 135.

Singh, B. R. and Uriyo, A. P. (1978). Some acidic soil in Tanzania, their occurrence and chemical properties. *University Science Journal* 4: 3 - 9.

Sleight, D. M., Sander, D. H. and Pertison, G. A. (1984). Effects of fertiliser phosphorus placement on availability of phosphorus. *Soil Science Society of America Journal* 48: 336 - 340.

Smeck, N. E. (1973). Phosphorus: An indicator of pedogenic weathering processes. *Soil Science* 115: 199 - 206.

Snedecor, G. W. and Cochran, W. G. (1989). *Statistical Methods.* 8th edition. The Iowa State University Press/Ames, Iowa, United State of America. 593pp.

Sobulo, R. A., Agboola, A. A. and Fayeni, A. A. (1978). Effect of phosphorus placement on yield of tomatoes in southwestern Nigeria. *Agronomy Journal* 70: 521 - 524.

Sterwart, J. W. B. and Tiessen, H. (1987). Dynamics for soil organic phosphorus. *Biogeochemistry* 4: 41 - 60.

Syers, J. K. and Macky, A. D. (1986). Reaction of Senchura phosphate rock and single superphosphate in soil. *Soil Science Society of America Journal* 50: 480 - 485.

Syers, J. K., Hanafi, M. M. and Bolan, N. S. (1992). Leaching effect of two phosphate rocks in acid soils. *Soil Science Society of America Journal* 56: 1325 - 1330.

Tandon, H. L. S. (1987). *Phosphorus Research and Agricultural Production in India.* Indraprastha Press, New Delhi. 160pp.

Tandon, H. L. S. (1995). *Method of Analysis of Soils, Plants, Waters and Fertilisers.* Fertilisers Development and Consultation Organization, New Delhi, India. 146pp.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. (1993). *Soil Fertility and Fertiliser.* 5th edition. Printice-Hall, INC. New Jersey. 634pp.

Uriyo, A. P., Singh, B. R. and Kimambo, A. E. (1977). Influence of phosphorus placement method on maize on Oxisols. *East African Agricultural and Forestry Journal* 42: 353 - 358.

Van Straaten, P., Semoka, J. M. R., Kamasho, J. A. M., Mchihiyo, E. P., Mnkeni, P. N. S., and Chesworth, W. (1992). *Report on the Results of the Tanzania Canada Agrogeology Project, phase II* (1988-1991). Department of Land Resource Science, University of Guelph, Canada. 127pp.

Welte, E. (1978). *View-Point on Utilisation of Phosphate Rock for Direct Application.* International Fertiliser Development Centre, Muscle Shoals, Alabama. 356pp.

Wendt, J. W. and Jones, R. B. (1997). Evaluation of efficacy Tundulu phosphate rock for maize production. *Nutrient Cycling in Agroecosystems* 48: 161 - 170.

Yost, R. S., Kamprath, E. J., Lobato, E and Naderman, G. (1979). Phosphorus response of corn on oxisol as influenced by rates and placement. *Soil Science Society of America Journal* 43: 338 - 343.