EFFECT OF PHOSPHATE ROCK PLACEMENT METHODS AND INCORPORATION OF ORGANIC RESIDUES ON PHOSPHORUS AVAILABILITY AND MAIZE YIELDS IN TWO SOILS WITH DIFFERENT PHOSPHORUS FIXING CAPACITIES

BY

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ABSTRACT

A study was conducted under pot and field conditions to evaluate the effects of Minjingu phosphate rock (MPR) placement methods and organic residues on MPR dissolution, P availability and maize yields in two soils with different P fixing capacities. Observations from two field experiments, one at Sasanda, Mbeya and another at Magadu, Morogoro were continued to evaluate the effect of continued addition of organic materials (OM) banded with MPR on MPR dissolution, P availability and maize yields. One field experiment was carried out at Sasanda to evaluate the effects of different rates of OM applied together with MPR on MPR dissolution, P availability and maize yields. For the continued experiments, the treatments tested were control, broadcasted MPR, 2 to 5 cm width strip banded MPR, 20-cm wide MPR band incorporated to 10 or 20 cm depth, and 20-cm MPR band + O.M incorporated down to 10 or 20 cm depth. These were tested only in the field. For the new experiment the treatments tested were control, broadcasted MPR, 2 to 5 cm width strip banded MPR, 20-cm wide MPR band incorporated to 20 cm, and 20-cm band MPR + OM applied together at 2, 4, 6 and 8 t/ha and incorporated down to 20cm depth. Field experiments were laid using Randomized Complete Block Design (RCBD) with four replications while pot experiment was laid using Complete Randomized Design (CRD) with three replications. Dry matter yields (DM) yields, P uptake, P concentrations, extractable P and grain yields were used to assess the effects of these treatments. The results showed that continued incorporation of OM banded together with MPR significantly (P=0.05) improved MPR dissolution, P availability, and increased grain yields. This was supported by highest maize grain yield (3.01 t/ha) obtained from these continued observations, which was higher than

the maximum (2.27 t/ha) obtained in the previous study from the MPR + OM incorporated down to 20 cm depth. The results of the new experiment showed that banding of MPR together with OM at the rates of 2, 4 6 and 8 t/ha significantly (P=0.05) increased MPR dissolution, P availability, and maize grain/ dry matter yields. The increase was in proportion to the increased rates of OM. For example, in the pot experiment, MPR + OM increased DM yields from 14.14 to 76.17 g/pot and 4.10 to 70.87 g/pot in Magadu and Sasanda soils, respectively. In the field experiment, MPR + OM at 2, 4 and 6 t/ha increased extractable P in the soil from 0.18 to 0.47 mg/kg and maize grain yields from 0.36 to 3.38 t/ha. The increase was also proportional to the increased rates of OM. The highest extractable P (0.47 mg/kg) and grain yields (3.38 t/ha) were observed from MPR + 6 ton OM/ha.

DECLARATION

I, MGETA STEVEN MERUMBA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and has not been submitted for a degree award at other University.

Signature:.....Date.....

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DEDICATION

This dissertation is dedicated to Lord God who is the source of life and the pioneer of Science. I also dedicate this work to my father, Mussa Merumba, and my mother Pennina Lugobi who laid the foundation of my education and through their tireless effort this achievement was possible. The work is also dedicated to my wife to be Yuster J. Limandola.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

AAS	Atomic Absorbency Spectrophotometer
CEC	Cation exchange capacity
cmol (+)/kg	Centimole (+)per kilogram
CRBD	Complete randomized block design
CRD	Complete randomized design
CV	Coefficient of variation
DAP	Diammonium phosphate
DNMRT	Duncan's New Multiple Range Test
DANIDA	Danish International Development Agency
DM	Dry matter
DTPA	Diethylenetriaminepentacetic acid
FYM	Farmyard manure
g/pot	Gram per pot
MAP	Monoammonium phosphate
m.a.s.l.	Meter above sea level
ml	Millilitre
mmol/kg	Millimole per kilogramme
mm	Millimeter
MPR	Minjingu phosphate rock
nm	Nanometer
OM	Organic material
PARP	Partially acidulated rock phosphate

pH	Negative logarithim of hydrogen ion concentration
Pi	Inorganic phosphorus
Po	Organic phosphorus
PR	Phosphate rock
SA	Sulphate of ammonia
SSP	Single superphosphate
SUA	Sokoine University of Agriculture
t/ha	Tonnes per hectare
TSP	Triple super phosphate
USDA	United States Department of Agriculture
UH	Uyole hybrid
OC	Organic carbon
r.p.m.	Revolutions per minute
µg	Microgramme

CHAPTER ONE

1.0 INTRODUCTION

In most tropical soils low levels of phosphorus is one of the most limiting factors in crop production, especially in weathered, leached and, consequently, acidic soils such as Ultisols and Oxisols. The deficiency is aggravated by nutrient mining through successive cropping without P fertilization in such soils. Native P compounds are mostly unavailable for plant uptake, some being highly insoluble. When soluble forms of P are added to soils, they are fixed or changed to unavailable forms. Therefore, many soils in the humid tropics require good P management because only a small fraction of the total P in soils is available for plant uptake.

Other factors reported to contribute to the low available P for plant uptake include sub-optimal application of P, erosion of the top soil by runoff (Smaling *et al.,* 1993; Swift *et al.,* 1994) and losses by leaching especially in sandy soils (Paton and Loneragan, 1960). The low plant available P in soils has contributed greatly to declining food crop production (Shepherd *et al.*, 1995).

In order to increase the P content of soils with low native P, fertilizer materials that contain P should be added to such soils. However, there is little use of inorganic P fertilizers by resource-poor farmers due to high prices of these inputs. These P fertilizers are water-soluble P fertilizers, which include triple superphosphate (TSP), single superphosphate (SSP), mono- and di- ammonium phosphate (MAP and DAP). Due to high cost of these inputs, therefore, research has been focussed on possible

use of agromineral deposits, namely phosphate rocks, to improve agricultural production.

Phosphate rocks have received attention as low cost P fertilizers for acid soils (Khasawneh and Doll, 1978; Chien and Menon, 1995). In Tanzania, PRs occur in various locations namely Minjingu in Arusha region, Chali hills in Dodoma region, Sangu-Ikolla , Panda hill, Mbalizi, Njelenje, Songwe and Nguala in Mbeya region (Patel, 1975; Mchihiyo, 1991; Mwambete, 1991) and Bachuba and Ichwandini in Muleba district in Kagera region (Mkamba, 1988). Significant deposits occur at Panda hill, Mbeya (igneous origin) and at Minjingu, Arusha (sedimentary origin). Panda hill deposits contain P_2O_5 varying from 14 to 30% (Mchihiyo, 1991) while Minjingu deposits contain P_2O_5 varying from 6 to 32% (Mwambete, 1991).

In this study MPR (sedimentary origin) was prefered over the others (igneous origin) due to the fact that sedimentary phosphate rocks are more soluble than igneous phosphate rocks (Mnkeni *et al.*, 1986). Also the results of experiments conducted in Tanzania have shown that the use of MPR is most effective when soils are acidic and deficient in P (Mnkeni *et al.*, 1986) which are the properties of the soils used in this study.

Many researchers (Ikerra, 1986; Kimambo *et al.*, 1988; Mowo and Gama, 1988; Meda and Kullaya, 1988; Ngatunga *et al.*, 1988, Semoka, 1988; Okalebo *et al.*, 1991; Kimbi *et al.*, 1996; Kitua, 1997; Tusekelege, 1997) have reported results on the agronomic effectiveness of MPR in different soils. Generally in acid soils low in P,

the performance of MPR applied to such soils either directly or as partially acidulated PR was more or less similar to that of soluble P fertilizers. However, dissolution of PR in such soils is necessary for P from PR to be available to plants.

As in the case for all fertilizers, PR has to undergo dissolution before it releases the P contained in it. Many factors have been reported to affect PR dissolution. These include properties of PR, plant factors, agronomic practices and soil factors. Soil factors are soil organic matters content, soil pH, P retention capacity of soil, levels of soil P, moisture content of soil, soil clay content and exchangeable Ca (Khasawneh and Doll, 1978; Kanabo and Gilkes, 1988; Wright *et al.*, 1992; Syers *et al.*, 1992; Mnkeni *et al.*, 1992).

In addition, fertilizer placement methods have also been reported to affect the solubility of PR, hence its utilization by crops. Kanabo and Gilkes (1987) reported that the extent to which PR comes into contact with soil affects PR dissolution hence P availability for plant uptake. The extent of contact of PR with soil, and its subsequent dissolution, will be governed by method of placement.

Many researchers have reported inferior dissolution of PR on band application. For example, Kanabo and Gilkes (1987) and Sale and Mokwuye (1993) observed lower dissolution of PR in band application than where PR was broadcasted. Also Kadogholo (2001) reported lower yields of maize from Sasanda (Mbeya) volcanic soils when MPR was banded than when MPR was broadcasted due to poor dissolution of MPR when banded. Mhagama, (2003) reported improved availability

of P and higher maize yields when the PR band was broadened. Many researchers have reported that organic materials in combination with PR enhanced the dissolution of PR due to simple organic acids produced upon decomposition of organic materials. But not much has been done, for example on what rates of these organic materials should be applied. These need to be tasted.

Fertilizer applied by banding comes into contact with a small volume of soil, thereby limiting P dissolution. Thus, there is possibility for the little P dissolved to be easily taken up by plants. Kanabo and Gilkes (1987) found high proportion of dissolved P being available to plants where PR was banded than where PR was broadcasted. However, the only problem when PR is banded is the inferior dissolution associated with banding. In Tanzania Kadogholo (2001) observed low dissolution where MPR was banded using soils from Sasanda in Mbeya region.

Therefore, there is a need of searching for an appropriate agronomic practice that can be used within the band to enhance the dissolution of MPR and, consequently, higher availability of P from banded PR in soils with different phosphorus-fixing capacities.

Organic materials produce organic acids (H^+) that may help in solubilizing PR if incorporated into soil (Sanchez *et al.*, 1997) and their effects need to be evaluated. The soils of Sasanda in Mbeya region and SUA farm in Morogoro region where inferior dissolution of banded MPR has been reported are the case in point. The Sasanda soil has high P fixing capacity while that of Magadu (SUA farm) has

medium P fixing capacity. Therefore, the studies reported here were conducted, using these two soils, with the following objectives:

1. To evaluate the effect of MPR placement methods on dissolution and availability of phosphorus in the soil.
2. To evaluate the effect of continued addition of organic materials mixed with MPR on dissolution, phosphorus availability and maize yield.
3. To evaluate the effect of different rates of organic materials mixed with MPR on dissolution and availability of P from banded MPR.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Phosphate rock as a source of P and other plant nutrients

A lot of work has been focussed on possible use of phosphate rock to improve agricultural production. Hu *et al.* (1995) observed the following changes in properties of soil (ultisols) after six seasons of PR applications. The amount of exchangeable Ca increased from 1194 μg/g to 1300-2100 μg/g. The content of exchangeable Mg increased from 330 μg/g to 350-400 μg/g while the amount of available P increased from 4.3 μg/g to 4.7-6.5 μg/g. Soil pH increased from 4.82 to about 4.9-5.3. They also observed that while the soil treated with TSP supplied more available P than that treated with PR, PR treated soils were superior to TSP treated soils for supplying Ca and Mg, raising soil pH and reducing active Al species and thus reducing soil Al toxicity.

In Tanzania, a number of research work has been done on MPR as source of P including; Anderson (1971) on groundnuts, Patel (1975) on maize, Ngatunga and Deckers (1984) on sorghum and Gama and Mowo (1990) on cotton. They showed that Minjingu rock phosphate (MPR) performed better in light textured, low pH soils. Mnkeni *et al.* (1991) working with four different soils observed varied effects of MPR on maize yield. In their studies, they observed that the rates of 80 kg and 240 kgP/ha significantly increased maize yield on Magadu and Mzumbe soils (Morogoro), both of which had <6.5 mgP/kg soil and pH value <5.2. Semoka *et al.* (1992) observed that MPR applied at the rate of 40 mgP/kg soil was as effective as TSP with relative agronomic effective value of 92 % and 111 % in an ultisols and an

oxisols, respectively. However, the emerging problem is poor dissolution of MPR (Kanabo and Gilkes, 1987; Ngatunga *et al.*, 1988, Wendt and Jones, 1997).

2.2 Residual effect of phosphorus

Nutrients applied in fertilizers may not be completely utilized by the currently growing crops. Some of these nutrients may be lost by leaching and some are changed through chemical and biological reactions into forms not readily used by plants (Cook and Ellis, 1987). Where nutrients have been applied, a certain portion is left in the soil after harvesting. The amounts remaining depend on the amount added, the yield, the portion of the crop harvested, and the soil. According to Miller and Donahue (1995), in general fertilizer usage, the expected efficiencies are approximately 30 to 70% of added nitrogen, 5 to 30% of added phosphorus and 50 to 80% of added potassium. A marked residual effect has been reported with P fertilizers. When P is applied to the soil, only a small percentage is taken up by plants; the remainder is either permanently or temporarily fixed in forms varying in plant availability (Moughli *et al.*, 1999). The source of a fertilizer is important as far as residual effect is concerned. For instance, Sale and Mokwunye (1993) reported the superiority of residual effects of finely ground phosphate rocks to water soluble phosphate fertilizers in an oxisols of the tropics. At Mlingano in Tanga, Tanzania, Minjingu rock phosphate showed higher residual effect than water-soluble fertilizers (Mowo, 2000). He ascribed the higher residual effects to the continuing dissolution of the phosphate rocks compared to the declining availability of P from the residues and reaction products of the water-soluble P sources over time. A higher residual

effect has also been reported in the second and third year after PR application as opposed to water-soluble P fertilizers.

The duration of crop yield response to P applications depends on the amount of P applied, the soil's P sorption, and cropping intensity. The larger the P application rates the longer the residual effect. Meanwhile low P sorbing soils have short residual effects. The higher the number of crops (cropping seasons) harvested per year the shorter the residual effect (Sanchez *et al.,* 1997).

2.3 Dissolution of phosphate rock

Dissolution of PR is a necessary precondition for the P it contains to be available for plant uptake. Dissolution of phosphate rock proceeds with a high demand for protons (H^+), bringing phosphate, calcium and hydroxyl ions into the soil solution. Thus acid soils should, in principle, provide protons. Any process taking away these ions (phosphate, Ca^{2+}, or OH^-) stimulates PR dissolution. Plants take up phosphate ions, thus furthering PR dissolution. Stimulation of crop growth, for example, by application of nutrients other than P or by improving soil physical conditions may also indirectly promote PR dissolution (Mowo, 2000).

Khasawneh and Doll (1978), Sanya and Datta (1991), Dong and Li (1992) and Hu *et al.* (1995), using fluorapatite as an example, explained the dissolution of PR by considering the following equations.

$Ca_{10}(PO_4)_6F_2 + 12H^+ = 10\,Ca^{2+} + 6H_2PO^-_4 + 2F^-$

$H_2PO^-_4 + OH^-\,soil = H_2PO^-_4\,soil + OH^-$

$F^- + OH^-$ soil $= F^-$ soil $+ OH^-$

From this reaction, it shows that the rate of PR dissolution is controlled by the concentration of protons (H^+) and concentration of reaction products (Ca^{2+} and $H_2PO_4^-$).

2.4 Factors affecting dissolution and availability of phosphate rocks in the soil

It is important to note that all factors which affect the dissolution phosphate rocks (PRs) have a direct effect on P availability from PR. This is because PR should first undergo dissolution so as to release P in soil solution for the P to be available for plants uptake. However, the extent of PR dissolution in soil does not necessarily control the amount of P available to plants because soil factors may intervene (Bolan and Hedley, 1990). It has been observed that three fractions, namely Ca-P, Fe-P and Al-P are responsible for P availability in the soil.

Total inorganic P fractions (P_i) are divided into active and inactive forms. The former consists of Al-P, Fe-P and Ca-P, and the later consists of occluded, reductant soluble, and residual P (Chang and Jackson, 1957). The more active forms are the fractions most available to plants, with the degree of availability increasing in the order Ca-P< Fe-P <Al-P in the upland conditions (Thomas and Peaslee, 1973). But like organic matter, the inactive P_i forms act as the long-term reservoir of P, depending on soil properties such as pH (Murrman and Peech, 1969). The relative abundance of inorganic forms also gives an indication of the degree of chemical weathering of the soils, the strongly weathered soils having a higher proportion of inactive inorganic forms and Fe-P than others.

A number of factors have been reported to affect the dissolution and agronomic effectiveness of phosphate rocks (PRs) under direct application (Khasawneh and Doll, 1978; Hammond *et al.*, 1986). These are: soil factors, plant factors, properties of phosphate rocks (PRs) and agronomic practices.

2.4.1 Soil factors

2.4.1.1 Soil organic matter

Soil organic matter plays a great role in the dissolution of phosphate rocks. Soil organic matter, upon hydrolysis, supplies some functional groups or organic acids such as aliphatic acids, carboxylic acids, phenols, citrate, mineral acids, fulvic acids and oxalates (Alexander, 1961; Hammond *et al.*, 1986). The functional groups and anions together with carbonic acid produced in soil as metabolic waste of plant roots and microbial decomposition processes help in the dissolution of PR to mono and di-basic phosphates (Alexander, 1961). These functional groups or anions so produced can chelate Ca ions in soil, thus lowering the activity of Ca^{2+} in the soil solution. Consequently, this encourages further dissolution of PRs (Hammond *et al.*, 1986; Sale and Mokwunye, 1993). Robinson and Syers (1992) pointed out that provision of a sink for Ca in soil would lead to small concentration of Ca in soil solution, thereby promoting more dissolution of PR.

Results from application of 5 and 10 t/ha of organic materials (manure and compost, respectively) mixed with MPR at the rate of 40 kgP/ha enhanced the release of P from MPR and resulted in significant increased in dry matter yield of maize as compared to MPR or FYM applied alone (Ikerra *et al.*, 1994). Buresh *et al.* (1997)

reported higher maize yield due to application of *Tithonia diversifolia* than due to a combination of urea with 50 and 250 kgP/ha of TSP and MPR, respectively. However, Iyamuremye and Dick (1996) reported that organic acids produced during the decomposition of organic matter may temporarily reduce P fixation of the soil by binding to the oxides and hydroxide surfaces of clay particles, thereby increase nutrient availability into soil solution and thus nutrient use efficiency. Singh and Jones (1976) reported that organic materials can increase or decrease amount of P sorbed depending on the type of organic materials, amount of organic materials added, P concentration and duration of decomposition of organic materials (incubation period).

Fox and Comerford (1992) reported the effect of organic matter application on the availability of P. Organic anions can increase the availability of applied P in the soil solution by the formation of organophosphate complexes that are more easily assimilated by plants. Anion replacement of $H_2PO_4^-$ on the adsorption sites, coating of Al and Fe particles by humus and formation of complexes of organic anions prevent the adsorption of P by the soil colloids, hence availing P in the soil solution for plant uptake (Mnkeni and Mackenzie, 1985).

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 from Ca phosphates, and thus increased P concentration in soil solution. 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 through ligand exchange on the mineral surface, thus competing with P for adsorption sites, and thereby releasing more P into soil solution.

2.4.1.2 Soil pH

Phosphate rocks dissolve more readily in acid than in alkaline soils. Thus, an acid pH is a prerequisite for the dissolution of PR in soil due to a net supply of protons (H^+) (Kanabo and Gilkes, 1987; Robinson and Syers, 1992). Anderson *et al.* (1985) observed that as reactivity of PR material increased, the dissolution of PR material also increased at low soil pH and soil solution P level. Khasawneh and Doll (1978) and Marwaha and Kanwar (1981) reported that availability to crop of P from PR was significant at soil pH values less than 6.

Mnkeni *et al.* (1991), working with four different soils observed varied effects of MPR on maize yield. Application of 80 kg and 240 kg P/ha significantly increased maize yield on Magadu and Mzumbe soils both with < 6.5 mg P/kg and pH value < 5.2. However, there was no response to MPR application observed neither on Mafiga soil with comparable P levels to the above two soils nor on Mafiga soil with slightly higher P level but where pH values were less than 6.

Laboratory experiments using a single soil modified to various pH levels have shown that PR dissolution increased linearly with decreasing pH (Kanabo and Gilkes, 1987). Likewise, agronomic effectiveness of PR has been found to be higher in acid soils than in neutral or alkaline soils (Peaslee *et al.*, 1962; Hammond *et al.*, 1986).

Soil pH greatly affects the release of phosphorus into the soil solution. The maximum availability of phosphorus occurs in soils with a pH range of 6.0 to 7.0. Increasing soil acidity (decreasing pH) increases the solubility of iron and aluminium which are capable of fixing or removing phosphorus from the soil solution, thereby limiting the availability of inorganic phosphorus to plants. In high pH soils, phosphorus reacts with calcium and magnesium to form insoluble compounds which limit phosphorus 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 adsorption of the phosphate at lower soil pH. Rajan and Ghani (1997) similarly observed a decrease of available P due to decrease in pH from 6.5 to 5.0.

2.4.1.3 Phosphate sorption capacity of the soil

Phosphate sorption capacity is an important reaction that affects the rate of, and crop response to, fertilizer application (Fox and Kamprath, 1970; Holford and Mattingly, 1976), the downward movement of applied phosphate and the dissolution of rock phosphate in soil (Symith and Sanchez, 1982).

High capacity of the soil to retain P and Ca has been found to promote the dissolution of phosphate rock (Chien *et al.*, 1980; Mackay *et al.*, 1986). It has been pointed out that although PR materials may dissolve quickly in higher P retaining soil, a high proportion of P initially dissolved may be rapidly retained by the soil colloids and thus reduce its availability to crops. In soil with very high P sorption

capacity the agronomic effectiveness of PR is reduced as acquisition of dissolved P by plant roots is restricted by competition from P sorption processes in the soil. Although PR dissolution may be increased by high sorption capacity of the soil a number of studies indicated that the agronomic effectiveness is low in such soils (Sale and Mokwuye, 1993).

The retention of phosphate by soil components is thought to occur in three stages. The stages include a high extent of chemisorption, precipitation of the separate phase and retention of phosphate onto precipitates at lower, medium and higher concentrations of phosphate in the equilibrium solution, respectively (Coleman *et al.*, 1960; Bache, 1964; Griffin and Jurinack, 1974), hence rendering the phosphate unavailability to plants. Syers *et al.* (1992) observed the difference in the amount of phosphate retained by the soil at levels higher than 200 μg soil. This could be attributed to the gradual saturation of the phosphate retention sites on the soil colloids and the nature and type of the anion retention sites. The higher phosphate retention by an ultisol and an oxisol as opposed to a vertisol at higher levels of added phosphate suggests that the 1:1 layer silicate clay (kaolinite) and the hydroxides of Al and Fe have higher affinity for phosphate than the 2:1 layer silicate clays (smectite). The lower pH of the ultisol and oxisol could also account for the higher phosphate retention through its influence on the activities of Al^{3+} and Fe^{3+} in soil solution (Kimaro and Mrema, 1985).

2.4.1.4 Soil extractable phosphorus

Level of soluble phosphorus in a soil plays a great role in phosphate rock dissolution.

Soil phosphorus is commonly expressed by the activity of $H_2P0_4^{1-}$ or the phosphate potential (Khasawneh and Doll, 1978). Low soil P would favor PR dissolution. The beneficial effect of PR is realized when applied to soils which are severely to moderately deficient in P. Applied PR has little or no value in soil of medium to high P status (Amberger, 1978). To ensure PR dissolution the soil should provide a positive gradient in the electrochemical potential of both P and Ca^{2+}. If the soil is supersaturated with Ca^{2+} and P, PR will not dissolve or participate in supplying P to the soil (Khasawneh and Doll, 1978). A number of workers (Peaslee *et al.*, 1962; Sale and Mokwunye, 1993) have reported that for high PR dissolution, the soil in question should be low in P. It is generally accepted that high PR dissolution is limited to soils with low to medium phosphate ions while low dissolution occurs in soils with medium to high P status (Amberger, 1978).

2.3.1.5 Exchangeable Calcium

The extent of rock phosphate dissolution depends on the level of calcium in the soil solution and the Ca sink of the soil. Many workers (Khasawneh and Doll, 1978; Robinson and Syers, 1990; Mnkeni *et al.*, 1992; Sale and Mokwunye, 1993) have reported that low calcium concentration enhances PR dissolution. This is due to the law of mass action where low Ca in soil solution favors release of Ca, hence P from PR. Poor PR dissolution can be caused by the presence of high Ca or free $CaCO_3$ in the soil. This has been explained as being a result of the calcium common ion effect, whereby high Ca level in soil solution depresses Ca dissolution from PR (Welte, 1978). Robinson and Syers (1990) reported that a sink for Ca is an important factor

influencing the dissolution of PR. Furthermore, in (1991) they also reported that dissolution of Gafsa PR decreased with increased exchangeable Ca in soil.

2.3.1.6 Soil texture and structure

Soil texture is closely related to cation exchange capacity (CEC) of a soil. A sandy soil with low CEC cannot provide a sink for Ca ions released from PR. This leads to poor dissolution of PR. A good soil structure encourages optimum aeration and water holding capacity. This will facilitate soil microorganisms to grow and multiply faster and promote the action of microorganisms on soil organic matter. As a result, sufficient organic acids would be increased to act on rock phosphate and increase its solubility (Alexander, 1977). The hydrolysis of soil organic matter in tropical soils provides a substantial sink for Ca through the supply of chelating agents that can reduce the activity of Ca ions in the soil solution through chelation (Chien, 1979). The reduced activity of Ca consequently enhances the dissolution of PR and thus increases P concentration in soil solution for plant uptake.

Soil texture or the amount of clay in soil influences the rate of diffusion of phosphorus to crop roots. Unlike nitrogen, phosphorus does not move readily in a soil but is held in soil compounds. As a result, phosphorus does not leach readily through the soil and a high percentage is within the cultivated layer (0-15 cm) of many soils. Due to the low movement or immobility of phosphorus in the soil, it is necessary that phosphorus fertilizers be placed close to the seed where the young plant roots have access to this nutrient early in the season. Soils high in clay particles will adsorb (bind to their surfaces) more nutrients, while fertilizer will leach (wash

through) faster through sandy soils. Organic matter in the soil will increase the soil's nutrient -holding capacity and contribute nutrients upon its decomposition (Tisdale *at el.*, 1993).

2.3.2 Properties of phosphate rock

2.3.2.1 Chemical composition

Phosphates are found in all three types of rocks namely igneous, metamorphic and sedimentary. These phosphate rocks vary widely in their reactivities and subsequent agronomic effectiveness (Lehr and McClellan, 1972). In most cases only sedimentary phosphate rocks have been proven beneficial for direct application. The igneous and metamorphic rocks have much lower solubility than the sedimentary rocks. This is because igneous and metamorphic rocks are coarsely crystalline and do not possess internal surfaces. Thus they are uncreative. Sedimentary rocks are microcrystalline in nature and consist of fairly open, loosely consolidated aggregates of microcrystals with a relatively large specific area, making them more reactive (Hammonds *et al.*, 1986). Sedimentary rocks have a high CO_3^{-2} and F^- substitution for PO_4^{-3} in their apatite crystal lattice. Substitution of CO_3^{-2} for PO^{-3}_4 decreases the crystal size and increases the specific surface area of the apatite aggregates.

This results in increasing rates of dissolution (McClellan and Lehr, 1969;Khasawneh and Doll, 1978; Marwaha and Kanwar, 1981).

2.3.2.2 Physical composition

Hard coarsely textured particles or highly crystalline apatites are often uncreative in the acidulation process especially in the manufacture of superphosphates. Hammond *et al.* (1986) reported that the dissolution of PR increased with increase in its fineness. Economically feasible grinding of PR has been reported to be those from which at least 80% of the material pass through 100-mesh screen (Hammond *et al.*, 1986).

2.3.3 Plant factors

Crops vary greatly in their ability to utilize P from phosphate rocks. Generally, differences among crops are thought to be related to their demand for both P and Ca and the way these demand patterns for P and Ca alter the composition of soil solution at the soil root interface (Cook, 1935; Fried and Mackenzie, 1949; Khasawneh and Doll, 1987). Increased P and Ca uptake has been thought to be a result of enhanced supply of P and Ca in soil solution consequent to the increased Ca^{2+} and $H_2PO_4^-$ concentrations in soil solution in response to the dissolution of PR.

Semoka and Mnkeni (1986), working with Minjingu PR using maize, cotton, groundnut, pasture and sorghum as test crops, found that in most cases Minjingu PR gave a positive response. When assessed for a period of 3 to 6 years (including residual effect), the residual P from MPR application was found to be equal to or greater than that from super phosphates.

Ikerra (1986) working with an ultisol and maize as test crop found MPR to be inferior to TSP at equal rates of P application. This was attributed to the low degree

of solubility of PR as compared to TSP. Mnkeni *et al.* (1991) using four soils observed TSP and MPR being equally effective sources of P for maize in acid soils low in extractable phosphorus. In a long-term field experiment conducted on acid sandy loam soils of Naliendele in South Tanzania, Ngatunga *et al.* (1988) found MPR to be as effective as TSP as a source of P for sorghum. Acidification in the plant's rhizosphere environment is one of the processes that have been suggested to enhance the release of P from PR (Flach *et al.*, 1987; Bolan and Hedley, 1991). Accumulation of H ions in the rhizosphere surrounding root surface increases the rate of dissolution of adjacent PR. Concurrent with the enhancement of microbial activities in the root zone, net microbial immobilization of P and excretion of organic acids from microbes are enhanced, which, in turn, give rise to more dissolution of phosphate rock (Bolan and Hedley, 1991).

Plants can also promote dissolution of PR through a high rooting density. High rooting density stimulates dissolution of PR due to enhanced P uptake, thus lowering the concentration of Ca^{2+} and H_2PO_4 in soil solution. Differences in the promotion of PR dissolution by different plants is caused by the differential demand pattern of Ca and P by the plants. Plants with high Ca and P demand will promote high PR dissolution and vice versa (Khesawhneh and Doll, 1978).

The P feeding power of plants also affects utilization of PR by crops. It was found that cereals are among the poor feeders while legumes are among the good feeders. Thus the possibility of growing crops of high feeding power to supply available P in rotation with crops of low feeding power is of importance in the utilization of PR.

The difference between species and varieties in P feeding power is attributed to the root-absorptive surface and relative size of roots. (Khasawneh and Doll, 1978).

2.3.4 Agronomic practices

2.3.4.1 Phosphate rock placement methods

Equally important in phosphate rock effectiveness is the method of application. Fertilizer placement method refers to the practice of positioning fertilizer in a local area, generally near the plants. The effectiveness of fertilizer placement as a means of increasing the yield obtainable from a given quantity of fertilizer depends in part upon plant behavior and in part upon interaction of fertilizer with soil (Black, 1993). Placement practices depend on the crop, degree of deficiency, mobility of the nutrient in the soil and equipment availability. Fertilizer placement methods have been reported to substantially affect PR dissolution and thus P availability and utilization by crops. It has been reported that to ensure effectiveness of PR, its placement should ensure thorough mixing with soil in the rooting zone (Khasawneh and Doll, 1978). Applying PR near the plant roots would ensure exploitation of rhizosphere acidification. Meanwhile, only a small fraction of the bulk soil acidity can be used for PR dissolution. Therefore, there must be a balance between rate and method of application in relation to soil properties (Mowo, 2000).

2.3.4.1.1 Broadcasting

This is the method whereby fertilizer is applied uniformly over the field surface and incorporated by tilling or cultivating of the land. Broadcasting of the finely ground PR material followed by incorporation has been found to be the best PR placement

method especially in soils medium in P and low in P sorption capacity due to the fact that it affords the widest distribution of PR in the upper zone. It, thus, permits the largest extent of contact between plant roots and PR particles. Broadcasting followed by thorough mixing of PR with soil increases the surface area of contact between the soil colloids and PR granules hence increased reaction rates. Kanabo and Gilkes (1987) found greater PR dissolution in broadcasting than in banding application. However, fertilizer applied by broadcasting comes into contact with a large volume of soil and thus there is a high risk of the dissolved P to be fixed by the soil colloids (Forth, 1990), especially in high P fixing soils. Broadcasting requires high rate of PR application to satisfy the P fixing capacity of the soil. However, the method is laborious due to the fact that it requires a 'second tilling' of the land to incorporate the broadcasted PR into soil.

2.3.4.1.2 Banding

Fertilizer use efficiency or crop recovery of nutrients can be increased through banding application. Several researchers (Ozanne, 1980; Kanabo and Gilkes, 1987; Ngatunga *et al.*, 1988) reported that banding of PR gave more efficient use of fertilizer by plants than did broadcasting. Kanabo and Gilkes (1987) observed that for equal amount of PR a high proportion of dissolved P was available to plants where PR was banded than where PR was broadcasted. However, the main problem when PR is banded is inferior dissolution. Thus, improving PR dissolution may increase availability of P to plants, consequently increasing crop yield. Ngatunga *et al.* (1988) also observed better performance of MPR when banded than broadcasted in soil with high P-fixing capacity, despite low dissolution of the banded MPR.

Inferior dissolution within a band is due to accumulation of the dissolution products (Ca and P) which reduces further dissolution of PR due to the Ca/P common ion effect (Bolland and Gilkes, 1986; Bollan and Hedley, 1990). Low rates of PR are used when banding application is practiced. At the same time, this method is not laborious as compared to broadcasting, which as pointed out earlier needs second tilling of the land so as to incorporate the broadcasted PR into the soil.

2.3.4.2 Rate of phosphate rock application

It has been found that phosphate rock application rates affect its dissolution in soil. Hughes and Gilkes (1986) observed that an increase in the level of rock phosphate in most soils resulted in a smaller proportion of dissolving PR. This was confirmed by the result obtained in South America using a Haplorthox soil where the percentage dissolution of PR after 31 days was 27 % when 500 μgCa/g was added as PR and only 4 % when 12,500 μgCa/g was added as PR.

Khasawneh and Sample (1978), working with a variety of PRs, obtained an increase in dry matter yield of maize at six weeks as the rates of application of PR were increased from 15 to 180 mg/kg. Further increases in PR application rate greater than 180 mg/kg were not beneficial with regard to dry mater yield of maize. This could be attributed to the assumption that PR application above 180 mg/kg was beyond the optimal application rates for the soil in question. Sidhu (1978), working with rice and a variety of PRs on acid soil, reported that rice grain yields increased as the rates of PR were increased from 25 to 175 kgP/ha. Beyond 175 kg/ha, P did not give a significant increase in grain yields.

Kimbi (1991), when evaluating partially acidulated and non-acidulated MPR as sources of P for maize in various soils, observed that using P carriers at the rate of 80 kgP/ha increased dry matter yields in those soils with P deficiency. Generally, the rates of PR to be applied to various soils for optimal crop response/growth vary from soil to soil depending on the chemical properties of the soil, particularly pH and mineralogy.

2.3.4.3 Time of PR application

It has been recommended that applying PRs well ahead of planting of crops has often increased PR dissolution and thus increased the rate of P uptake from PRs. Semoka (1988), working on Minjigu, Njelenje and Mbalizi phosphate rocks, observed that P released from MPR increased with soil-PR equilibration time. Through such observations, it could be concluded that P dissolution from PRs increases with time of contact between rock phosphate and soil.

2.4 Plant uptake of phosphorus from soils

Reserves of plant-available P in soils come from native P, past fertilization or both (Pothuluri *et al.*, 1991). The major forms of P taken by plants from the soil solution are $H_2PO_4^-$ and HPO_4^{-2}. The average soil solution P concentration is about 0.05 μg/g but varies widely among soils. The P concentration required by most plants varies from 0.003 to 0.3 μg/g depending on crop species and level of production (Tisdale *et al.*, 1993).

The supply of inorganic P (P_i) to plants depends on the concentration of P_i in the soil solution, the quantity of the solid phase P_i that serves as a reserve to replenish P in soil solution and the ability of the soil to maintain the solution P concentration (Holford, 1997). Though desorption of P_i is smaller than adsorption of P_i, a portion of the P_i sorbed by Fe and Al oxides can be reversibly released to replenish P_i in the soil solution (Barrow, 1983). Desorption of P in a soil is inversely related to the duration of P sorption, soil P-sorption capacity, the amount of soil-sorbing capacity that is unoccupied and content and form of Fe and Al oxides in the soil (Frossard *et al.*, 1995).

Net mineralization of organic phosphorus is generally directly related to total soil organic phosphorus (P_o) for both fertilized and non-fertilized soils (Sharpley, 1985). Net mineralization of P_o tends to be more important as a source of plant available P on highly weathered soils such as oxisols and ultisols. This is because of the generally greater P_o in highly weathered soils (Tiessen *et al.*, 1984; Sharpley *et al.*, 1987). Organic phosphorus as a source of plant-available P might be an alternative explanation of the poor correlation between crop response to applied P and P extracted by conventional soil P tests that do not assess P_o (Warren, 1992; Tiessen *et al.*, 1984). Such poor correlation might arise when the mineralization of P_o supplies sufficient amount of plant available P to match or exceed the shortfall in P releases from labile P_i to meet plant demand for P.

Browman and Cole (1978) proposed that the sum of bicarbonate P_i and P_o would be a better indicator of plant response to P than bicarbonate P_I alone, as was the case of the soils low or deficient in P based on bicarbonate P_i. Soils with low bicarbonate P_i

and much higher bicarbonate P_o, however, can be responsive to P fertilizer (Buresh *et al.*, 1997). But extractable P_i together with a labile P_o to labile P_i ratio might be valuable in assessing the importance of mineralization. The relative importance of P_o mineralization, compared with desorption of P_i, as a source of plant available P would presumably be greatest at low extractable P_i, high labile P_o to labile P_i ratio, and high microbial P (Buresh *et al.*, 1997). When P_o supplied available P that was sufficient for plant demand, the combination of an indicator of P availability from P_o with extractable P_i did not improve the correlation with plant growth (Mnkeni *et al.*, 1995).

Phosphorus has frequently been quoted as being out of balance in organic materials. This is due to low amount of this element in many organic substrates and the slow rate of its release from the organic forms (Kasembe *et al.*, 1983). In the case of nutrient imbalance where both nitrogen and phosphorus are deficient in a soil, both nutrients must be added in order to maximize yields. The maximum response to nitrogen fertilizer cannot be obtained when phosphorus and other essential nutrients are in short supply. The response to added phosphorus fertilizers could also be limited if available soil nitrogen is at low levels.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Pot and field experiments were conducted to assess the effect of phosphate rock placement methods and incorporation of organic residues on phosphorus availability and maize yields in two soils with different phosphorus fixing capacities. These soils were from Sasanda, Mbozi district (Mbeya region), classified as Drystropept by Van Straaten *et al.* (1992) and SUA-farm (Magadu), Morogoro district (Morogoro region), classified as Oxic Haplustult by Kaaya (1989). The soil from Magadu is known to have medium P fixing capacity with P adsorption maximum of 466 mg P/kg while that from Sasanda is known to have high P fixing capacity with P adsorption maximum of 4110 mg P/kg (Mwakisimba, 1999). The organic materials used in this study were plant residues indigenous in each of these two areas. *Pycnanthemum tenuifolium* (mountain mint) was used for Magadu soil, whereby *Ageratum conyzoides* (goat weed) was used for Sasanda soil. Maize(*Zea mays* L.) varieties UH 615 and KITO were used as test crop in field experiments for soil of Sasanda and Magadu, respectively while in pot experiments variety UH 615 was used in both soils (Sasanda and Magadu soils).

3.1 Soil sampling and preparation

Soil samples for use in this study were collected from Magadu and Sasanda. Composite topsoil (0 to 20 cm) sampled from each site were air dried and thereafter ground to pass through a 6 mm sieve for the pot experiment or through a 2 mm sieve for routine soil analysis (Gee and Bouder, 1986).

3.2 Routine soil analysis

3.2.1 Particle size distribution

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Fifty grams air-dried soil samples were weighed into 250-ml plastic bottles and mixed with 50 ml of the dispersing agent (sodium hexametaphosphate) followed by 200 ml of distilled water. The bottles were placed in a horizontal position and the soil suspensions shaken at 150 rpm overnight on a reciprocating shaker. The suspension from each bottle was transferred to a one-litre sedimentation cylinder. The volume of mixture was made to one litre with distilled water. The mixture was stirred for one minute and left to stand. Hydrometer readings were taken after five minutes and again after five hours and the relative size proportions (i.e. sand, silt and clay) were calculated. The textures were determined using the USDA textural class triangle (USDA, 1975).

3.2.2 Soil pH

Soil pH was determined in 1: 2.5 soil: water ratio. Ten g of soil sample was weighed into 100-ml plastic bottles and mixed with 25 ml of water. The mixture was shaken for 30 minutes on a reciprocating shaker and pH was determined electronicaly using a pH meter (MacLean, 1982; Moberg, 2000).

3.2.3 Organic carbon

Organic carbon was determined by the wet digestion method of Walkley and Black (Nelson and Sommer, 1982). One g of soil samples were weighed into 500-ml Erlenmeyer flasks and mixed with 10 ml 1N $K_2Cr_2O_7$ and 20 ml of conc. H_2SO_4.

The flasks were carefully swirled for one minute and allowed to stand for 30 minutes. Then 200 ml of distilled water, 10 ml of conc. H_3PO_4 and 2 ml of diphenyalamine indicator solution were added. The mixture (excess dichromate) was titrated with 0.5M ferrous sulphate to the end point (deep green). The amount of dichromate reduced was a measure of organic carbon content in the soils after multiplying it with 1.33 as recovery factor (Moberg, 2000).

3.2.4 Total nitrogen

Total nitrogen was determined by micro-Kjeldahl digestion method followed by distillation (Bremner and Mulvaney, 1982). One gram of soil sample was digested with 10 ml of conc. H_2SO_4 in the presence of K_2SO_4, CuH_2SO_4 and selenium powder as catalyst, mixed together and swirled in the digestion tubes and digested at about 360°C to pale green colour (Moberg, 2000). Tubes were then removed from digestion block and allowed to cool, followed by addition of 50 ml of distilled water, while swirling. Twenty five 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 50 ml of 40% NaOH. The ammonia liberated was collected in the 4% boric acid-mixed indicator and the distillate was titrated with standard 0.01M H_2SO_4 until the colour changes from green to pink. The titre was used to calculate the total N.

3.2.5 Extractable phosphorus

Extractable P was determined by Bray 1 method (Moberg, 2000; Bray and Kurtz, 1945) followed by colour development by the ascorbic acid method of Murphy and

Riley, 1962) or Moberg (2000). Air-dried 3.5 g soil samples were weighed into 50 ml plastic bottle, and 25 ml of extracting solution containing 0.03M NH_4F + 0.025M HCl were added. The bottles were shaken (by hand) for one minute and immediately the suspension was filtered.

Ten ml of extract were transferred into 50 ml volumetric flask, and 30 ml of distilled water and 4 ml of ascorbic acid were added. The contents were then made to the mark with distilled water and thoroughly mixed. Absorbency was measured by an Atomic Absorption Spectrophotometer (AAS) at 884 nm wavelength after the blue colour had fully developed with appropriate standards (Moberg, 2000). The absorbency was used to calculate percentage phosphorus.

3.2.6 Exchangeable bases

Ammonium acetate saturation method was used to determine the exchangeable bases. Five grams of soil sample was weighed into plastic bottles, 35 ml of ammonium acetate (pH 7) were added and the mixture was shaken for 30 minutes on a shaker. The suspension was filtered and the filtrates were used for the determination of the exchangeable bases. Exchangeable Ca and Mg were determined by atomic absorption spectrophotometer at wavelengths of 422.5nm and 285nm, respectively, with appropriate standards. Exchangeable K and Na were determined by flame photometer at wavelengths of 768 and 589nm, respectively with appropriate standards.

3.2.7 Cation exchange capacity

The soil remaining on the filter paper after filtration for the exchangeable bases (in 3.2.6 above) was washed using 100 ml of ethanol and then placed into plastic bottles. Fifty ml of 4% KCl were added and shaken for 30 minutes on a shaker. The mixture was filtered and the residue washed by 4% KCl. The filtrates were used for the distillation process as for total N (section 3.2.4). The distillate was titrated with 0.1N H_2SO_4 and the titre value was used to calculate the CEC.

3.2.8 Exchangeable acidity and aluminium

Exchangeable acidity and aluminium were determined by the potassium chloride method described by McLean (1982). Thirty gram of soil sample were extracted by 75 ml of 1M KCl and the suspensions were shaken for 15 minutes and filtered. Ten ml 0f 40% NaF-solution and 5 drops 0f phenolphthalein indicator were added to 25 ml of filtrate. Then the 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 disappeared. Titre volume were used to calculate extractable acidity and aluminium.

3.2.9 Micronutrients

DTPA extractable Zn and Cu were determined by atomic absorption spectrophotometer (Lindsay and Norvell, 1978; Moberg, 2000). Ten grams of soil sample were weighed into 100 ml plastic bottle, and 30 ml of the buffered DTPA extracting solution (Lindsay and Norvell, 1978) were added. The suspension was shaken for two hours and immediately filtered through Whatman No.1 filter paper

into 50 ml plastic bottle. The extract was used to measure the contents of Cu and Zn using atomic absorption spectrophotometer at wavelengths of 324.8 and 213.9 nm, respectively.

Post-harvest soil samples from the field and pot experiments were also analyzed for the different nutrients using the methods described above.

3.3 Glasshouse pot experiment

The two soils, one from Magadu SUA-farm (Morogoro) and the other from Sasanda (Mbeya) were used. Maize (variety UH 615) was the test crop. Plant materials (*Ageratum conyzoides* for Sasanda soil and *Pycnanthemum tenuifolium* for Magadu soil) used in this study were fine ground using a hammer mill so as to facilitate decomposition in the pots. Five litre plastic pots were washed using clean water and sun dried. Four kg of air dried composite soil samples ground to pass through 6 mm sieve were weighed into the five litre plastic pots. The pots were arranged in a Complete Randomized Design with three replications. The treatments were:

1. Control: No MPR added,
2. Broadcasted MPR,
3. Strip banded MPR,
4. MPR+ organic residues banded (20 cm width band) at a rate of 2 ton/ha and incorporated to 20 cm depth within the pot,
5. MPR + organic residues banded (20 cm width band) at a rate of 4 ton/ha and incorporated to 20 cm depth within the pot,
6. MPR + organic residues banded (20 cm width band) at a rate of 8 ton/ha and incorporated to 20 cm depth within the pot.

The organic residues were thoroughly mixed with the soil within the 20 cm depth in the pots. The MPR was applied at the rate of 80 mgP/kg while N, Mg, Zn and Cu were applied at the rates of 200, 25, 5 and 5 mg/kg, respectively. Thereafter, the pots were watered to field capacity and left for 12 hours to equilibrate. Five maize seeds (variety UH 615) per pot were planted in both soils. Thinning was done to two plants per pot one week after emergence. The soils were maintained at field capacity using distilled water. The pots were maintained weed free during the whole period of the experiment. Plant shoots were cut at a height of 1 cm above ground after 42 days of plant growth using a stainless knife, rinsed in distilled water oven dried at 70°C to constant weight. Data were recorded as dry matter weight. Thereafter the plant samples were fine ground using Tecator Cyclotec 1093-sample mill for plant tissue analysis.

3.4 Field experiment

3.4.1 Location of the study sites

The field experiments were conducted at Magadu and Sasanda sites. The Magadu site is located within the SUA farm in Morogoro municipality at latitude 6.85^{0}S and longitude 37.64^0 E and an elevation of 568 m.a.s.l. The Sasanda site is in Mbozi district, Mbeya region. The site is located at latitude 9,16^{0}S and longitude 33.03^{0}E, at an elevation of 1650 masl.

3.4.2 Treatments

3.4.2.1 Sasanda site

Two experiments were conducted at Sasanda.

One was a continuation of a previous experiment (Mhagama, 2003) to evaluate the effects of banding and organic materials on MPR dissolution and maize yields. And the other was a new experiment, which in addition evaluated the rates of the organic materials.

For the continued experiment treatments were tested as follows:

1. Control: No MPR added,
2. MPR broadcasted and ploughed in to a 5-10 cm depth,
3. MPR banded in a strip of 4-5 cm band and covered with soil,
4. MPR applied as a 20 cm wide band and ploughed down to 10 cm depth,
5. MPR applied as 20 cm band and ploughed down to 20 cm depth,
6. MPR + OM band and ploughed to 10 cm depth,
7. MPR + OM band and ploughed to 20 cm depth.

For the new experiment, treatments were tested as follow:

1. Control: No MPR added,
2. Broadcasted MPR and ploughed down to 10 cm depth,
3. Strip banded MPR incorporated to 5 cm depth,
4. MPR applied as 20 cm band and ploughed down to 20 cm depth,
5. MPR+ organic residues banded at the rate of 2 ton/ha and incorporated down to 20 cm depth,
6. MPR + organic residues banded at the rate of 4 ton/ha and incorporated down to 20 cm depth,
7. MPR + organic residues banded at the rate of 6 ton/ha and incorporated down to 20 cm depth.

3.4.2.2 Magadu site

At the Magadu site, one experiment was conducted which was a continuation of the previous experiment (Mhagama, 2003), and treatments were as follow:

1. Control: No MPR added,
2. MPR broadcasted and ploughed in to a 5-10 cm depth,
3. MPR banded in a strip of 4-5 cm band incorporated to 5 cm depth,
4. MPR applied as a 20 cm band and ploughed down to 10 cm depth,
5. MPR applied as 20 cm band and ploughed down to 20 cm depth,
6. MPR + OM band and ploughed to 10 cm depth,
7. MPR + OM band and ploughed to 20 cm depth.

3.4.3 Experimental design and fertilizer and organic material placement

The above treatments for both Sasanda and Magadu sites were replicated four times and arranged in RCBD, to constitute 28 plots at each site. The plots size was 5 m X 5 m. Maize seeds were sown at a spacing of 75 cm X 30 cm. The inter plot and inter block spacing were 0.5 m and 1 m, respectively, while a 2 m pathway surrounded the experimental area.

Broadcasting of MPR was done by spreading the fertilizer material manually on the soil surface followed by incorporating down to about 10 cm to ensure thorough mixing with the soil. Strip banded MPR was done by opening a strip on soil surface in rows using a piece of stick and covered with soil. Banding of MPR alone and MPR + OM ploughed and incorporated into 10 cm or 20 cm depths was done by opening hoe-width furrows. MPR was applied at the rate of 80 kg P/ha and OM rates

were 2, 4 and 6 t/ha. At the same time, N, Zn, Mg and Cu fertilizers were applied at the rates of 100 kg/ha, 5 kg/ha, 25 kg/ha and 5 kg/ha, respectively, for Sasanda soil. For the Magadu soil, P, N, Zn and Mg fertilizers were applied at the same rates as Sasanda soil but Cu was not applied because there was no Cu deficiency in the Magadu soil.

Nitrogen fertilizer was applied in three splits. The first split (30 kgN/ha) was applied during planting time, the second split (40 kgN/ha) at active vegetative growth and the last split (30 kgN/ha) was applied at the onset of tasselling. However, P, Mg, Zn, and Cu fertilizers were applied during planting time. The organic materials used were the same as those used in the pot experiments.

3.4.4 Cultural practices

Planting was done in early December 2002 and early March 2003 at Sasanda and Magadu sites, respectively. The maize varieties used were kito for Magadu site and UH 615 for Sasanda site. Three maize seeds were sown per hole and seedlings were thinned to one plant per hill two weeks after seedling emergence. Weed free plots were maintained for most of the plant growth period. At Sasanda experimental site, Maize cobs were harvested at maturity, from five inner rows of each plot, shelled, grains weighed and moisture content of the grains determined using an electronic moisture meter. Thereafter, the grain yield data was reported as t/ha at 12.5% moisture content. At Magadu experimental site, maize stalks from five inner rows of each plot were harvested by cutting 2 cm above the soil at the onset of tasseling. The stalks were chopped into small pieces, washed using distilled water to remove soil

particles, dried at 70^{0}C, weighed and data were recorded as weight of dry matter (dry matter yield). The maize stalks were harvested at Magadu site because of severe drought conditions, which occurred this year in most parts of Tanzania including Magadu SUA farm (Morogoro) where this experiment was set. The drought caused the plants to dry before seed setting.

3.5 Plant sampling and analysis

3.5.1 Plant sampling

In both field experiments, 15 representative ear leaves were harvested in each plot at 50 % plant tasseling using a knife. The plant samples for analysis of macronutrients were washed using distilled water whereas for micronutrients they were washed using deionised water and placed in clean paper bags. The plant samples were dried at 70 ^{0}C to constant weight and ground using a Tecator Cyclotec 1093 sample mill for plant tissue analysis.

3.5.2 Plant material analysis

The plant samples were digested using a mixture of HNO_3 and H_2O_2 as outlined by Moberg (2000). The 0.5 g of plant samples were weighed into digestion tubes. Five milliliters of 68% HNO_3 were added into each digestion tube using an automatic pipette and the mixture was left to stand overnight. The tubes were then placed in a digestion block, temperature was raised to 125°C for one hour before they were taken off and cooled. After cooling, 5 ml H_2O_2 was added into each tube and heated at 80°C on the digestion block until the reaction stopped. This was repeated until the digests were almost colourless or nearly colourless. The digests were then heated at

180°C to almost dryness and left to cool. After cooling 10 ml of 10% HNO_3 were added and the dissolved digests were transferred quantitatively to a 100 ml volumetric flask and filled to the mark with distilled water. Thereafter the content of P in the digests was determined using the ascorbic acid molybdate blue method of Murphy and Riley, 1962) or Moberg (2000). Magnesium, Calcium and Zinc in the digests were determined using atomic absorption spectrophotometer while, potassium was determined using flame spectrophotometer (Bremner and Mulvaney, 1982) as described in sections 3.2.6 and 3.2.9.

Total N was determined by semi micro-Kjeldahl digestion method followed by distillation (Bremner and Mulvaney, 1982) as described in section 3.2.4.

3.5.3 Statistical analysis

The MSTATC computer program was used for data analysis. Analysis of variance (ANOVA) was performed on the data obtained from routine soil analysis, maize dry matter yields, maize grain yields, and plant P, Ca, K, Mg Zn and N concentrations. Dancun's New Multiple Range Test (DNMRT) was used for the separation of the means (means ranking). The model as described by Snedecor and Cochran (1989) was used for data analysis as shown below:

$Y_{ij} = U + T_i + B_j + E_{ij}$

Where:

$i = 1, 2, 3, \ldots\ldots i, \quad j = 1, 2, 3, \ldots\ldots j$

Y_{ij} = Maize yields/nutrient uptake (Response)

U = General effect

T_i = Treatment effect

B_j = Block effect

E_{ij} = Experimental (error) effect

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Description of properties of experimental soils and organic materials used

4.1.1 Some chemical and physical properties of experimental soils

Some of the chemical and physical characteristics of Sasanda (Dystropept) by Van Straaten *et al.* (1992) and Magadu (Oxic Haplustult) by Kaaya (1989) soils are presented in Table 1. Soil pH (in water) for both Sasanda and Magadu experimental soils were medium. Total N in Sasanda and Magadu soils were medium and low, respectively. Organic carbon in Sasanda soil was medium while that of Magadu soil was very low. All experimental soils contained low extractable P. The exchangeable Ca levels were low in both Magadu and Sasanda soils. The levels of exchangeable Mg and K were high in both soils. The levels of CEC were medium and high for Sasanda and Magadu soils, respectively. Extractable Zinc levels in both soils were deficient. The textures of the experimental soils were sand loam and sandy clay for Sasanda and Magadu, respectively. The levels of nutrients in both experimental soils were ranked according to Landon (1996) who ranked Bray 1 extractable P of <15, 15 to 50 and > 15 mgP/kg as being low, medium and high respectively. Total N of 0.1 to 0.2% as being low, 0.2 to 0.5% as being medium and > 0.5% as being high. Organic carbon of <2% as being very low and 2 to 4% as being low. CEC of 15 to 25, 25 to 40 and >40 cmol(+)/kg as being medium, medium and very high respectively. Exchangeable Ca values of <4 cmol(+)/kg as being low, 4 to 10 cmol(+)/kg as being medium and >10 cmol(+)/kg as being high. Exchangeable K values of 0.03 to 0.2, 0.2 to 0.4, and 0.4 to 0.8 cmol(+)/kg as being low, medium and high, respectively.

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

Parameters	Soil sampled Area	
	Sasanda	Magadu
PH in water	5.6	5.2
Total N %	0.37	0.10
Organic carbon (%)	4.34	1.17
Extractable P (mg/kg)	0.81	7.14
Exchangeable Ca {cmol (+)/kg}	1.10	3.08
Exchangeable Mg {cmol (+)/kg}	0.56	2.15
Exchangeable K {cmol (+)/kg}	0.97	0.76
Exchangeable Na {cmol (+)/kg}	0.75	0.65
CEC {cmol (+)/kg}	16.8	28.9
Base saturation (%)	20.12	23.01
Exchangeable Al{cmol (+)/kg}	0.10	0.41
Exchangeable H{cmol (+)/kg}	0.10	0.09
Extractable Zn (mg/kg)	0.55	0.69
Extractable Cu (mg/kg)	1.53	1.22
Total acidity{Cmol (+)/kg}	0.2	0.5
Particle size analysis (%)		
Sand	67	55
Silt	22	5
Clay	11	40
Textural class	Sandy clay	Sandy loam

Extractable Zn values of 0.5 to 1 mg/kg as being deficient and >1 as being adequate and exchangeable Mg values of <0.2, 0.2 to 0.5 and >0.5 cmol(+)/kg as being low, medium and high respectively.

Based on the above rankings, both Sasanda and Magadu experimental soils have low soil fertility status. Therefore those nutrients which were in low levels were applied in order to correct the observed deficiencies.

The Low levels of extractable P, exchangeable Ca^{2+}, and the acidic nature of both soils, imply that these soils might offer conditions favourable for high dissolution of MPR, eventually leading to increased P absorption by maize plants (Mnkeni *et al.* 1992).

4.1.2 Chemical properties of the organic materials

Table 2 shows some nutrient content and ratios of organic materials used in this study. The results showed that *Pycnanthemum tenuifolium* contain relatively higher N (1.75 %) than *Ageratum conyzoides* (1.33 %). Phosphorus content was slightly higher (0.22 %) in *Ageratum conyzoides* than in *Pycnanthemum tenuifolium* (0.17 %).

Organic carbon content in *Pycnanthemum tenuifolium* was 44.69% while in *Ageratum conyzoides* was 45.19%. Calcium content was 0.464 and 0.477% in *Ageratum conyzoides* and *Pycnanthemum tenuifolium,* respectively. *Ageratum conyzoides* had higher C:N ratio (34:1) compared to *Pycnanthemum tenuifolium* (26:1).

Handayanto *et al.* (1994) reported that organic materials with narrow C:N ratios if incorporated into soil decompose faster that those with wider C:N ratios. Uriyo *et al.*

(1979) reported that the available nitrogen content in a soil decreases following the addition of organic materials having C:N ratios greater than 30. It remains balanced for ratios between 20-30 and increases for ratios below 20.

Table 2: Some chemical properties of the organic matrerials

Organic matter	Parameter (%)				Ratios	
	OC	N	P	Ca	C:N	C:P
Ac	45.19	1.33	0.22	0.46	34	120
Pt	44.69	1.75	0.17	0.48	26	264

Ac = *Ageratum conyzoides*
Pt = *Pycnanthemum tenuifolium*

They further reported that if the decomposing organic materials have a wide C:N ratios the microorganisms will utilize any available nitrogen present in the soil to further the decomposition. The C/P ratio of *Ageratum conyzoides* was 120:1 while that of *Pycnanthemum tenuifolium* was 264:1. Tisdale *et al.* (1993) reported that organic materials having C:P ratios >300 if incorporated into soil, gave negative effects on P mineralization. Based on this findings of Tisdale *et al.* (1993) it showed that both organic materials used in this study had positive effects on P mineralization because they had C:P ratios <300.

4.2 Glasshouse pot experiment

4.2.1 Maize dry matter yields

Maize dry matter yields as influenced by methods of MPR application and rates of organic materials are presented in Table 3. The dry matter yields obtained ranged from 4.10 to 70.87 and 14.14 to 76.17 g/pot for Sasanda and Magadu soils, respectively. Both soils gave low drymatter yields in treatment controls as compared to MPR treatments. MPR + OM banded at 2, 4, and 8 t/ha and incorporated to 20 cm depth within the pot gave significantly (P=0.05) higher maize dry matter yields than the other treatments, with dry matter yields increasing as rate of OM was increased. MPR + OM banded at a rate of 8 t/ha gave the highest maize dry matter yields of 76.17 and 70.87 g/pot in Magadu and Sasanda soils, respectively. Broadcasted MPR treatment gave significantly (P=0.05) higher dry matter yield than strip banded MPR in both Magadu and Sasanda soils.

The lower DM yields in controls compared to MPR treatments may be due to low levels of P in these soils (Table 1) since no P source was applied in the controls. The higher dry matter yields from Magadu control treatment compared to those of Sasanda control treatment may be due to slightly higher P level in Magadu soil than Sasanda soil. The increase in DM yield as OM was increased may be due to increased dissolution of MPR probably caused by increased supply of organic acids (H^+) in the soil during the decomposition of organic materials (section 4.1.4).

Table 3: Effects of MPR placement and rates of organic materials on maize dry matter yields

Treatment	Maize dry matter yields	
	Sasanda soil	Magadu soil
	.....g/pot.....	
Control	4.10f	14.14e
Broadcasted MPR	40.53d	50.54c
Strip banded MPR	24.81e	25.35
MPR + OM at 2 t/ha banded to 20 cm depth	45.37c	54.30c
MPR + OM at 4 t/ha banded to 20 cm depth	58.37b	60.23b
MPR + OM at 8 t/ha banded to 20 cm depth	70.87a	76.17a
CV (%)	3.37	6.49

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 higher DM yields in broadcasted MPR than strip banded MPR in both Sasanda and Magadu soils may be due to increased MPR dissolution in broadcasted MPR over strip banded MPR hence increasing the level of available P for plant uptake. Khaswaneh and Doll (1978), Hammond *et al.* (1986) and Mhagama (2003) have reported similar results. The decrease in available P in the strip banded MPR might have been caused by limited contact between the soil and the MPR, hence causing

limited supply of H^+ from soil for the dissolution of MPR. Kanabo and Gilkes (1987) and Robinson and Syers (1990) reported that a net supply of H^+ in the soil was a prerequisite for the dissolution of PR.

The higher yields in OM treated soils as observed in the present results may also be explained in terms of reduction of P fixation. Iyamuremye and Dick (1996) and Le Mare (1991) reported that organic acids produced during the decomposition of organic matter may temporarily reduce P fixation of the soil. In addition, Le Mare (1991) and Ikerra *et al.* (1994) 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 through binding of the organic matter/acids to the oxides and hydroxides surfaces of clay particles, thereby releasing more P into soil solution for plant uptake.

In general, the results showed that maize dry matter yields from Magadu soil were relatively higher than that from Sasanda soil in all treatments. The relatively higher inherent soil P in Magadu soil might have contributed to the relatively higher DM yields from that soil.

4.2.2 Effect of MPR placement and rates of organic materials on phosphorus uptake by maize plants

The uptake of phosphorus by maize plants as influenced by phosphorus placement methods and rates of organic materials is presented in Table 4.

Table 4: Phosphorus uptake as influenced by MPR placement methods and rates of organic materials

Treatment	Phosphorus uptake by maize plant	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	3.33d	16.87c
Broadcasted MPR	69.04b	114.60ab
Strip banded MPR	31.79c	44.02c
MPR + OM at 2 t/ha banded to 20 cm depth	66.20b	99.12b
MPR + OM at 4 t/ha banded to 20 cm depth	126.60a	140.10a
MPR + OM at 8 t/ha banded to 20 cm depth	126.00a	127.7ab
CV (%)	17.12	19.54

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.

Phosphorus uptake by maize plants ranged from 16.87 to 140.1 mg/pot and 3.33 to 126.60 mg/pot in Magadu and Sasanda soils, respectively. In both soils controls gave significantly (P=0.05) lower P uptake values compared to the other treatments except for the strip banded MPR in Magadu soil. Strip banded MPR resulted in significantly (P=0.05) lower P uptake than the other treatments that received MPR. For the Magadu soil, maize from broadcasted MPR or MPR + OM banded at 2, 4, and 8 t/ha

did not differ very much in P uptake. But for the Sasanda soil, there was significant (P=0.05) difference in P uptake between broadcasted MPR and MPR + OM banded at the rates of 4 and 8 t/ha, broadcasted MPR having lower P uptake value than the two treatments received MPR and organic material at the mentioned rates. The highest values of P uptake in both soils were generally observed in MPR + OM banded at a rate of 4 t/ha. In soils, broadcasted MPR and MPR + OM banded at a rate of 2 t/ha did not show significant (P = 0.05) difference in P uptake by maize plants.

These findings are similar to that reported by Mhagama (2003) who worked with the same soils.

The lower P uptake in the control treatments in both soils might have been caused by low inherent P in these soils (Table 1) since no P sources were applied. Coupled with their high fixing capacities of these soils for what little P is there (Mwakisimba, 1999).

The lower P uptake in strip banded MPR than other MPR treatments may be due to low P in the soil solution for plant uptake due to low dissolution of MPR when strip banded as discussed in section 4.1.1. Insignificant (P=0.05) difference in P uptake in most of the MPR treatments in Magadu soil may be due to its relatively higher inherent P status and less fixation of P compared to Sasanda soil.

The lower P uptake in the broadcasted MPR than in the MPR + OM at the rates of 4 and 8 t/ha in Sasanda soil may be due to higher dissolution of MPR resulting from higher supply of H^+ following decomposition of the OM. Thus, more of the dissolved P was available for plant uptake.

4.2.3 Phosphorus concentration in maize plant shoots

Table 5 shows the effects of MPR placement and rates of organic materials on P concentration in maize plant shoots. Phosphorus concentrations in maize plant from Magadu and Sasanda soils ranged from 0.12 to 0.23 and 0.08 to 0.22%, respectively.

Table 5: Phosphorus concentration in maize plant shoots as influenced by MPR placement and rates of organic materials

Treatment	Phosphorus concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	0.08c	0.12c
Broadcasted MPR	0.17ab	0.23a
Strip banded MPR	0.13bc	0.14c
MPR + OM at 2 t/ha banded to 20 cm depth	0.15ab	0.18ab
MPR + OM at 4 t/ha banded to 20 cm depth	0.22a	0.20ab
MPR + OM at 8 t/ha banded to 20 cm depth	0.18ab	0.17ab
CV (%)	13.35	21.19

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.

Except for the control treatments, none of P deficient symptoms were expressed in the MPR treatments. The lowest P concentration for both Magadu and Sasanda soils was observed in the control treatments. Strip banded MPR treatments for both soils had the lowest P concentrations as compared to the other treatments that received MPR fertilizer. There was no significant (P=0.05) difference in P concentration between the control treatment and strip banded MPR in both Magadu and Sasanda soils. Also in both soils, there were no significant (P=0.05) difference in P concentration in maize shoots between broadcasted MPR and MPR + OM at different rates.

These trends generally agreed with those of P uptake (section 4.1.2).

The lower level of P concentration in maize shoots observed from the controls in both soils may be due to low inherent soil P (Table 1) as already discussed. Thus, application of MPR increased the P shoot content in maize as observed in MPR treatments.

The lower P concentration in strip banded MPR compared to other MPR treatments could be attributed to poor dissolution of MPR when strip banded. Insignificant (P=0.05) difference in maize shoot P concentration between control treatments and strip banded MPR treatments in both soils may imply that strip banding did not substantially improve P dissolution from the MPR.

4.2.4 Uptake of other nutrients

4.2.4.1 Nitrogen uptake by maize plants

The uptake of N by maize from Magadu and Sasanda soils as influenced by MPR placement and rates of organic materials is shown in Table 6.

Table 6: Effects of MPR placement and rates of organic materials on Nitrogen uptake by maize plants

Treatments	Nitrogen uptake by maize plants	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	109.40e	384.5c
Broadcasted MPR	855.60b	749b
Strip banded MPR	547.10d	387.70c
MPR + OM at 2 t/ha banded to 20 cm depth	714.40c	779.10b
MPR + OM at 4 t/ha banded to 20 cm depth	913.10b	775.6b
MPR + OM at 8 t/ha banded to 20 cm depth	1019a	942a
CV (%)	6.65	10.95

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.

Plant N uptake ranged from 384.5 to 942.0 mg/pot for the Magadu soil and from 109.4 to 1019.0 mg/pot for the Sasanda soil. In both soils treatments that received MPR gave higher N uptake values than control treatment. There was no significant (P=0.05) difference in N uptake by maize plants between control reatment and strip banded MPR and between broadcasted MPR and MPR + OM banded at 2, and 4 t/ha in Sasanda soil. Magadu soil showed significant (P=0.05) difference in N uptake between control treatment and strip banded MPR and between broadcasted MPR and MPR + OM banded at 2, 4, and 8 t/ha.

The higher N uptake in MPR treatment than controls in both soils may be due to the availability of P in soil solution after the dissolution of MPR that enhanced N uptake by maize plants. The observed insignificant (P=0.05) difference in N uptake among treatments in Sasanda soil may be due to inherent medium N status (Table 1) in Sasanda soil, according to the rankings of Landon (1996). However, the observed significant differences in N uptake among treatments in Magadu soil may be due to the low N status of this soil (Landon, 1996). This means that the application of ammonium sulphate fertilizer increased solution N and, thus, N uptake by maize. The lowest and highest N uptake in control treatment and MPR + OM at the rate of 8 t/ha, respectively, in both soils, may be due to P and N nutrition relationship.

A good supply of extractable P usually leads to increased root growth consequently, leading to increased N uptake by maize plants (Tisdale *et al.*, 1993). The increased uptake of N agrees well with that for P uptake and dry matter yields (section 4.1.1 and 4.1.2).

4.2.4.2 Nitrogen concentration in maize plant shoots

Table 7 shows the effect of MPR placement and rates of organic materials on N concentration in maize plant shoots.

Table 7: Effects of MPR placement and rates of organic materials on nitrogen concentration in maize plant shoots

Treatment	Nitrogen concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	2.68a	2.74a
Broadcasted MPR	2.11b	1.48b
Strip banded MPR	2.21b	1.52b
MPR + OM at 2 t/ha banded to 20 cm depth	1.58c	1.24c
MPR + OM at 4 t/ha banded to 20 cm depth	1.56c	1.23c
MPR + OM at 8 t/ha banded to 20 cm depth	1.54c	1.17c
CV, %	13.35	5.57

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.

Nitrogen concentrations ranged from 1.17 to 2.74% and 1.54 to 2.68% for Magadu and Sasanda soils, respectively. These N concentration values are considered to be not adequate according to Tandon (1995) who ranked N concentration values of <3.5% as being low, 3.5 to 5% as being sufficient and >5 % as being high for maize shoots grown for 30 to 45 days. There was slightly higher N concentration in Sasanda than in Magadu soil. In both soils, the control treatment showed significantly (P=0.05) higher N concentrations than the other treatments that received MPR. Also MPR + OM banded at 2, 4, and 8 t/ha gave significantly (P=0.05) lower N concentration values than other treatments.

The higher N concentrations in Sasanda soil compared to Magadu soil may be due to relatively higher inherent N status in Sasanda soil than in magadu soil (Table 1). The higher N concentration in the control treatment than in the MPR treatments may be as a result of the low yields in the control. The lower N concentrations in the MPR + OM treatments might have been caused by a dilution effect due to high dry matter yields (section 4.1.1) in these treatments. These results correspond to the findings of Marschner (1990) who reported that the increased DM yields caused dilution of nutrients within the plant tissues, hence low nutrient concentrations.

4.2.4.3 Potassium concentration and uptake as influenced by MPR and rates of organic materials

The results of K concentration as influenced by MPR placement and rates of organic material are presented in Table 8. Potassium concentrations ranged from 1.81 to2.81% and 1.92 to 3.28% for Sasanda and Magadu soil, respectively.

Table 8: Effects of MPR placement and rates of organic materials on potassium concentration in maize plant shoots

Treatment	Potassium concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	2.81a	3.28a
Broadcasted MPR	1.81c	1.92c
Strip banded MPR	2.36b	2.57b
MPR + OM at 2 t/ha banded to 20 cm depth	2.11bc	2.19b
MPR + OM at 4 t/ha banded to 20 cm depth	2.04bc	2.32b
MPR + OM at 8 t/ha banded to 20 cm depth	2.25b	2.46b
CV (%)	8.29	6.42

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.

Tandon (1995) reported that sufficient K concentration in maize plant range from 1 to 5%. Therefore, the observed K concentrations in maize shoots were in the sufficiency range. In both soils, control treatment significantly (P=0.05) gave higher K concentration than treatments that received MPR. Plants from broadcasted MPR contained significantly (P=0.05) lower K concentration than those from treatments that received 2, 4, and 8 t/ha of organic materials. There was no significant (P=0.05)

difference in K concentration in maize shoots among MPR + OM at 2, 4, and 8 t/ha treatments in both soils.

Data for the potassium uptake by maize plants as influenced by MPR placement and rates of organic material are presented in Table 9.

Table 9: Effects of MPR placement and rates of organic materials on potassium uptake by maize plants

Treatment	Potassium uptake by maize plants	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	115f	134.50f
Broadcasted MPR	733.50d	777d
Strip banded MPR	585.60e	438.80e
MPR + OM at 2 t/ha banded to 20 cm depth	955.50c	995.70c
MPR + OM at 4 t/ha banded to 20 cm depth	1193b	1391b
MPR + OM at 8 t/ha banded to 20 cm depth	1591a	1740a
CV (%)	9.62	6.96

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

There was also significant (P=0.05) difference in K uptake among treatments that received MPR. There was increased K uptake by maize plants as the amount of OM increased. The lowest K uptake value was observed in the control treatment while the highest K uptake value was observed from MPR + OM at the rate of 8 t/ha in both soils. Banding of MPR together with organic materials increased K uptake by maize plants as compared to MPR applied alone in both Magadu and Sasanda soils.

The higher K concentration in plants from the control treatment was due to low yields. The lower K concentrations in plants from the MPR treatments in both soils may be a result of increased maize growth due to adequate N and P that resulted in high DM yields. This then caused a dilution effect of K (Marschner, 1990). The lower K uptake in controls than MPR treatments in both soils was a result of the low dry matter yields. The increase in K uptake as OM increased may be due to increased dry matter yields in the MPR treatments.

4.2.4.4 Calcium concentration and uptake as influenced by MPR placement and rates of organic materials

The Ca concentration as influenced by MPR placement and rates of organic materials in Magadu and Sasanda soils are presented in Table 10. Calcium concentration in maize plants ranged from 0.25 to 0.35% and 0.20 to 0.32% for Sasanda, and Magadu soils respectively. According to Tandon, (1995) critical level of Ca concentration in plant shoots range from 0.2 to 1.0 %. Therefore, all treatments showed sufficient levels of Ca in plant shoots. In both Sasanda and Magadu soils, control treatment showed significantly (P=0.05) higher Ca concentration than MPR treatments.

In both Sasanda and Magadu soil, there was no significant (P=0.05) difference in plant Ca concentration among the MPR treatments.

Table 10: Effects of MPR placement and rates of organic materials on calcium concentration in maize plant shoots

Treatment	Calcium concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	....%	
Control	0.35a	0.32a
Broadcasted MPR	0.26b	0.23b
Strip banded MPR	0.29b	0.25b
MPR + OM at 2 t/ha banded to 20 cm depth	0.27b	0.23b
MPR + OM at 4 t/ha banded to 20 cm depth	0.25b	0.23b
MPR + OM at 8 t/ha banded to 20 cm depth	0.26b	0.20b
CV (%)	7.39	3.09

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.

Data for Ca uptake for Magadu and Sasanda soils as influenced by MPR placement and rates of organic material are presented in Table 11. The lowest Ca uptake was observed in the control treatment in both soils.

Table 11: Effects of MPR placement and rates of organic materials on calcium uptake by maize plants

Treatment	Calcium uptake by maize plants	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	14.34f	49.48c
Broadcasted MPR	104.20d	130b
Strip banded MPR	72.38e	73.95c
MPR + OM at 2 t/ha banded to 20 cm depth	124.20c	148.60b
MPR + OM at 4 t/ha banded to 20 cm depth	147.50b	153.40b
MPR + OM at 8 t/ha banded to 20 cm depth	183.10a	187.8a
CV (%)	9.62	12.28

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.

There was no significant (P=0.05) difference in Ca uptake between control treatment and strip banded MPR in Magadu soil, as well as between broadcasted MPR and MPR + OM at the rate of 2 and 4 t/ha in Magadu soil.

The highest Ca uptake was observed when MPR was banded together with OM at the rate of 8 t/ha in both soils. The Ca uptake increased significantly (P=0.05) with MPR application and rates of organic materials.

The higher Ca concentration in the controls than the MPR treatments in both soils may be due to dilution effect (Marschner, 1990) of Ca caused by improved plant growth due to increased P availability in soil solution after MPR addition, as well as availability of other nutrients as already discussed. Kadogholo (2001) reported similar results when working with the same soils. Insignificant difference in Ca concentration in maize shoots among the MPR treatments may suggest that the amount of Ca supplied was sufficient for maize growth in these treatments.

The lower Ca uptake in the controls in both soils may be due to the low yields, since no MPR was applied in the control treatment. Insignificant (P=0.05) difference between the control treatment and the strip banded MPR in Magadu soil may be due to poor dissolution of MPR when it was strip banded as reported by Mhagama (2003). There is little contact of MPR and soil in the strip band. The increased Ca uptake with MPR application and rates of organic materials may be due to the fact that organic materials upon decomposition released organic acids such as aliphatic acids, which can chelate Ca ions in soil. These lower the activity of Ca^{2+} in the soil solution, consequently enhancing the dissolution of MPR and releasing more Ca. As a result, the Ca becomes available in soil solution for plant uptake (Hammond *et al.*, 1986).

4.2.4.5 Magnesium concentration and uptake as influenced by MPR placement and rates of organic materials

Table 12 shows the effects of MPR placement and rates of organic materials on magnesium concentration in maize shoots for Sasanda and Magadu soils.

Magnesium concentration in maize from the Magadu soil ranged from 0.15 to 0.24% while in the Sasanda soil it ranged from 0.15 to0.34%.

Table 12: Effects of MPR placement and rates of organic materials on magnesium concentration in maize plant shoots

Treatment	Magnesium concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	.....%	
Control	0.34a	0.24a
Broadcasted MPR	0.15b	0.15b
Strip banded MPR	0.20b	0.20ab
MPR + OM at 2 t/ha banded to 20 cm depth	0.15bc	0.16bc
MPR + OM at 4 t/ha banded to 20 cm depth	0.15b	0.15b
MPR + OM at 8 t/ha banded to 20 cm depth	0.15b	0.15b
CV (%)	12.91	6.21

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 highest Mg concentration for both soils was observed in the control treatment and there was significant (P=0.05) difference in Mg concentration between the control treatment and the MPR treatments.

There was no significant (P=0.05) difference in Mg concentration in maize shoots among the MPR treatments.

The results for Mg uptake by maize plants as influenced by MPR placement and rates of organic matter for Magadu and Sasanda soils are presented in Table 13.

The trend of Mg uptake for both soils was similar, of which the MPR + OM banded at the rate of 8 t/ha gave the highest Mg uptake while the control treatment gave the lowest Mg uptake. In both soils there was significant (P=0.05) difference in Mg uptake between MPR placement and rates of organic materials.

Tandon (1995) reported that the critical range of Mg concentration in maize plant is 0.15 to 0.45%. According to these rankings all soils from all the treatments in this study, for both Magadu and Sasanda soils, had Mg concentration values which were within the critical range. This means that Mg was not limiting in both Sasanda and Magadu soils. The higher Mg concentration in the controls compared to the MPR treatments might have been caused by dilution effect due to increased dry mater yields (Table 3) in MPR treatments (Marschner, 1990).

Although higher levels Mg concentration were observed in control treatment (Table 12), Mg uptake was low due to low yields in the controls (section 4.1.1).

Table 13: Effects of MPR placement and rates of organic materials on magnesium uptake by maize plant

Treatment	Magnesium uptake by maize plants	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	14.34f	49.48c
Broadcasted MPR	104.20d	130b
Strip banded MPR	72.38e	73.95c
MPR + OM at 2 t/ha banded to 20 cm depth	124.20c	148.60b
MPR + OM at 4 t/ha banded to 20 cm depth	147.50b	153.40b
MPR + OM at 8 t/ha banded to 20 cm depth	183.10a	187.8a
CV (%)	9.62	12.28

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.

4.2.4.6 Zinc concentration and uptake as influenced by MPR placement and rates of organic materials

The effects of MPR placement and rates of organic materials on zinc concentration in maize plant shoots are shown in Table 14. Zinc concentrations ranged from 11.92 to 23.55 mg/kg and 18.12 to 35.38 mg/kg for Sasanda and Magadu soils, respectively.

The control treatment Showed significantly (P= 0.05) higher Zn concentrations than MPR treatments.

Table 14: Effects of MPR placement and rates of organic materials on zinc concentration in maize plant shoots

Treatment	Zinc concentration in maize plant shoots	
	Sasanda soil	Magadu soil
	.....mg/kg.....	
Control	23.55a	35.38a
Broadcasted MPR	11.92d	20.62cd
Strip banded MPR	17.92b	31.45b
MPR + OM at 2 t/ha banded to 20 cm depth	15.28c	23.78c
MPR + OM at 4 t/ha banded to 20 cm depth	14.05c	22.62c
MPR + OM at 8 t/ha banded to 20 cm depth	12.52d	18.12d
CV (%)	9.08	6.95

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 data for Zn uptake by maize plants as influenced by MPR placement and rates of organic materials are presented in Table 15. Zinc uptake values ranged from 0.50 to 1.39 mg/pot and 0.10 to 0.89 mg/pot in Magadu and Sasanda soils, respectively. The control treatment showed significantly (P=0.05) lower Zn uptake than the MPR treatment.

Table 15: Effects of MPR placement and rates of organic materials on zinc uptake by maize plants

Treatment	Zinc uptake by maize plants	
	Sasanda soil	Magadu soil
	.....mg/pot.....	
Control	0.10d	0.5d
Broadcasted MPR	0.68b	1.04b
Strip banded MPR	0.44c	0.80c
MPR + OM at 2 t/ha banded to 20 cm depth	0.69b	1.29a
MPR + OM at 4 t/ha banded to 20 cm depth	0.82a	1.38a
MPR + OM at 8 t/ha banded to 20 cm depth	0.89a	1.39a
CV (%)	8.72	11.85

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.

Strip banded MPR resulted in significantly (P=0.05) lower Zn uptake than the other MPR application methods. In Sasanda soil, broadcasted MPR and the MPR + OM banded at the rate of 2 t/ha did not differ significantly (P=0.05) while MPR + OM banded at the rates of 4 and 8 t/ha did not differ significantly (P=0.05) in Zn uptake.

There was no significant (P=0.05) difference in Zn uptake among the MPR + OM at different rates in Magadu soil.

Tandon (1995) ranked zinc concentration values of <20 mg/kg as being low and values between 20 to 60 mg/kg as being sufficient for maize plant growth. Thus, in Magadu soil, all maize plants except those from MPR + OM at the rate of 8 t/ha showed sufficient levels of Zn in their shoots. In Sasanda soil, only maize plants from the control treatment showed sufficient levels of Zn. The lower Zn concentration in the MPR treatments in both soils may be due to antagonistic relationships between Zn and P. Tandon (1987) found that increased supply of P in soil solution induced low level of Zn in plants due to an antagonistic effect of P on Zn. This might have been the case in the present studies, upon addition of MPR.

4.2.5 Residual Bray 1 phosphorus

The results of Bray 1 P after harvesting maize plant from the pots, as a measure of P availability during the plant growth period, are presented in Table 16. The results for Bray 1 P ranged from 0.07 to 0.93 mg/kg for the Sasanda soil and 2.60 to 20.33 mg/kg for the Magadu soil.

Table 16: Effects of MPR placement and rates of organic materials on residual Bray 1 phosphorus

Treatments	Bray 1 phosphorus	
	Sasanda soil	Magadu soil
	.....mg/kg.....	
Control	0.07d	2.60c
Broadcasted MPR	0.75ab	19.14a
Strip banded MPR	0.52c	10.36b
MPR + OM at 2 t/ha banded to 20 cm depth	0.75ab	19.83a
MPR + OM at 4 t/ha banded to 20 cm depth	0.93a	20.33a
MPR + OM at 8 t/ha banded to 20 cm depth	0.69bc	11.86b
CV (%)	18.18	6.94

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.

According to Msanya *et al.* (2001) the following are the rankings of available P in the soil: <7 mgP/kg was ranked as being low, 7 to 20 mgP/kg was ranked as being medium and >20 mgP/kg was ranked as being high. Based on these rankings, all treatments in the Sasanda soil as well as the control treatment in Magadu soil showed low levels of residual extractable P. There was no significant (P=0.05) difference in

extractable P between the broadcasted MPR and the MPR + OM at the rates of 2 or 4 t/ha.

The highest value of residual extractable P was observed from MPR + OM at the rate of 4 t/ha in both soils.

The higher Bray 1 P in the MPR treatments as a result of addition of OM may be due to decreased P sorption of the soils due to products of organic matter decomposition (Nziguheba *et al.*, 1998). Also, decomposition of OM produce organic acids (H^+) that enhanced MPR dissolution (Hammond *et al.*, 1986), and thus increasing the Bray 1 P in soil solution.

The lower extractable Bray 1 P in strip banded MPR than other MPR treatments may be due to poor dissolution of MPR when strip banded as already discussed and also reported by Mhagama (2003).

4.3 Field experiments

As explained under materials and methods (Chapter three), field studies were conducted using the same soils used in pot studies (Magadu and Sasanda soils) to evaluate the effect of MPR placement and incorporation of organic residuals on MPR dissolution, P availability and maize yields in these soils. Two of the experiments (one at Sasanda and another at Magadu) were continuations from the previous year, conducted to evaluate the effects of continued addition of organic materials, mixed with MPR, on P dissolution and availability and maize yields in banding application.

There was one new experiment at Sasanda site conducted to evaluate the effect of rates of organic materials, on P dissolution, availability and maize yields.

4.3.1 Maize grain/dry matter yields

Continued experiments

The results of maize grain yields from the Sasanda site and maize dry matter yields from the Magadu site as influenced by continued addition of organic materials mixed with MPR are presented in Table 17. The lowest maize grain yield (0.11 t/ha) was obtained from the control treatment while the highest maize grain yield (3.01 t/ha) was recorded from the MPR + OM incorporated down to 20 cm depth. The strip banded MPR treatment had significantly (P=0.05) lower maize grain yields compared to the other treatments that received MPR. Broadcasted MPR gave maize grain yields statistically (P=0.05) similar to those from the 20 cm MPR placement treatment and MPR + OM. Depth of MPR incorporation, with or without O.M., did not result in any significant (P=0.05) difference in maize grain yields. Maize grain yields obtained from the current studies generally followed a similar trend but were higher than those obtained from the previous studies conducted by Mhagama (2003) on the same field plots. The highest grain yield obtained from this study was 3.01 t/ha while that reported from previous study was 2.27 t/ha from MPR + OM incorporated down to 20 cm depth.

Table 17: Effects of continued addition of organic materials mixed with MPR in the soil on maize grain and dry matter yields

Treatment	Grain yields (t/ha)	Dry matter yields (kg/plot)
	Sasanda	Magadu
Control	0.11d	1.23d
Broadcasted MPR	2.78ab	2.78bc
Strip banded MPR	1.93c	1.94cd
20-cm MPR Band, incorporated 10cm deep	2.42ab	2.38c
20-cm MPR Band, incorporated 20cm deep	2.58bc	2.88bc
20-cm MPR Band + O.M, incorporated 10cm deep	2.87ab	3.41ab
20-cm MPR Band +O.M, incorporated 20cm deep	3.01a	4.16a
CV (%)	14.59	7.29

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.

Maize dry matter yield from the continued studies in the Magadu site ranged from 1.23 to 4.16 kg/ha. The lowest maize dry matter yield was recorded from the control treatment while the highest (P=0.05) maize dry matter yield was recorded from MPR + OM incorporated down to 20 cm depth. Strip banded MPR gave lower maize dry

matter yield compared to the other MPR treatments. Broadcasted MPR gave dry matter yields statistically (P=0.05) similar to those from the banding MPR alone and MPR + OM. The depth of MPR incorporation, with or without OM depth, did not result in any significant (P=0.05) difference in maize dry matter yields. These results are somewhat similar to the trend of grain yields observed in the previous experiment by Mhagama (2003).

Poor maize grain/dry matter yield observed from the control treatment at both experimental sites was probably due to deficiency of P in these soils (Table 1) since no P source was applied in the control treatment. The results showed that upon addition of P in the MPR treatments, maize grain/dry matter yield was increased (Table 17) as a result of increased P supply. Semoka (1999), Kadogholo (2001) and Mhagama (2003) also reported increased maize grain yields upon application of MPR in these soils. The lower maize grain/dry matter yields from the strip banded MPR compared to the other MPR treatments continue to suggest that there was poor dissolution of MPR in strip banding and, consequently, low amount of P was released into soil solution for plants uptake. The higher maize grain/dry matter yields obtained from broadcasted MPR than strip banded MPR and 20 cm band MPR may be due to higher MPR dissolution associated with greater volume of contact between soil and MPR when the MPR was thoroughly mixed into the soils. The highest grain/dry matter yields recorded from the MPR + OM when incorporated down to 20 cm depth may be due to increased dissolution of MPR following decomposition of the OM which supplied the H^+ that enhanced MPR dissolution. These results are similar to findings from other researchers (Le-Mare, 1991; Ikerra *et al.*, 1994) who

found that the application organic matter together with PR increased PR dissolution and P availability and resulted in higher yields.

The generally higher maize grain yields at Sasanda during the second year as compared to the first year may be ascribed to the overall higher level of P in soil following MPR addition in the second year also.

New experiment

The effects of MPR placement and rates of organic materials on maize grain yields at the Sasanda site are shown in Table 18. Maize grain yields ranged from 0.36 to 3.38 t/ha. The control treatment had significantly (P=0.05) lower maize grain yields than MPR treatments. The maize grain yields from strip banded MPR was significantly (P=0.05) lower than the yields from the other treatments that received MPR. Broadcasted MPR gave significantly (P=0.05) lower maize grain yields than MPR + OM at the rates 2, 4 or 6 t/ha. MPR + OM at the rate of 6 t/ha gave the highest (P=0.05) maize grain yields than the other treatments.

The lower maize grain yields observed in the control treatment in this soil was due to inherent low P status since no P source was applied (see also section 4.1.1). Upon addition of P, maize grain yields (Table 18) increased. Kadogholo (2001) and Mhagama (2003) also reported increased maize grain yields due to MPR application when working with the same soil. The lower maize grain yields in strip banded MPR compared to the other MPR treatments confirm, as seen in the pot studies (section

4.1.1), that there was poor dissolution of MPR when MPR was strip banded which resulted in low levels of P in the soil solution for plant uptake.

Table 18: Effect of MPR placement and rates of organic materials on maize grain yields at Sasanda

Treatment	Maize grain yields (t/ha)
Control	0.36g
Broadcasted MPR	2.12d
Strip banded MPR	1.39f
20 cm MPR band and ploughed down to 20 cm depth	1.72e
MPR + OM at 2 t/ha banded to 20 cm depth	2.67c
MPR + OM at 4 t/ha banded to 20 cm depth	3.02b
MPR + OM at 6 t/ha banded to 20 cm depth	3.38a
CV (%)	9.54

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

The increased maize grain yields with respect to the increased rates of organic materials may be associated with higher dissolution of MPR as reflected by higher levels of extractable P in MPR-treated soils as explained in section 4.2.9.

These results conform to the findings by Le Mare (1991) who reported that the dissolution of PR increase when mixed with organic materials. He further noted that

availability of P to maize was improved when soil was supplied with organic matter as this reduced P sorption by the soil. Banding of MPR with organic materials also has the practical advantage relative to broadcasting with respect to saving on labour and amount of MPR (Forth, 1990). Row application of MPR mixed with organic materials needs a comparatively lower human labour input than when the MPR is broadcasted and then ploughed into the soil. Meanwhile you need relatively low MPR rates when mixed with organic materials than when applied alone.

4.3.2 Phosphorus concentration in maize ear leaves as influenced by continued addition of organic material mixed with MPR in the soil

Table 19 shows phosphorus concentrations in maize ear leaves as influenced by continued (year 2) addition of organic materials mixed with MPR in Sasanda and Magadu soils. The data ranged from 0.10 to 0.2% and 0.12 to0.21% in Sasanda and Magadu soils, respectively. There was significantly (P=0.05) lower P concentration in the control treatment compared to the MPR treatments. In both sites, strip banded MPR showed lower P concentration in maize ear leaves as compared with the other treatments that received MPR. At the Magadu site, maize plant leaves from those treatments that received MPR did not show significant (P=0.05) difference in P concentration.

The lower P concentration in the control treatment compared to MPR treatments may be due to P deficiency in the former since no P source was added. The lower ear leaf P concentration in the strip banded MPR as compared to the other MPR

treatments may be due to poor dissolution of MPR when strip banded due to limited contact with soil (Mhagama, 2003).

Table 19: Effects of continued addition of organic materials mixed with MPR in the soil on phosphorus concentration in maize ear leaves at Sasanda and Magadu sites

Treatment	Phosphorus concentration in leaves	
	Sasanda	Magadu
	.....%	
Control	0.10c	0.12b
Broadcasted MPR	0.20a	0.20a
Strip banded MPR	0.15ab	0.17a
20-cm MPR Band, incorporated 10 cm deep	0.17ab	0.20a
20-cm MPR Band, incorporated 20 cm deep	0.17ab	0.20a
20-cm MPR Band + O.M, incorporated 10 cm deep	0.18a	0.21a
20-cm MPR Band + O.M, incorporated 20 cm deep	0.17ab	0.20a
CV, %	18.06	9.52

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.

Insignificant (P=0.05) difference among MPR treatments in Magadu soil might have been caused by low moisture status due to drought condition that occurred at the Magadu site in the second year which might have limited the dissolution of MPR and the decomposition of the applied organic materials. There was prolonged moisture stress that affected maize plants at tasselling stage. For the Sasanda soil, insignificant (P=0.05) difference among the MPR treatments may be due to high P fixing capacity of this soil (Mwakisimba, 1999).

4.3.3 Phosphorus concentration in maize ear leaves as influenced by MPR placement and rates of organic materials

The results for phosphorus concentration in maize ear leaves as influenced by MPR placement and rates of organic materials are presented in Table 20. Phosphorus concentration in maize ear leaves ranged from 0.10 to 0.23%. The control treatment had significantly (P=0.05) lower P concentration than the MPR treatments. There were no significant (P=0.05) differences in ear leaf P concentration among the various MPR treatments.

The lower ear leaf P concentration in the control may be due to low inherent P status in this soil (Table 1). The increase in ear leaf P concentration with respect to the addition of MPR + OM may be due to the contribution of P by the added MPR upon its dissolution (Hammond *et al.*, 1986).

Table 20: Effect of MPR placement and rates of organic materials on phosphorus concentration in maize ear leaves at Sasanda site

Treatment	Phosphorus concentration in leaves (%)
Control	0.10b
Broadcasted MPR	0.20a
Strip banded MPR	0.18a
20 cm MPR band and ploughed down to 20 cm depth	0.20a
MPR + OM at 2 t/ha banded to 20 cm depth	0.21a
MPR + OM at 4 t/ha banded to 20 cm depth	0.22a
MPR + OM at 6 t/ha banded to 20 cm depth	0.23a
CV (%)	9.11

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

4.3.4 Nitrogen concentration in maize ear leaves

The concentrations of nitrogen in maize ear leaves as influenced by continued addition of organic materials mixed with MPR are presented in Table 21. Nitrogen concentrations ranged from 1.72 to 2.01% and 1.58 to 1.77% for Sasanda and Magadu sites, respectively. The higher ear leaf N concentration was observed in the control treatment. Generally there were no significant (P=0.05) differences in N concentration in ear leaves in all tested treatments and in both soils.

Table 21: Effects of continued addition of organic materials mixed with MPR in the soil on nitrogen concentration in maize ear leaves at Sasanda and Magadu sites

Treatment	Nitrogen concentration in leaves	
	Sasanda	Magadu
	.....%.....	
Control	2.01a	1.77a
Broadcasted MPR	1.87ab	1.69a
Strip banded MPR	1.95ab	1.72a
20-cm MPR Band, incorporated 10 cm deep	1.74ab	1.65a
20-cm MPR Band, incorporated 20 cm deep	1.83ab	1.68a
20-cm MPR Band + O.M, incorporated 10 cm deep	1.79ab	1.58a
20-cm MPR Band + O.M, incorporated 20 cm deep	1.72b	1.60a
CV (%)	9.14	7.43

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 N concentration in ear leaves at Sasanda site as influenced by MPR placement and rates of organic materials is presented in Table 22. The concentration ranged from 1.80 to 2.22%.

Table 22: Effect of MPR placement and rates of organic materials on nitrogen concentration in maize ear leaves at Sasanda site

Treatment	Nitrogen concentration in leaves (%)
Control	2.22a
Broadcasted MPR	1.82bc
Strip banded MPR	1.99b
20 cm MPR band and ploughed down to 20 cm depth	1.94bc
MPR + OM at 2 t/ha banded to 20 cm depth	1.87bc
MPR + OM at 4 t/ha banded to 20 cm depth	1.85bc
MPR + OM at 6 t/ha banded to 20 cm depth	1.79c
CV %	5.68

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

The control treatment gave significantly (P=0.05) higher ear leaf N concentration than MPR treatments. There was no statistical difference in N concentration in maize ear leave among the MPR treatments.

For the continued studies (year 2), the results showed that N concentrations were below the critical levels of 2.8 to 3.2 for maize ear leavevs at tasselling (Robert, 1998). The lack of significant differences in leaf N concentration in plants from Sasanda is consistent also with P concentration.

When P is deficient, there is poor utilization of N. The insignificant (P=0.05) difference in ear leaf N concentration in all treatments in the Magadu soils, might have resulted from the drought condition that occurred at this site.

Soon after applying the second dose of N fertilizer (ammonium sulphate) the rains stopped. Due to this it is probably that the second dose of N fertilizer was not fully utilizes by the maize plants.

For the new studies, the higher ear leaf N concentration in plants from the control than in plants from the MPR treatments is attributed to dilution effect of absorbed N due to high DM yields in the MPR treatments.

According to Robert (1998) N concentration values were below the critical level and this might have been due to leaching of applied N fertilizer, since Sasanda site receives very high rainfalls of up to 1000 mm or more annually (Kadogholo, 2001).

4.3.5 Potassium concentration in maize ear leaves

The concentrations of K in maize ear leaves as influenced by continued application of organic materials mixed with MPR at Magadu and Sasanda sites are presented in Table 23. The K concentrations in ear leaves ranged from 1.65 to 1.76% in Magadu soil and 1.62 to2.03% in Sasanda soil. For the Magadu site, maize plants from the control treatment had lower K concentration in their leaves than those from the MPR treatment incorporated 20 cm deep. For the Sasanda soil, the situation was the opposite in that the MPR incorporated to 20 cm depth gave significantly (P=0.05) lower K concentrations in maize ear leaves as compared to the control treatment.

Table 23: Effects of continued addition of organic materials mixed with MPR in the soil on potassium concentration in maize ear leaves at Sasanda and Magadu sites

Treatment	Potassium concentration in leaves	
	Sasanda	Magadu
	.....%	
Control	2.03a	1.65b
Broadcasted MPR	1.62c	1.67ab
Strip banded MPR	1.71b	1.66ab
20-cm MPR Band, incorporated 10 cm deep	1.67ab	1.66ab
20-cm MPR Band, incorporated 20 cm deep	1.65ab	1.68ab
20-cm MPR Band + O.M, incorporated 10 cm deep	1.65ab	1.71ab
20-cm MPR Band + O.M, incorporated 20 cm deep	1.62c	1.76a
CV (%)	3.24	3.77

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.

Plants from strip banded MPR also showed significantly (P=0.05) higher K concentrations than plants from broadcasted MPR and MPR + OM banded down to 20 cm depth.

Potassium concentration in maize ear leaves at Sasanda site as influenced by MPR placement and rates of organic materials is presented in Table 24.

Table 24: Effect of MPR placement and rates of organic materials on potassium concentration in maize ear leaves at Sasanda site

Treatment	Potassium concentration in leaves (%)
Control	2.22a
Broadcasted MPR	1.82bc
Strip banded MPR	1.99b
20 cm MPR band and ploughed down to 20 cm depth	1.94bc
MPR + OM at 2 t/ha banded to 20 cm depth	1.88bc
MPR + OM at 4 t/ha banded to 20 cm depth	1.85bc
MPR + OM at 6 t/ha banded to 20 cm depth	1.79c
CV (%)	6.39

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

The concentration ranged from 1.79 to 2.22%. Maize plants from the control treatment had significantly (P=0.05) higher K concentration than those from the MPR treatments. There was no significant difference in ear leaf K concentration between plants from most of the MPR treatments. The lowest K concentration was observed from the MPR + OM at the rate of 6 t/ha.

The higher K concentration in MPR treatments compared to the control treatment in Magadu soil may be due to increased utilization of soil native K by maize plants which was adequate for maize growth (Landon, 1996) after P was supplied, since no K was added to this soil. The higher K concentration in the control over MPR treatments and the strip banded MPR over the other MPR treatments, in the Sasanda soil, may probably be due to the increased DM accumulation associated with increased supply of P, which caused a dilution effect as reported by Sharma and Tandon (1992) and Tisdale *et al.* (1993).

According to Robert (1998) who reported sufficient K concentration in maize ear leaves at tasselling as being from 1.75 to 2.25%, all tested treatments in the Sasanda soil showed sufficient levels of K concentrations, which means that K was not limiting. Kadogholo (2001) and Mhagama (2003) working with the same soil also reported the decrease in maize ear leaf K concentration following application of TSP or MPR.

4.3.6 Calcium concentration in maize ear leaves

The Ca concentrations in maize ear leaves as influenced by continued (year 2) application of organic materials mixed with MPR at Magadu and Sasanda sites are presented in Table 25. The ear leaf Ca concentrations for the Sasanda and Magadu soils ranged from 0.15 to 0.24% and 0.16 to 0.22%, respectively. Maize plants from the control treatment in Sasanda soil had significantly (P=0.05) lower Ca concentration in their leaves than from the MPR treatments.

Table 25: Effects of continued addition of organic materials mixed with MPR in the soil on calcium concentration in maize ear leaves at Sasanda and Magadu sites

Treatment	Calcium concentration in leaves	
	Sasanda	Magadu
	.....%	
Control	0.15c	0.22a
Broadcasted MPR	0.22ab	0.16b
Strip banded MPR	0.16c	0.20ab
20-cm MPR Band, incorporated 10 cm deep	0.19abc	0.18ab
20-cm MPR Band, incorporated 20 cm deep	0.18ab	0.16b
20-cm MPR Band + O.M, incorporated 10 cm deep	0.22ab	0.17ab
20-cm MPR Band + O.M, incorporated 20 cm deep	0.24a	0.16b
CV (%)	2.39	16.15

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 plants from the strip banded MPR also had significantly lower Ca concentration than plants from the other MPR treatments. For the Magadu soil, maize plants from the control treatment had significantly (P=0.05) higher Ca concentration than those

from the MPR treatments. There was also no significant (P=0.05) difference in ear leaf Ca concentration between broadcasted MPR and MPR + OM banded.

The Ca concentration in maize ear leaves as influenced by MPR placement and rate of organic materials is presented in Table 26. The calcium concentrations ranged from 0.02 to 0.20%. There was significantly (P=0.05) lower Ca concentration in maize ear leaves from the control treatment than the MPR treatments. There were also no significant (P=0.05) differences in ear leaf Ca concentration between the broadcasted MPR and the MPR + OM at the rates of 2, 4 or 6 t/ha.

The increase in ear leaf Ca concentration with respect to MPR addition in Sasanda soil may be due to increased supply of Ca in soil solution following the dissolution of MPR. This implies that MPR application significantly increased Ca concentration in the soil, which became available for plant uptake.

The lower Ca concentration in maize ear leaves in the strip banded MPR than the other MPR treatments in Sasanda soil may be due to poor dissolution of MPR in the strip band (Mhagama, 2003). The higher ear leaf Ca concentration in the control treatment over the MPR treatments, and the strip banded MPR over the other MPR treatments in Magadu soil, might be attributed to dilution effect of Ca as already discussed in section 4.1.3.4.

Table 26: Effect of MPR placement and rates of organic materials on calcium concentration in maize ear leaves at Sasanda site

Treatment	Calcium concentration (%)
Control	0.02b
Broadcasted MPR	0.20a
Strip banded MPR	0.15a
20 cm MPR band and ploughed down to 20 cm depth	0.16a
MPR + OM at 2 t/ha banded to 20 cm depth	0.16a
MPR + OM at 4 t/ha banded to 20 cm depth	0.20a
MPR + OM at 6 t/ha banded to 20 cm depth	0.16a
CV (%)	6.96

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

The lower Ca concentration in the control treatment than the MPR treatments in Sasanda soil (new experiment) may be due to low native soil Ca (Table 1).

This implies that the addition of MPR in the soil increased Ca in soil solution for plant uptake. The lower Ca concentration in the strip banded MPR than the other MPR treatments may be due to poor dissolution of MPR when strip banded. Insignificant difference between broadcasted MPR and MPR + OM at the different rates of OM in Sasanda soil may be due to increased dissolution of MPR following the decomposition of organic materials which supplied organic acids (H^+) responsible for the dissolution of MPR (Iyamuremye and Dick, 1996).

4.3.7 Magnesium concentration in maize ear leaves

Table 27 shows magnesium concentration in maize ear leaves as influenced by continued addition of organic materials banded together with MPR in both Magadu and Sasanda soils. The Mg concentrations ranged from 0.14 to 0.17% and 0.14 to 0.20% for Sasanda and Magadu soils, respectively. For the Magadu soil, the control treatment had significantly (P=0.05) higher ear leaf Mg concentration than the MPR treatments. Also, there was no significant difference in ear leaf Mg concentration among the MPR treatments.

Table 28 shows the concentration of Mg in maize ear leaves as influenced by MPR placement and rates of organic materials. Magnesium concentration in maize ear leaves ranged from 0.12 to 0.23%. Maize plants from the control treatment had significantly (P=0.05) higher Mg concentration in their leaves than those from the MPR treatments. There were no significant (P=0.05) difference in Mg concentration in maize ear leaves among the MPR treatments.

Magnesium concentrations in both Magadu and Sasanda soils were sufficient for maize plant growth according to Robert (1998) who ranked the values from 0.12 to 0.3% as being sufficient for maize growth.

As already discussed in section 4.1.3.5, high dry matter yields in the MPR treatments might have caused Mg dilution effect hence lowering ear leaf Mg concentrations in the MPR treated maize compared to the control treatment.

Table 27: Effects of continued addition of organic materials mixed with MPR in the soil on magnesium concentration in maize ear leaves at Sasanda and Magadu sites

Treatment	Magnesium concentration in leaves	
	Sasanda	Magadu
	.....%	
Control	0.17a	0.20a
Broadcasted MPR	0.14a	0.15ab
Strip banded MPR	0.15a	0.18ab
20-cm MPR Band, incorporated 10 cm deep	0.14a	0.17ab
20-cm MPR Band, incorporated 20 cm deep	0.15a	0.16ab
20-cm MPR Band + O.M, incorporated 10 cm deep	0.15a	0.14b
20-cm MPR Band + O.M, incorporated 20 cm deep	0.14a	0.15b
CV (%)	14.67	14.12

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 28: Effect of MPR placement and rates of organic materials on magnesium concentration in maize ear leaves at Sasanda site

Treatment	Magnesium concentration (%)
Control	0.23a
Broadcasted MPR	0.12b
Strip banded MPR	0.17b
20 cm MPR band and ploughed down to 20 cm depth	0.14b
MPR + OM at 2 t/ha banded to 20 cm depth	0.13b
MPR + OM at 4 t/ha banded to 20 cm depth	0.12b
MPR + OM at 6 t/ha banded to 20 cm depth	0.12b
CV (%)	11.23

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

Insignificant (P=0.05) difference in ear leaf Mg concentration among the MPR treatments in the Magadu soil, may be due to the presence of higher native soil Mg.

According to Robert (1998), all treatments tested at the Sasanda new site showed sufficient levels of ear leaf Mg concentrations. The higher ear leaf Mg concentration in the control treatment than the MPR treatments may be due to Mg dilution effect resulting from high plant growth in MPR treatments than in the control treatment (Maschner, 1990).

4.3.8 Zinc concentration in maize ear leaves

Zinc concentrations in maize ear leaves for the continued experiments at Sasanda and Magadu are presented in Table 29. The concentrations ranged from 6.75 to 10.07 mg/kg for the Sasanda soil and 8.15 to 11.20 mg/kg for Magadu soil. In both soils, there were significant (P=0.05) differences in ear leaf Zn concentration between the control treatment and the treatments that received MPR. In Sasanda soil, the control treatment showed significantly (P=0.05) higher Zn concentration than the MPR control treatments. Strip banded MPR also showed significantly higher Zn concentration than the broadcasted MPR.

Table 30 shows the concentration of Zn in maize ear leaves as influenced by MPR placement and rates of organic materials. Zinc concentration in maize ear leaves ranged from 8.70 to 10.73 mg/kg. Zinc concentration in ear leaves decreased with respect to increased P concentrations in maize ear leaves. The trend was similar to that observed in the pot experiment (section 4. 1.3.6).

Generally, in the Sasanda soil, the trend showed that Zn concentration decreased as P concentration increased. (Table 20 and 30).

Table 29: Effects of continued addition of organic materials mixed with MPR in the soil on zinc concentration in maize ear leaves at Sasanda and Magadu sites

Treatment	Zinc concentration in leaves	
	Sasanda	Magadu
	.....mg/kg.....	
Control	10.07a	8.15c
Broadcasted MPR	6.75c	9.58b
Strip banded MPR	8.30b	8.605bc
20-cm MPR Band, incorporated 10 cm deep	7.65bc	9.08bc
20-cm MPR Band, incorporated 20 cm deep	7.58bc	9.15b
20-cm MPR Band + O.M, incorporated 10 cm deep	7.08c	9.58b
20-cm MPR Band + O.M, incorporated 20 cm deep	7.55bc	11.20a
CV (%)	8.93	8.05

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 effect of high dry matter yields on nutrient dilution may be the cause of the higher ear leaf Zn concentration in the control treatment than the MPR treatments.

Table 30: Effect of MPR placement and rates of organic materials on zinc concentration in maize ear leaves at Sasanda site

Treatments	Zinc concentration in leaves (mg/kg)
Control	10.73a
Broadcasted MPR	9.23a
Strip banded MPR	10.15a
20 cm MPR band and ploughed down to 20 cm depth	9.98a
MPR + OM at 2 t/ha banded to 20 cm depth	9.95a
MPR + OM at 4 t/ha banded to 20 cm depth	9.45a
MPR + OM at 6 t/ha banded to 20 cm depth	8.70a
CV (%)	22.62

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

The decrease in ear leaf Zn concentration as ear leaf P concentration increased in the Sasanda soil may be due to antagonistic relationship between Zn and P (Tandon, 1987) upon addition of MPR. Similar results were observed in the pot experiments (section 4.1.3.6).

4.3.9 Bray 1 phosphorus

The results of Bray 1 P for the Sasanda soil as influenced by MPR placement and rates of organic materials are presented in Table 31. The data for extractable P

ranged from 0.18 to 0.47 mg/kg. Only the broadcasted MPR and MPR + OM at 4 and 6 t/ha resulted in Bray 1 P levels higher (P=0.05) than those of the control.

Table 31: Effect of MPR placement and rates of organic materials on residual Bray 1 phosphorus in Sasanda soil

Treatment	Bray 1 phosphorus (mg/kg)
Control	0.18c
Broadcasted MPR	0.41ab
Strip banded MPR	0.23bc
20 cm MPR band and ploughed down to 20 cm depth	0.32abc
MPR + OM at 2 t/ha banded to 20 cm depth	0.35abc
MPR + OM at 4 t/ha banded to 20 cm depth	0.44ab
MPR + OM at 6 t/ha banded to 20 cm depth	0.47a
CV (%)	37.96

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

According to Landon (1996) and Msanya *et al.* (2001) all treatments showed low levels of Bray 1 P.

The increase in extractable P with MPR addition and increased rates of OM in this soil may be due to increased dissolution of applied MPR fertilizer caused by supply of H^+ ions from the decomposition of OM. It showed further that the higher the OM,

the more the supply of (H^+). Consequently, increased MPR dissolution increased P availability for plant uptake.

Similar results were observed in the pot experiment (section 4.1.4). The very low levels of Bray 1 P in this soil according to the rankings of Landon (1996) and Msanya *et al.* (2001) are due to the very high P fixing capacity of the Sasanda soil as reported by Mwakisimba (1999) who observed that P adsorption maximum for this soil was 4110 mgP/kg.

It is interesting to note that such low levels of Bray 1 P (Table 31) ordinarily characterized as being low (Landon, 1996), could sustain relatively high levels of maize yields (Table 18). These P levels were determined after harvest.

It may be revealing to monitor the Bray 1 P with time from planting till harvest, to evaluate the trend of this index during the growing season.

4.4 Change in soil pH due to MPR and organic material addition

Table 32 shows the soil pH (water) as influenced by MPR placement and rates of organic materials in Sasanda soil. Soil pH ranged from 5.2 in the control to 6.1 in the MPR + OM at 6 t/ha, with all the treatments having significantly (P=0.05) higher pH values than that of the control. The results also showed that there was no significant difference in soil pH among the MPR + OM treatments.

Table 32: Effect of MPR placement and rates of organic materials on soil pH in Sasanda soil

Treatment	Soil pH (1: 2.5, soil : water)
Control	5.2d
Broadcasted MPR	5.8b
Strip banded MPR	5.5c
20 cm MPR band and ploughed down to 20 cm depth	5.5c
MPR + OM at 2 t/ha banded to 20 cm depth	6.95ab
MPR + OM at 4 t/ha banded to 20 cm depth	6.0ab
MPR + OM at 6 t/ha banded to 20 cm depth	6.1a
CV (%)	2.49

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

The increase in soil pH with respect to MPR addition and increased rates of OM in this soil may be due to increased MPR dissolution. Following the decomposition of OM, organic acids (H^+) so produced might have improved MPR dissolution. Releasing Ca^{2+} into the soil solution leading to increase in soil pH (Table 32). These results conform to that reported by Chien *et al.* (1987) when studying long-term reactions of phosphate rocks with Oxisol in Columbia who observed an increased soil pH in all the PR treatments over the control treatment. Also Hu *et al.* (1995) after six seasons of PR application in Ultisol observed increased in soil pH from 4.85 to 4.90-5.30.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of these studies showed that MPR placement methods and organic residues incorporation significantly (P=0.05) improved MPR dissolution, P availability and maize grain/dry matter yields in the studied soils in both pot and field experiments.

The results indicated that MPR incorporated down to 20 cm in a hand hoe width significantly (P=0.05) improved dissolution of MPR and increased availability of P from the 20 cm banded MPR as compared to strip banded MPR. This was supported by higher P uptake by maize plants, plant P concentrations, grain/dry matter yields and residual extractable P. This also suggests that there was poor dissolution of MPR when it was strip banded, which resulted in low available P for plant uptake and, hence, poor maize yields.

Continued incorporation of organic materials mixed with MPR was found to significantly (P = 0.05) improve dissolution, availability of P from banded MPR, and maize grain/ dry matter yields. This was supported by higher maize grain yields obtained from the current study than that reported one year earlier by Mhagama (2003). The highest grain yields (3.01 t/ha) obtained from this study were higher than that reported from Mhagama's (2003) study (2.27 t/ha).

Banding of MPR together with the organic materials at the rates of 2, 4 6 and 8 t/ha significantly (P=0.05) improved the dissolution of MPR, P availability and thus increased maize grain/dry matter yields. The results showed that MPR + OM at the rates of 4, 6 and 8 t/ha in most cases increased P uptake by plant, P concentrations, the amounts of extractable soil P, and grain/dry matter yields. These results, therefore, suggest that banding of MPR mixed with organic matter resulted in effective utilization of P from MPR by maize plants and, hence, increased crop yields. Furthermore, the results show that banding of MPR with OM can be a good method of MPR application in acid and high P fixing soils.

5.2 Recommendations

From the this study, the following recommendations are made:

1. MPR can be used as alternative source of P for maize crop production in these two soils when it is banded and incorporated to 20 cm in the soil together with organic residues.

2. Strip banded MPR should not be used as a method of applying MPR in these soils due to observed poor dissolution of MPR, P availability and maize grain/dry matter yields.

3. Further studies on combining the two methods of MPR placement (broacasting and banding) should be undertaken so as to improve MPR dissolution, P availability and maize yields. This is recommended because when MPR is banded it concentrates only in the position where it has been banded (rows), leaving the

inter-row space without phosphorus. Due to this reason, therefore, a farmer should mark where the rows were, so that the following season the same band would be identified for the plants to utilize the residual phosphorus. This is cumbersome. But also broadcasting wastes fertilizer material to weeds where it falls away from the planting zone/row.

4. Further studies should also be undertaken at the Sasanda site to monitor the Bray 1 P with time, from planting to harvest, so as to evaluate the trend during the growing season. This is because the Bray 1 P determined after harvest was found to be very low while the maize yields obtained were relatively high.

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