

**STRATEGIES FOR ESTABLISHING ADEQUATE PHOSPHORUS LEVELS
IN THREE SOILS WITH DIFFERENT PHOSPHORUS FIXING
CAPACITIES**

BY

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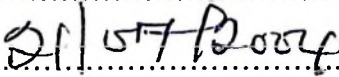
ABSTRACT

A study was conducted under pot and field conditions to establish adequate levels of phosphorus in three soils with different P fixing capacities. These soils were from Magadu, Morogoro District, classified as *Oxic Haplustult*, Sasanda, in Mbozi District, classified as *Drystropept* and Nkundi in Nkasi District, classified as *Acruoxic Kandiuustult*. A pot experiment was conducted at SUA- Department of Soil Science while field experiment was carried out at Sasanda in Mbozi District in Mbeya region. The treatments were 0, 40, 80 and 160 mg P/kg of soil for Nkundi, 0, 100, 200 and 400 mg P/kg of soil for Magadu and 0, 800, 1600 and 3200 mg P/kg of soil for Sasanda soil. For field experiment the treatments were 0, 800, 1600 and 3200 kg P/ha. The sources of P were TSP and MPR. There were seven treatments for field and eight treatments for pot experiment. The experiment was laid out in a Randomized Complete Block Design. The tested crop was maize (*Zea mays* var UH 615). The objectives of the study were to identify rates of P required for optimizing maize dry matter grain yields, and associated available P levels in the soils. Results of the study showed that, both TSP and MPR were effective sources of P in the soils studied. Both TSP and MPR significantly ($P = 0.05$) increased DM and grain yield, P uptake and available P over the control by 97.7, 95.8, 76.8 and 95.3%, respectively in Sasanda soil. This was attributed to 95.3% increase in available P in the soil after TSP and MPR application in Sasanda soil. This was supported by the highest grain yield, DM yield, and P uptake of 2.97 t/ha, 64.18 g, and 124.8 mg/kg at the rates of 3200 kg P/ha and 3200 mg/kg, respectively in Sasanda soil. However, MPR was slightly less effective than TSP for most of the aspects studied. The optimum rates were 160, 200 and 3200 mg P/kg for Nkundi, Magadu and Sasanda soils,

respectively under pots. However, these rates have to be confirmed under field conditions. In Sasanda field experiment, P application did not significantly ($P = 0.05$) increase available P and the available P was below the critical level. This was attributed to high fixing capacity of the soil. The rate of 1600 kg P/ha gave the highest grain yield of 2.97 t/ha in the current study. Results from the current study indicated that MPR has the potential of supplying P for maize production therefore it could be used as an alternative source of P to TSP. A large, one-time application of P on highly P deficient soils is not always the solution for correcting P deficiency in all soils like in Sasanda soil. A gradual seasonal P application might be the most cost-effective approach for high P-fixing soils.

DECLARATION

I, STEPHAN NGAILO ELIUTH, 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 any other University.

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

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DEDICATION

To God, for without His guidance and love this work would never have become a reality. To my parents, Fred Ngailo and Mrs Besta Ngailo who laid the foundation of my education and through their tireless effort this achievement have become possible. Lastly to my wife Mary for her prayers and encouragement.

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LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| Δ | Difference/change |
| Al | Aluminium |
| $\text{Al}(\text{OH})_2\text{H}_2\text{PO}_4$ | Aluminium dihydroxyphosphate |
| Al^{3+} | aluminium ion |
| Ap | April |
| Ca | Calcium |
| CEC | Cation exchange capacity |
| cm | Centimetre |
| cmol (+)/kg | Centimole(+) per kilogram |
| CO_3^{2-} | Carbonate ion |
| conc | Concentration |
| Cu | Copper |
| $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ | Hydrated copper sulphate |
| CV | Coefficient of variation |
| DANIDA | Danish International Development Agency |
| DAP | Days after planting |
| DM | Dry matter |
| DMRT | Duncan's Multiple Range Test |
| DTPA | Diethylenetriaminepentacetic acid |
| e.g. | Example |
| <i>et al.</i> | and others |
| Fe | Iron |

| | |
|---|-----------------------------|
| $\text{Fe}(\text{OH})_2\text{H}_2\text{PO}_4$ | Iron dihydroxy phosphate |
| g/pot | Gram per pot |
| H^+ | hydrogen ion |
| H_2O | Water |
| H_2O_2 | hydrogen peroxide |
| H_2PO_4^- | Orthophosphate |
| HNO_3 | nitric acid |
| i.e. | That is |
| K | Potassium |
| KCl | potassium chloride |
| Kg/ha | Kilogram per hectare |
| m^2 | Square metre |
| Mg | Magnesium |
| mg/kg | milligramme per kilogramme |
| $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ | Hydrated magnesium sulphate |
| ml | Millilitre |
| mm | Millimetre |
| Mn | Manganese |
| MPR | Minjingu phosphate rock |
| N | Nitrogen |
| Na | Sodium |
| NaOH | Sodium hydroxide |
| $^{\circ}\text{C}$ | Degree Celsius |

| | |
|--|---|
| P | Phosphorus |
| pH | Negative logarithim of hydrogen ion concentration |
| PO_4^{3-} | Phosphate ion |
| PR | Phosphate rock |
| PRs | Phosphate rocks |
| RCBD | Randomized complete block design |
| SA | Sulphate of ammonia |
| SUA | Sokoine University of Agriculture |
| t/ha | tonnes per hectare |
| TSP | Triple super phosphate |
| UH | Uyole hybrid |
| Zn | Zinc |
| $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ | Zinc sulphate monohydrate |

CHAPTER ONE

1.0 INTRODUCTION

1.1 General overview

Phosphorus is an essential element second to nitrogen for plant growth and its input has long been recognized as necessary to maintain crop production. However, its deficiency is a common soil fertility constraint in humid and subhumid uplands. In highly weathered soils such as Ultisols and Oxisols as well as in slightly weathered soils such as Andepts and Vertisols due to low native P and high fixation by Al and Fe (Buresh *et al.*, 1997; Sanchez 1976). So alleviation of P deficiency through application of fertilizer inputs is necessary if optimum crop yield is to be realised.

Phosphorus fertilizers have been widely used to build up soil P and boost crop production in intensive agricultural systems. However use of P fertilizers in subsistence agriculture by resource-poor farmers in the tropics has frequently been low due to economic constraints. Subsistence farmers in the tropics have traditionally relied on shifting cultivation systems to build up the availability of nutrients in soils. Increasing population pressure, however, has led to shorter fallowing periods for natural regrowth of vegetation and has led to intensive cultivation. So the increased intensity of cropping, insufficient inputs of fertilizers to replenish the nutrients removed with harvested products, and soil erosion have all led to mining of soil nutrients and loss of soil productivity (Mwangi, 1997).

Phosphorus fertilizer is a critical input for improving agricultural technology and increasing crop yields. However, the use of inorganic P fertilizers by resource-poor

farmer is a major production constraint due to high prices, which have more than doubled following the removal of subsidies in response to structural adjustment programs (SAPs). In the case of Tanzania, the closing of Tanga fertilizer factory has aggravated the problem. As a result, use of low cost indigenous phosphate rock (PR) for direct application has been suggested as an alternative to expensive conventional P sources (Ikerra, 1986; Mwangi, 1997).

Phosphate rock as an alternative, low cost P-fertilizer has been given considerable attention (Khasawneh and Doll, 1978). A number of studies have been done to evaluate the effectiveness of PR. Mnkeni *et al.* (1991) obtained significant response to MPR in some soils of Morogoro district and significantly high response was reported in soils with low pH values. In their research they tested P at the rates of 40 and 120 mg/kg and for both rates the highest response was obtained at Magadu soil with pH 4.8 and available P of 5.67 mg/kg and lowest response at Mafiga 2 soil with pH 6.2 and available P of 21.6 mg/kg.

In Tanzania PR deposits are found in several places including Minjingu-Arusha region, Panda Hill, Songwe Scarp, Mbalizi and Ngualla carbonatites in Mbeya Region, Zizi near Kisaki in Morogoro, Chali hills in Dodoma and Buchuba and Ichwandini in Muleba district - Kagera Region (Mkamba, 1988).

Among these deposits, Minjingu phosphate has been extensively evaluated for its agronomic effectiveness and costs associated with its use by farmers (Ikerra, 1986).

Research done in North Carolina comparing PR and TSP showed that, PR and TSP were equally effective in increasing dry matter yield and P-uptake by maize. In acid and P deficient soils it was found that PR was approximately 83 and 91% as effective as TSP in increasing dry matter yield and P-uptake, respectively (Wright *et al.*, 1992). Wendt and Jones (1996) reported that PR has the potential of replacing conventional P-fertilizers on some soils. Therefore, use of PR may be equally effective and less costly than conventional P-fertilizers. Floor and Kimambo (1989) cited by Kimbi *et al.* (1996) pointed out that the cost of P in beneficiated MPR was about 40% of the cost of the same quantity of P in TSP and has relatively higher residual effect than TSP at Mlingano and some parts of Tanga.

Fixation of applied phosphatic fertilizers in soils and its subsequent decrease in availability to growing plants has led many researchers to examine the relationship between adsorbed P and solution P concentration (Choudhary *et al.*, 1996). Phosphorus sorption capacity has been extensively studied and Fox and Kamprath (1970) basing on P-sorption isotherm, found that a concentration of 0.2 mg P L^{-1} in the soil solution was sufficient for optimum plant growth in any type of soils. Different soils require different amounts of P to be added to give a soil solution concentration of 0.2 mg P L^{-1} . For example, Babili (1999), using MPR, found that $102.4 \text{ kg P ha}^{-1}$ and 376 kg P ha^{-1} were required to reach a soil solution concentration of 0.2 mg P L^{-1} for soils of Kilosa and Magadu, respectively. Mwakisimba (1999) found that 710 mg P kg^{-1} and 705 mg P kg^{-1} soil were required to give a soil solution concentration of 0.2 mg P L^{-1} for Sasanda and Ng'anda(2) soils, respectively also using MPR. So, there are wide variations of P requirements among soils. Basing on

P-fixation capacity, soils have been categorised as low-, medium- and high-P fixing (Buresh *et al.*, 1997; Szilas 2002).

The optimum fertilizer rates are not universal, but vary from site to site, season to season and crop to crop, and with environmental conditions such as water regime, targeted crop yield and the fertility status of the soil (Tandon, 1993).

It is evident from the above that, the use of adequate levels of P for maximum economic yield is possible if detailed P calibration data are available for a given crop and soil type. As such, studies on P status and adsorption characteristics of respective soils are important due to prevalence of P deficiency in most tropical soils. A number of studies have been, and are still being, conducted to evaluate the effectiveness of different P fertilizers and their optimum rates of application for maximum crop growth (SFR, 1989; Ikerra, 1986; Semoka and Mnkeni, 1986; Mnkeni *et al.*, 1992).

Different rates have been established either using adsorption studies in the laboratory or in glasshouse or under field conditions (Mnkeni *et al.*, 1991; Mnkeni *et al.*, 1992; Semoka, 1986; Babili, 1999; Mwakisimba, 1999; Szilas 2002).

However, no further studies have been undertaken to confirm the suggested rates, which have been highly variable. So, the current study was initiated to confirm the recommended rates both under glasshouse and field conditions based on the assumption that a rate that will give a soil solution concentration of 0.2 mg P L^{-1} for each soil will supply adequate P to plants (Fox and Kamprath, 1970).

1.2 Objectives

1.2.1 General objective

The overall objective of this study was to establish optimum rates of P for maize grown in three soils varying widely in P fixing capacities.

1.2.2 Specific objectives

Specific objectives were:

- (i) To evaluate the rates of P required for optimizing maize grain yield.
- (ii) To determine the effects of P rates on available P in soils.
- (iii) To determine the effects of P rates on P contents in plants.
- (iv) To determine the effects of P application rates on maize dry matter yield.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of P in plants

Phosphorus has been called "the key of life" and life in any form can not exist without P. No plant can grow normally or give good yield if it suffers from P deficiency. No soil can sustain high yields if it is deficient in P and this deficiency is not corrected (Tandon, 1987). So P is a master key to agriculture because it is directly involved in most life processes and is a component of every living cell. Low crop production is often due to lack of P than to the deficiency of other nutrient elements except nitrogen (Thompson and Troeh, 1973; Tamhane *et al.*, 1970; Jones, 1982). Phosphorus is required by all living organisms and every living cell. Plant and animal life cannot exist without it (Russell, 1963). Phosphorus is required for breakdown of carbohydrates, mitotic cell division, early root growth and development, hastening maturity and stimulation of fruit and seed production. It is also important in a number of enzymatic reactions, transfer of energy for biochemical processes (ATP, ADP and AMP) which supply energy for various reactions and is a constituent of nucleic acids (DNA and RNA). Furthermore P plays an important role in the formation of hormones and its also concerned with photosynthetic reactions (Teuscher, 1960; Pillai, 1964).

Phosphorus is taken up by plants in the form of monovalent phosphate (H_2PO_4^-) and to a lesser extent as HPO_4^{2-} . However the P uptake by plants and the relative amounts of these ions in soil solution is dependent on the type of the plant, stage of plant growth and soil chemicals properties such as pH, buffering capacity of the soil,

temperature, diffusion rate and level of Al and Fe oxides in the soil (Pillai, 1967; Cooke, 1967; Simpson, 1991). *P is to a plant what wheels are to a car it cannot run on a flat tyre even if the petrol tank (N supply) is full* (Tandon, 1995).

2.2 Agronomic effectiveness of P fertilizers

Most phosphatic fertilizers, contain P in water-soluble form. Phosphate rock carries P in insoluble form and therefore is suitable in moderately to strongly acid soils with moderate to high P-retention capacities (Tandon, 1994; 1995). Mnkeni *et al.* (1991) working with four different PRs, observed varied effects of MPR on maize yield. In their experiment, the rate of 80 kg and 240 kg P/ha significantly increased maize yields on Magadu and Mzumbe soils both with <6.5 mg P/kg and pH value < 5.2. Semoka *et al.* (1992) observed that MPR applied at the rate of 40 mg P/kg was as effective as TSP with relative agronomic effectiveness values of 92% and 111% in an Ultisol and an Oxisol, respectively. Ikerra *et al.* (1994) found MPR to be a good substitute for TSP in maize production especially when combined with organic materials (compost and manure). Generally the efficiency of P fertilizer will depend on the rate of application, soil P level, chemical and mineralogical properties of P source, environmental conditions and crop and fertilizer management (Tandon, 1993).

2.3 Standard P requirement

The use of adequate levels of P for maximum economic yield is possible if soil P test calibration data are available for a given crop and soil type, so as to achieve higher

soil P availability levels for a given crop species and soil type. Different crops and soils have different P requirements and supplying power respectively. Plant species probably differ more in their reaction to the supply of soil P due to differences among species in rate of P uptake (Black, 1968). As such, different studies have been conducted to determine rates of P that will meet crop requirements, in different soils. The quantity of P required to attain a standard P concentration in a soil solution is a useful index for comparing soils of widely varying properties in relation to P supply, requirement and availability.

Beckwith (1965) and Ozanne and Shaw (1967; 1968) cited by Kunishi and Vickers (1980) working with Australian soils and Fox *et al.* (1968) working with Hawaiian soils, introduced the use of P adsorption isotherms to determine P fertilizer requirement. They found that, the rate of P application that allow 95% of maximum plant yield, correlated highly with the amount of P the soil would adsorb to support an equilibrium phosphate concentration of 0.2 to 0.3 mg P L⁻¹. To support this, Fox and Kamprath (1970) reported that, plant yield was 95% of maximum when North Carolina soils were fertilized to support an equilibrium phosphate concentration of 0.2 ppm P.

Adequate levels of solution P for optimum crop yield are bound to vary for different soils depending upon pH, soil texture, nature and amount of clays. Content of CaCO₃ and organic matter content as these have strong impact on P adsorption.

2.3.1 Soil texture

Soils of different texture require different rates of fertilizer P to reach the soil solution concentration for optimum crop yield. Soil solution P concentration in sandy soils has to be higher than in clay soils in order to supply the same amount of P to plants due to influence of diffusion rate and buffering capacity. So sandy soils have higher requirement for solution P (Olsen and Watanabe, 1963) but such solution P levels are supported by relatively low rates of application in coarse textured soils (Juo and Fox, 1977).

2.3.2 Organic matter content

Soil organic matter is positively correlated with P adsorption (Singh and Tabatabai, 1977) as their functional groups can form stable complexes with Al, Fe and other metal ions. However, there is reduction in P adsorption following addition of organic matter as the organic anions released from decomposition of organic matter compete with phosphate ions for adsorption sites. Singh and Jones (1976) gave evidence that addition of organic matter depressed P adsorption by soil hence affect P requirement for adequate supply of P.

2.3.3 Clay content

The amount of P adsorbed at 0.2 mg P/L was found to be directly correlated to clay content and surface area of the soil (Duffera and Robarge, 1999). Differences in clay content significantly influence the adequate level of P needed for optimum crop yield. Clay content has been found to have good P buffering capacity in kaolinitic

soils and Oxisols (Lins and Cox, 1989). The differences in the effectiveness of applied P to change in extractable P as a function of clay content is important in making fertilizer P recommendations. The higher the clay contents the lower the P rates. Also Cox (1994) found an increase in availability of P in soils with only 10% clay while P availability decreased exponentially for soils with more than 50% clay.

2.3.4 Soil parent materials

Phosphorus sorption is related to nature of parent materials. Juo and Fox (1977) found that, soils developed from different parent materials had different standard P requirements. Soils derived from basic igneous rocks such as basalt sorbed the large amounts of P while those containing smectite sorbed little P. However, soils of volcanic origin sorbed the highest P due to their high P-fixing capacity.

2.3.5 Content of Al and Fe oxides

The oxides and hydrous oxides of Al and Fe influence fertilizer P requirement. Soils derived from acidic parent materials require relatively small amounts of P to attain 0.2 mg P in the equilibrium solution but the standard P requirement increases as the content of sesquioxides increases (Juo and Fox, 1977). Mnkeni and Akulumuka (1987) working with Alfisols and Ultisols soils found that, Alfisols retained more P than Ultisols since the Alfisol had relatively high extractable Al and Fe contents. Hue (1991) found that Andisols containing a high proportion of strongly reactive aluminosilicates sorbed most P whereas Vertisols with smectite (2:1 clays) as a

dominant mineral sorbed least P while Oxisols and Ultisols dominated by kaolinite and sesquioxides were intermediate.

2.3.6 Soil pH

Mnkeni and Akulumuka (1987) found a negative correlation between soil pH and P sorbed. This is due to indirect effect of pH on phosphate retention, i.e. at low pH the solubility of Al and Fe increases resulting in increased P retention mostly by precipitation.

2.3.7 Phosphorus fixation

Soils developed under humid conditions generally are acidic. Cultivation of such soils increases acidity, which in turn increases P fixation. Phosphorus fixation is recognized as the major obstacle to agricultural development of volcanic ash soils. For example, Hawaiian volcanic soils needed up to 1,350 kg P/ha to satisfy the P-fixing capacity (Olson and Engelstad, 1972). The high P-fixation is related to the clay mineralogy and the amorphous nature of the colloidal hydrated oxides of Fe and Al. Soils are categorized into high, medium and low P fixing capacities. Soils are considered high, medium or low P fixing when the amounts of P required to support 0.2 mg P L⁻¹ are >400, 100 to 400 and <100 mg P kg⁻¹, respectively (Buresh *et al.*, 1997).

2.3.8 Effectiveness and efficiency of P fertilizers

The quantity of P-fertilizer added to supply an adequate level or a standard soil solution concentration of 0.2 mg P/L largely depends on the source of P and soil properties, which determine its effectiveness and efficiency in supplying P in the soil solution. Olson and Engelstad, (1972) reported greater efficiency of soluble forms of phosphates than phosphate rocks and slags and observed that the former P sources improved growth faster than PRs despite rapid and strong fixation.

2.3.9 Buffering capacity

Choudhary *et al.* (1997) found that at equal P intensity the dry matter yield was directly proportional to maximum buffering capacity. Also P absorbed was directly related to maximum buffering capacity such that at higher buffer capacity, more P was released as solution P and this led to greater depletion by plant uptake.

2.3.10 CaCO₃ content

Mnkeni and Mackenzie (1985) reported reduction in P retention with added CaCO₃. due to its effect in precipitating exchangeable Al and reduction in the activities of Fe and Al compounds. In neutral and calcareous soils, inorganic phosphorus fertilizers applied in calcareous soils are fixed through adsorption and precipitation as calcium phosphate minerals. The amount and particle size (surface area) of calcium carbonate (CaCO₃) minerals will increase the precipitation of calcium phosphate minerals on its surfaces (Li, 1999). Phosphorus fertilizers applied in calcareous soils are fixed through adsorption and precipitation. Porter and Sanchez (1992) reported that the

reaction of P with carbonate salts depresses P availability by sorption or precipitation of P by exchangeable Ca or carbonate minerals.

2.4 Standard P and plant performance

The supply of P to crops depends directly on the concentration of phosphate in the soil solution. However, the availability of adequate level of P applied is dependent on several factors such as environmental conditions, management practices, nature of phosphate fertilizers, characteristics of soils and crop species. The amount of P in soil solution and the capacity of the soil to supply P to the soil solution for plant uptake are important factors affecting its availability hence crop growth.

2.4.1 Factors affecting availability of added P

Although the dissolution of P fertilizer in soil is a prerequisite for plant P uptake, dissolution alone should not be used as an indicator of P availability to plants because a number of soil factors intervene (Syers and Mackay, 1986). Soil types, soil pH, type and amount of clay minerals, hydrous oxides of Al and Fe, temperature, moisture and exchangeable Ca and CaCO_3 influence the availability of the added P to the crop (Sharpley *et al.*, 1994).

2.4.1.1 Soil types

Soil types affect response at a given soil test value due to differences in chemical, physical and mineralogical properties, which affect proportionate fraction of the

nutrient (Rouse, 1967). Onthong *et al.* (1999) reported lower amount of available P in fine-textured soils than in coarse-textured ones. While Cox (1994) reported the opposite, that there was an increase in available P per unit of applied P which decreased as the clay percentage decreased. 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.

2.4.1.2 Soil pH

Soil pH regulates the form in which soil phosphorus is found. Acid soils may contain a large amount of iron, aluminium, and manganese in solution. Alkaline and calcareous soils contain calcium, magnesium, and in some cases sodium. All of these elements combine with phosphorus to form compounds of varying solubilities and degrees of availability to the plant. Soil pH affects the availability of applied P by influencing the nature of P reactions and products formed. Phosphorus availability in most soils is optimum in the pH range of 5.5– 6.5. At low pH values P retention results largely from reaction with soluble iron and aluminium and precipitation as $\text{Al}(\text{OH})_2\text{H}_2\text{PO}_4$ and $\text{Fe}(\text{OH})_2\text{H}_2\text{PO}_4$ (Al/Fe hydroxyphosphate). As pH increases, activity of Al and Fe decreases resulting into higher concentration of P in solution. Above pH 7.0, Ca^{2+} can precipitate P as Ca – P (dicalcium phosphate) and P availability decreases (Juo and Fox, 1977).

Generally increasing soil pH decreases P concentration in the soil solution. The amount of exchangeable Al on soil exchange sites appears to be the main factor determining the change in solution P with varying soil pH.

2.4.1.3 Nature and amount of clay minerals

Adsorption reactions are affected by the type of mineral surfaces in contact with applied P in the soil solution (Jones and Fox, 1977). Woodruff and Kamprath (1965) reported that availability of P is related to the P associated with the reactive surfaces of the soil materials.

Solis and Torrent (1989a) cited by Castro and Torrent, (1995) pointed out that phosphorus availability decreases with increasing ratio between P adsorption and clay and iron oxide content as there is a positive correlation between P adsorption capacity and clay content. Volcanic soils with humus-Al complexes and amorphous aluminosilicates and Fe-oxides play a significant role in controlling the availability of P in the soil (Mankandani and Sasstry, 1988; Buresh *et al.*, 1997). Phosphorus sorption is an important process controlling P-availability in Oxisols and Ultisols.

Phosphorus fixation has been reported by Sanchez (1976) as an attribute that contributed to low crop yield on highly weathered acid soils such as Ferralsols and Acrisols. Phosphorus fixation in these soils plays an important role in determining the ultimate availability of phosphatic fertilizers to plants (Mrema, 1988).

Syers *et al.* (1973) stated that the P adsorption capacity of a soil increases with increase in clay content. Presence of kaolinite in tropical soils has been reported to increase the rate of P fixation due to the fact that this type of clay provides large surface area for P sorption hence reducing the available P in the soils (Sharpley, 1983).

Phosphorus applied to the soil, reacts with either Al and Fe or Ca to form insoluble compounds and finally becomes restricted in its availability to the plants (Jones, 1982).

2.4.1.4 Soil moisture content

Moisture content affects both the chemical availability of nutrients in soils and also the use that plants make of them. Olsen *et al.* (1961) reported that P uptake by maize seedlings was directly proportional to moisture content and when moisture was not limiting P uptake depended on the level of P in the soil solution. Uptake of phosphate was a linear function of soil moisture content for a given soil while uptake at constant moisture tension from soils differing in texture and soluble P level was a linear function of phosphate concentration in the soil solution.

2.4.1.5 Volcanic ash content

Volcanic ash content affects P availability through its effect on pH, total Ca, free CO₃ content and Fe and Al oxides and hydrous oxide content. These strongly influence P sorption hence its availability to plant (Porter and Sanchez, 1992).

2.4.1.6 Addition of organic matter

Fox and Comerford (1992) reported the effects of organic matter application on the availability of P. Organic anions can increase the availability of applied P in the soil solution by forming organophosphate complexes, replacement of H₂PO₄⁻ from adsorption sites, and coating of Al and Fe particles by humus. Furthermore addition organic matter leads to formation of complexes of organic anions and Fe and Al thus preventing their reaction with H₂PO₄⁻ (Juo and Fox, 1977; Mneni and Mackenzie,

1985). Efficiency of P fertilizer is likely to increase significantly if applied along with organic acids or acid forming materials such as green manures (Hue, 1991).

2.4.1.7 Application rates

Correct fertilizer application increases crop yields by removing soil nutrient deficiencies. The optimum rate of fertilizer application to a crop is the rate that produces maximum economic return, however it is smaller than the amount required to produce maximum crop yields but it is less likely to produce undesirable effects on the environment (Colwell, 1994).

The concentration of P in soil solution increases with increasing rates of P addition (Duffera and Robarge, 1999). Leaf P concentration increased as the quantity of P applied increased. At low P rates, most of the applied P is adsorbed by Fe, Al and Mn oxides while high rates of P may saturate the fixing sites, resulting in increased P concentration in the soil solution (Fageria *et al.*, 1997). Satisfying the P-fixing capacity of a soil by high rate of P application may result in effective crop response (LeMare, 1968 cited by Olsen and Engelstad, 1972). Heavy rates are needed particularly with Oxisols and Ultisols and soils formed from volcanic ash materials (Olsen and Engelstad, 1972). Crop yield can be increased with high P rates (Buresh *et al.*, 1997).

2.4.1.8 Mode of P application

Broadcasting of P-fertilizer exposes it to large surface for its fixation. So band placement has been found to increase P availability due to reduced contact between

the soil and fertilizer material with subsequent reduction in P adsorption (Tisdale *et al.*, 1993). Applying P fertilizer to a part of the soil volume increases P availability in the fertilized soil resulting in an increase in P uptake (Zhang and Barber, 1992).

2.4.1.9 Liming

Liming acid soils affects their P adsorption capacity. Malavilla *et al.* (1964) cited by Olson and Engelstad (1972) reported increased P availability with increasing rate of liming. Liming increases the availability of both native and applied P. Woodruff and Kamprath (1965) cited by Kamprath (1972) reported increased efficiency of fertilizer P in acidic soils after liming. However overliming reduces P availability.

2.5 Adequate P level and P fixation capacity

Different soils vary in their P- fixing capacities as does the same soil at different pH values. Thus the amount of fertilizer required to raise the soil test value for P by a given amount of P fertilizer depends upon soil type and soil pH. For example, soils derived from volcanic ash and strongly weathered soils have high P-fixing capacities, hence large amounts of P fertilizers have to be added to meet the standard P requirement (Buresh *et al.*, 1997). Much of the P applied to a soil is fixed in unavailable forms, as such more P must be applied to allow for fixation (Sperrow and Keefer, 1975).

Based on P adsorption isotherms, soils have been categorised into 3 groups in relation to the amount of P sorbed at 0.2 mg P/L. Low P fixing: <100 mg P/kg soil, moderate P fixing: 100 to 400 mg P/kg soil and high P fixing: > 400 mg P/kg soils,

respectively (Buresh *et al.*, 1997; Szilas, 2002). Soils with high P fixing capacities need large amounts of P fertilizers to be applied to reach the standard P requirement (Chen and Barber, 1990).

Studies on volcanic soils in Hawaii revealed that up to 1,350 kg P/ha was needed to satisfy the P fixing capacity (Fox *et al.*, 1962 cited by Olson and Engelstad, 1972).

Furthermore, Sasanda soil in Mbozi district-Tanzania, which is volcanic in origin has high P fixing capacity and large amounts of P fertilizers up to 600 kg P/ha have been applied without reaching the standard P requirement for maize (Semoka, 2001).

Generally, strongly acid and highly weathered soils are known to be low in total and available P (Jones, 1982). These soils are expected to fix large quantities of added P hence high rates of fertilizer P have to be added. So strategies are needed that will ensure adequate P levels for soils varying in P requirements due to differences in P fixing capacities.

2.6 Strategies for ensuring adequate P application

Among the strategies for ensuring adequate availability of P for growing plants are; methods of P fertilizer application and rates of P application. Concentrating the phosphate fertilizer near the seed has been found to reduce phosphate fixation and ensure a high concentration of soluble P for plants (Bear, 1964; Tunney *et al.*, 1997). Other studies report good responses with appreciable residual effects from nominal rates, while others emphasize the need to satisfy the P-fixing capacity of soils by heavy P dressings before effective crop response occurs (Olson and Engelstad, 1972).

Juo and Fox (1977) reported that in order to maintain a given level of solution P in soils with high P retention capacity, it is necessary to add larger quantities of P fertilizers as the P concentration in the solution increase with increasing P additions. Higher amounts of P fertilizers are required in soil with low initial P and high P fixing capacities in order to reach the critical concentration for plant uptake (Chen and Barber, 1990).

Mozaffari and Sims (1994) recommended long-term additions of P that may reduce P sorption capacity in some soils while Griffin and Hanna (1967) suggested a need for heavy and band applications of phosphate fertilizers for plant response to be realized. Izac (1997) and Buresh *et al.* (1997) support both approaches as means of improving P fertility of soils that can result in increased yields and income to farmers.

However, Jones (1982) recommended that to offset the rapid fixation of the applied phosphates, P fertilizers should be applied frequently instead of large infrequent applications aimed at supplying the P needs for plants for three or more years.

2.7 Critical concentrations of nutrients in plants

The critical concentration of an element is defined as the concentration below which deficiency symptoms may develop or above which toxicity symptoms may become likely (De Datta, 1981). The critical nutrient concentration is commonly used in the interpretation of total plant analysis results and consequently in the diagnosis of plant nutritional problems. Response to P fertilization is expected when the concentration of extractable P is below the critical level for a given crop grown on a specific soil (Fageria *et al.*, 1997).

The critical nutrient concentration of the primary macronutrients for maize are about 3% N, 0.3% P and 2%K. However, the critical nutrient concentration of P varies widely depending on plant species, plant age, plant part analyzed, stage of growth and growing season. In most plants the critical P concentration is between 0.1 and 0.4% (Tisdale *et al.*, 1993; Black, 1993; Marschner, 1995).

Plant analysis made early in the season may not be sufficiently responsive to higher levels of a nutrient added to be useful as an index of final yield (Tisdale *et al.*, 1993). Nutrient concentrations change markedly with plant age and there is a decrease in the concentrations of N, P and K with increasing age while concentrations of Ca and Mg increases with age (Black, 1993).

The stage of growth of plant sample is of prime concern as it greatly influences nutrient concentrations and unless the plant sample is taken at the proper time, the analytical results will be of little value (Tisdale *et al.*, 1993; Black 1993).

2.8 Difficulties in establishing P rates

There are difficulties in establishing adequate rates of phosphate fertilizers. These may be due to differences or variations in the nature of soils in relation to native P, P fixing capacities, organic matter content, nature of the P source and differences in crop requirements with regard to P. For example, soils with high P fixing capacities, high yields may be obtained if high rates of P fertilizers are applied (Goedert, 1983). Therefore, a good relationship between the established rates and various soil and

fertilizer properties need to be specifically and systematically studied for different crop species and management systems.

Furthermore, the relative effectiveness of the established P rates are management and site specific such that they cannot be readily transferred to other sites and management systems without calibration by on-site experiments that are very costly.

CHAPTER THREE

3.0 MATERIALS AND METHODS

Three soils which have not been treated with any phosphate fertilizer during the last ten years or more and which have different P fixing capacities were selected for the study. These soils were from Magadu in Morogoro district, classified as *Oxic Haplustult* by Kaaya (1989), Sasanda in Mbozi district, classified as *Drystropept* by Van straatens *et al.* (1992) and Nkundi in Sumbawanga district, classified as *Acruoxic Kandicustult* (Szilas, 2002). The soils from Nkundi, Magadu, and Sasanda with adsorption maximum of 80, 200 and 1560 mg P/kg respectively, were used for the current study due to their low level of available P for plant growth (Szilas, 2002).

All the three soils were evaluated under glasshouse conditions while a field experiment was conducted at Sasanda in Mbozi district.

3.1 Soil sampling and sample preparation

At each experimental site, a representative surface (0-20 cm) soil sample was collected at random across the field before fertilizer application and planting. The number of sub-samples were 30, 48 and 74 for Magadu, Nkundi and Sasanda, respectively and a composite sample was made from each site. The areas of the fields sampled were 250, 300 and 420 m² for Magadu, Nkundi and Sasanda, respectively. The sub samples from each site were thoroughly mixed to get a composite sample that was then air dried, ground and sieved through 2 mm sieves and 6 mm sieve for routine analysis and pot experiment, respectively.

3.2 Pot experiment

Four kg of soil samples sieved through 6 mm sieve were weighed and put into five litre plastic pots with holes plugged with cotton wool at the bottom for drainage. The soil samples in each of the plastic pots except pots for absolute control; were thoroughly mixed with an appropriate rate of P fertilizer, and other nutrients that were deficient. The rates of P application were 0, 800, 1600 and 3200 mg P/kg for the high P fixing Sasanda soil, 0, 100, 200 and 400 mg P/kg for the moderate P fixing Magadu soil and 0, 40, 80 and 160 mg P/kg for the low P fixing Nkundi soil. These rates were expected to give soil solution P contents of 0, 0.1, 0.2 and 0.4 mg P kg⁻¹ of soil and were estimated from P adsorption isotherms determined by Szilas (2002). The sources of P were Minjingu phosphate rock (13.1% P) and TSP (20.1% P). In addition to P, other nutrients were applied; namely N, K, Mg, Cu, and Zn as (NH₄)₂SO₄, KCl Mg(NO₃)₂, CuSO₄, and ZnSO₄, respectively. Maize (*Zea mays* L.) variety UH 615 was used as a test crop in both pot and field experiments. The treatment tested as well as the other nutrients applied in the glasshouse experiment are given in Table 2. The treatments were replicated three times and arranged in a completely randomized block design.

Table 1: Rates of different nutrients applied in three soils for pot experiment

| Sasanda soil | Magadu soil | Nkundui soil |
|--|--|--|
| P ₀ N ₀ Mg ₀ Zn ₀ Cu ₀ (Absolute control) | P ₀ N ₀ Mg ₀ Zn ₀ Cu ₀ (Absolute control) | P ₀ N ₀ K ₀ Zn ₀ Cu ₀ (Absolute control) |
| P ₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (Treatment control) | P ₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (Treatment control) | P ₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (Treatment control) |
| P ₈₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as MPR) | P ₁₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as MPR) | P ₄₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (P as MPR) |
| P ₁₆₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as MPR) | P ₂₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as MPR) | P ₈₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (P as MPR) |
| P ₃₂₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as MPR) | P ₄₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as MPR) | P ₁₆₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (P as MPR) |
| P ₈₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as TSP) | P ₁₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as TSP) | P ₄₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (P as TSP) |
| P ₁₆₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as TSP) | P ₂₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as TSP) | P ₈₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (P as TSP) |
| P ₃₂₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as TSP) | P ₄₀₀ N ₂₀₀ Mg ₅₀ Zn ₅ Cu _{2.5} (P as TSP) | P ₁₆₀ N ₂₀₀ K ₂₀₀ Zn ₅ Cu _{2.5} (P as TSP) |

The subscript numbers indicate the rates of the different nutrients that were applied, in mg/kg of soil.

Four maize seeds were planted per pot. Thinning was done two weeks after emergence leaving two plants per pot. Pots were watered to about field capacity moisture content using distilled water. Two weeks after plant emergence half of the N fertilizer rate was applied to each pot except for absolute control pot. The second split of N was applied at 28 days after planting.

3.3 Field experiment

A field experiment was conducted at Sasanda in Mbozi district where P was applied at the rates of 0, 800, 1600 and 3200 kg P ha⁻¹ from two source namely triple superphosphate (20.1% P) and Minjingu phosphate rock (13.1% P). These rates were used for ease of handling and research purposes. In addition to P, other nutrients applied were; N, K, Mg, Cu, and Zn as (NH₄)₂SO₄, KCl Mg(NO₃)₂, CuSO₄, and ZnSO₄, respectively. Nitrogen was applied at the rate of 120 kg/ha, Mg at 50 kg/ha, Cu at the rate of 5 kg/ha and Zn at the rate of 10 kg/ha.

The treatments were replicated three times in a completely randomized block design. The plot size was 5.0 m x 4.0 m. The plant spacing was 75 cm x 30 cm. The interplot and interblock spacings were 0.5 m and 1 m, respectively, while a 2 m pathway was left around the experimental area. Nutrient elements, P, Mg, Cu and Zn were broadcasted on appropriate plots followed by incorporation into the top 15 cm before planting.

Planting was done on 2nd December 2002. Four seeds were planted per hole and thinned to one seedling 14 days after planting. Nitrogen fertilizer was applied in four splits; the first application was done at planting, the second application immediately

after first weeding, 28 days after planting, and the third application 56 days after planting.

Table 2: Rates of different nutrients applied in field experiment

$P_0 N_{120} Mg_{50} Zn_{10} Cu_5$ (Treatment control)

$P_{800} N_{120} Mg_{50} Zn_{10} Cu_5$ (P as MPR)

$P_{1600} N_{120} Mg_{50} Zn_{10} Cu_5$ (P as MPR)

$P_{3200} N_{120} Mg_{50} Zn_{10} Cu_5$ (P as MPR)

$P_{800} N_{120} Mg_{50} Zn_{10} Cu_5$ (P as TSP)

$P_{1600} N_{120} Mg_{50} Zn_{10} Cu_5$ (P as TSP)

$P_{3200} N_{120} Mg_{50} Zn_{10} Cu_5$ (P as TSP).

The subscript numbers indicate the rates of the different nutrients that were applied, in kg/ha.

and the fourth application was done 84 days after planting at the rate of 30 kg N/ha at each application for effective utilization of N by plants and to avoid excessive leaching if applied once. The plots were kept weed free during the whole period of plant growth. Ear leaves were sampled at tasselling on 81st day of plant growth for nutrient analysis.

3.4 Plant sampling

3.4.1 Pot experiment

Maize shoots were cut at one cm above the soil surface at 42 days of plant growth for determination of dry matter yield and for plant tissue analysis. Plant samples were

washed with distilled water, and oven-dried at 65°C to constant weight. Dried samples were weighed to get drymatter yield then chopped and ground to pass through a 1mm sieve for analysis. The analysis of plant nutrients was done by procedures given in sections below.

3.4.2 Field experiment

At 50% tasselling, 15 earleaves from five inner rows per plot were randomly sampled and the samples were oven dried at 65⁰C to constant weight. The samples were then cut to small pieces and ground to pass through 0.5 mm sieve. The determination of N, P, K, Ca, Mg and Zn was done as described in section 3.6. Maize cobs were harvested after maturity, shelled and weighed to get the grain yield for each plot, which was then converted into tonnes/ha.

3.5 Soil analysis

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Soil textural classes were determined using USDA textural class triangle (USDA, 1975).

Soil pH was determined potentiometrically in 1: 2.5 soil: water using a pH meter (McLean, 1982).

Organic carbon was determined by the Walkley and Black method as described by Nelson and Sommer (1982).

Total N was determined by macro-Kjeldahl digestion followed by distillation and titration (Bremner and Mulvaney, 1982).

Available P was determined according to the Bray 1 method (Bray and Kurtz, 1945) and NaOH extractable P was also determined. In this procedure 1 g of dry soil was shaken with 50 ml of 0.5 M NaOH for 16 h after pre-washing with 1 M NaCl for 30 minutes (Syers *et al.*, 1972). The aliquot was used to determine P concentration colorimetrically as described by Murphy and Riley (1962).

Cation exchange capacity (CEC) was determined by the ammonium acetate saturation method (Rhodes, 1982), while the leachate from the preceding step was used to determine exchangeable Ca, and Mg, by atomic absorption spectrophotometer while K and Na were determined by flame photometer.

DTPA extractable Zn and Cu were determined by atomic absorption spectrophotometry (Lindsay and Norvell, 1978).

3.6 Analysis of plant materials

After processing the plant samples, the content of nutrients was determined. The HNO₃-H₂O₂ wet digestion method was used for the extraction of P, Mg, Ca, K and Zn (Moberg, 2001).

The content of P in the plant digest was determined using the ascorbic acid - molybdate blue method as described by Murphy and Riley (1962), while Mg, Ca, and Zn were determined by atomic absorption spectrophotometer (AAS) and K by a flame photometry (Moberg, 2001).

Total N was determined by macro-Kjeldahl digestion followed by distillation and titration (Bremner and Mulvaney, 1982).

3.7 Data analysis

For pot and field experiments, analysis of variance were used to evaluate the effects of the treatments on dry matter yield, contents of P in plant samples and maize grain yield. Duncan's Multiple Range Test was used for the separation of means. The statistical model used for data analysis was as described by Snedcor and Cochran (1989).

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

Where: Y_{ij} = Response

U = General effect

T_i = Treatment effect

B_j = Block effect

E_{ij} = Random error

$i = 1, 2, \dots, i$

$j = 1, 2, \dots, j$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical and chemical properties of experimental soils

Some of the properties of Nkundi, Sasanda and Magadu soils are shown in Table 3.

4.1.1 Physical properties of experimental soils

The textural classes of the soils were sandy clay loam (SCL) for Nkundi and Sasanda soils and sandy clay (SC) for Magadu soil.

4.1.2 Chemical properties of experimental soils

Soil pH

Soil pH (in water) values for the studied soils were 5.48, 5.87 and 6.01 for Magadu, Sasanda and Nkundi soils, respectively (Table 3). According to Landon, (1991), the soils were moderately acidic as pH values ranging between 5-7 are ranked as medium. Therefore, pH of the experimental soils was within the range satisfactory for crop production.

Organic carbon

The experimental soils were very low to medium in organic carbon as values <1.5% are considered as being very low and 1.5 to 4.5% are ranked as medium (Acres, 1983).

Table 3: Some physico-chemical properties of experimental soils

| Parameter | <u>Sampled areas</u> | | |
|-------------------------------|----------------------|---------|--------|
| | Nkundi | Sasanda | Magadu |
| pH in water | 6.01 | 5.87 | 5.48 |
| Organic carbon (%) | 1.11 | 4.21 | 1.13 |
| Extractable P (mg/kg soil) | 3.13 | 1.65 | 7.01 |
| Total N (%) | 0.1 | 0.3 | 0.1 |
| Exchangeable Ca (cmol (+)/kg) | 1.49 | 2.73 | 3.08 |
| Exchangeable Mg (cmol(+)/kg) | 1.12 | 1.4 | 2.85 |
| Exchangeable K (cmol(+)/kg) | 0.25 | 1.01 | 0.88 |
| Exchangeable Na (cmol (+)/kg) | 0.15 | 0.69 | 0.63 |
| CEC (cmol (+)/kg) | 13.9 | 28.2 | 17.5 |
| Base saturation (%) | 21.7 | 20.7 | 42.5 |
| Zinc (mg Zn/kg) | 0.51 | 0.37 | 0.66 |
| Copper (mg Cu/kg) | 1.25 | 1.12 | 1.03 |
| Particle size analysis | | | |
| % sand | 75.8 | 59.8 | 51.8 |
| % silt | 2.0 | 17.0 | 3.0 |
| % clay | 22.2 | 23.2 | 45.2 |
| Textural class | SCL | SCL | SC |

SCL: Sandy Clay Loam; SC: Sandy Clay.

Hence, Sasanda had medium organic carbon while Nkundi and Magadu had very low OC. The low level of organic carbon is a reflection of low soil organic matter that

may be attributed to low input of crop residues, high rate of decomposition, mineralization and oxidation of organic residues (Smith and Sanchez, 1980).

Total nitrogen

The total nitrogen contents ranged from 0.1 to 0.3% (Table 3). Based on the rating of Landon (1991), Nkundi and Magadu soils had low total N while Sasanda soil had medium level of total N. The low nitrogen content could be attributed to low organic matter content in the respective soils.

Phosphorus

The extractable P (Bray 1 P) for the soils ranged from 1.65 to 7.01 mg/kg soil (Table 3). According to Landon (1991) and Singh and Uriyo (1978), Bray-1-P < 15 mg/kg is rated as low. All soils had low Bray 1 P. The low level of P in the soils could probably be due to low level of P in the soil parent materials and conversion of P into forms not extractable by the Bray 1 reagent due to high activities of Al and Fe in soils (Kadoghola, 2001; Szilas, 2002). Further, phosphorus is deficient in most agricultural soils due to continuous uptake of P by plants (FAO, 2000).

Exchangeable bases

Calcium

The contents of calcium in the experimental soils varied from 1.49 to 3.08 cmol (+) /kg soil. According to Landon (1991) all soils had low exchangeable calcium.

Magnesium

The values for magnesium for soil studied are shown in Table 3. The values were 1.12, 1.4 and 2.85 cmol(+)/kg soil for Nkundi, Sasanda and Magadu soils, respectively. These values are ranked as medium according to Landon (1991) who categorised exchangeable Mg values >4 as high, those <0.5 as low and those in between as medium. Therefore, the soils for the current study have medium exchangeable magnesium.

Potassium

Potassium levels in the study soils ranged from 0.25 to 1.01 cmol(+)/kg soil. Based on guidelines by Landon (1991), Magadu and Sasanda soils had high levels of potassium while Nkundi soil had medium potassium. As such response to potassium fertilizer is more likely for Nkundi soil than Magadu and Sasanda soils.

Sodium

Sodium levels for study soils ranged from 0.15 to 0.69 cmol(+)/kg soil. All soils had low levels of exchangeable sodium (<1.0 cmol(+)/kg soil) based on Landon (1991).

Cation exchange capacity

The cation exchange capacity ranged from 13.9 to 28.2 cmol (+)/kg soil (Table 3). Nkundi soil had low CEC, Magadu soil had medium CEC and Sasanda soil had high CEC based on guidelines by Landon (1991). The high CEC for Sasanda soil might

have been contributed by its high organic fraction relative to Magadu and Nkundi soils (Brady and Weil, 1996).

Base Saturation

The percentage base saturation for the soils ranged from 20.7 to 42.5. Based on guidelines by Landon (1991). The tested soils had medium base saturation. According to this categorisation, all soils are marginally fertile.

Zinc

The available zinc was 0.51 mg/kg for Nkundi, 0.37 mg/kg for Sasanda and 0.66 mg/kg for Magadu. Nkundi and Magadu soils had zinc level within the critical range of 0.5 to 0.8 mg Zn/kg while Sasanda soil had low level of zinc based on rating by Randhawa *et al.* (1978) that called for zinc fertilizer application.

Copper

The amounts of available copper were 1.25, 1.12 and 1.03 mg/kg for Nkundi, Sasanda and Magadu respectively. According to Landon (1996) and Randhawa *et al.* (1978) the studied soils had high amount of available copper above the critical level of >0.2 mg Cu/kg.

4.2 Pot experiment

4.2.1 Visual assessment of maize growth

Severe purplish colour was observed for treatments with all nutrients except P (treatment control) while for absolute control, a yellowish colour was more intense and tended to mask the purplish colour. The situation was very severe for Sasanda soil. The early senescence of lower leaves was also observed in the treatment control in all soils, which might have been accentuated by N: P imbalance.

4.2.2 Effects of rates and sources of P on maize dry matter yield

The data showing the effect of P rates and sources on the dry matter yields for the pot experiments are presented in Tables 4 5 and 6 for Nkundi, Magadu and Sasanda soils, respectively. The soils tested varied in productivity as shown by yield in the controls. Nkundi and Magadu soils had comparable yield while Sasanda soil had lower yield.

Application of P significantly increased dry matter yield over the treatment control in all soils. The rates of 160 and 3200 mg P/kg TSP significantly increased dry matter yield in Nkundi and Sasanda soils, respectively. In Magadu soil rates of 200 and 400 mg P/kg soil from TSP and MPR gave comparable dry matter yield. This implies that, P rate beyond 200 mg P/kg had a non significant effect on increasing dry matter yield in this soil. Of the two sources, TSP applied at the rate of 3200 mg P/kg soil performed significantly better than the same rate of P from MPR in Sasanda soil.

Table 4: Effects of rates and sources of P on dry matter yield, P concentration and uptake in Nkundi soil

| P source and rate (mgP/kg soil) | DM yield (g/pot) | P conc (%) | P uptake (mgP/pot) |
|------------------------------------|---------------------|---------------|-----------------------|
| Absolute control | 3.70d | 0.11a | 4.1e |
| Treatment control | 4.17d | 0.10a | 4.2e |
| MPR (40) | 21.07c | 0.13a | 27.4d |
| MPR (80) | 42.31b | 0.11a | 46.5c |
| MPR (160) | 51.65ab | 0.16a | 82.6ab |
| TSP (40) | 28.20c | 0.13a | 36.7cd |
| TSP (80) | 48.60ab | 0.14a | 68.b |
| TSP (160) | 53.36a | 0.16a | 85.4a |
| CV (%) | 16.71 | 13.02 | 19.58 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

These results show that in Nkundi and Magadu soils P rates equal to the standard P requirement (160 and 200 mg P/kg soil for Nkundi and Magadu soils, respectively from both sources) could be recommended for optimizing maize yield. When these rates were doubled DM yield was increased only slightly but not significantly. However, TSP performed slightly higher than MPR.

Table 5: Effects of rates and sources of P on dry matter yield, P concentration and uptake in Magadu soil

| P source and rate (mgP/kg soil) | DM yield (g/pot) | P conc (%) | P uptake (mgP/pot) |
|------------------------------------|---------------------|---------------|-----------------------|
| Absolute control | 4.13c | 0.10b | 4.3c |
| Treatment control | 4.17c | 0.13ab | 5.2c |
| MPR (100) | 30.04b | 0.16ab | 46.7b |
| MPR (200) | 42.50a | 0.23a | 97.3ab |
| MPR (400) | 41.13a | 0.22ab | 114.6a |
| TSP (100) | 34.03b | 0.13ab | 44.7b |
| TSP (200) | 38.63a | 0.20ab | 75.4ab |
| TSP (400) | 40.06a | 0.24a | 93.5ab |
| CV (%) | 8.89 | 35.44 | 48.1 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

In Sasanda soil TSP at the rate of 1600 and 3200 mg P/kg soil gave comparable performance while MPR at the rate of 3200 mg P/kg soil was close to TSP at 1600 mg P/kg. However, TSP performed better than MPR at all rates of application. This implies that 1600 and 3200 mg P/kg TSP and MPR, respectively, could be recommended for optimizing maize yield in Sasanda soil.

4.2.3 Effects of P rates and sources on plant P concentration and uptake

The effects of rates and sources of P on P concentration and uptake are presented in Tables 4, 5 and 6. The P concentration in maize shoots ranged from 0.10 to 0.16, 0.10 to 0.24 and 0.10 to 0.20% for Nkundi, Magadu and Sasanda soils, respectively. Phosphorus application increased the concentration of P in shoots over the treatment control. At the highest rates of 160, 400 and 3200 mg P/kg, the P sources had similar effects on P concentration in plants in all soils.

Table 6: Effects of rates and sources of P on dry matter yield, P concentration and uptake in Sasanda soil

| P source and rate (mgP/kg soil) | DM yield (g/pot) | P conc (%) | P uptake (mgP/pot) |
|------------------------------------|---------------------|---------------|-----------------------|
| Absolute control | 2.70e | 0.10c | 2.8e |
| Treatment control | 3.56e | 0.10c | 3.6e |
| MPR (800) | 22.21d | 0.13bc | 29.4d |
| MPR (1600) | 37.07c | 0.19a | 69.6c |
| MPR (3200) | 52.94b | 0.18ab | 94.1b |
| TSP (800) | 50.08b | 0.12c | 69.5c |
| TSP (1600) | 58.85ab | 0.20a | 118.8a |
| TSP (3200) | 64.18a | 0.20a | 124.8a |
| CV (%) | 16.93 | 18.02 | 16.2 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

However, the concentrations varied greatly and could be categorized into three groups namely deficient (< 0.13%), marginal (0.13 to 0.19%) and adequate (0.2 to 0.3%) based on Tisdale *et al.* (1993). In Nkundi soil P application led to marginal increase in P concentration in plant shoots. In Magadu soil a significant increase in P concentration was observed at the rates of 200 and 400 mg P/kg for MPR and TSP, respectively. In Sasanda soil a significant increase in P concentration over the treatment control was realised at the rates of 1600 and 3200 mg P/kg. Applying the standard P requirement at Nkundi appears to underestimate the P requirement at least in pot experiment. Application of P at standard P requirement in Magadu and Sasanda soils increased P concentrations to adequate levels while the same level of application increased P to marginal level with MPR in Sasanda. However, plants supplied with P from both sources did not manifest P deficiency symptoms in plants. The observed low P concentration in plants at all P rates and sources may be attributed to inadequate supply to meet the plant requirements during plant growth. Despite the high rates of P application in Sasanda, the results from the current study indicate that the application of P in the form of MPR or TSP for Magadu and Sasanda soils have comparable effect on plant growth and performance. These results conform to those reported by Nsenga (2001) and Mnkeni *et al.* (1991).

The application of P significantly ($P = 0.05$) increased P uptake over the control for all soils tested. The P uptake ranged from 4.2 to 90.2, 4.3 to 114.6 and 2.8 to 124.8 mg P/pot for Nkundi, Magadu and Sasanda soils, respectively. The effect of rates and sources of P on P uptake varied among soils. In Nkundi soil, TSP at all rates

performed better than MPR. A significant increase in P uptake was observed at the rate of 160 mg P/kg TSP. This is consistent with dry matter yield (Table 4).

In Magadu soil, a significant increase in P uptake was obtained at the rate of 400 mg P/kg MPR. This is consistent with the dry matter yield (Table 5). Further, a non significant difference between TSP and MPR was realised at the rate of 200 mg P/kg, the rate equal to the standard P requirement. In Sasanda soil, rates and sources of P have significant effects on P uptake. With regard to P sources TSP significantly ($P = 0.05$) increased P uptake at all rates compared to MPR. The increased P uptake may be attributed to the response of maize plants to released P from the readily availability of TSP and dissolution of MPR. Bhat and Nye (1974) and Ozanne (1980) reported that the increase in phosphorus concentration in soil solution increased the diffusion gradient from the soil to plant roots thereby increasing phosphorus uptake by plants. These results conform to those reported by Babili (1999) and Mwakatenya (1996). Further, these results indicate that P application increased P concentration and uptake in plants, which in turn improve crop yield. In addition the results show that MPR and TSP gave comparable performance.

4.2.4 Effects of rates and sources of P on nitrogen concentration and uptake

The effect of rates and sources of applied P on the concentration and uptake of nitrogen are given in Tables 7, 8, and 9. The treatment control had significantly ($P = 0.05$) higher nitrogen concentration than P treated pots. Phosphorus application significantly decreased N concentration in plant shoots. Nitrogen concentration decreased by 66%, 49% and 57% for Nkundi, Magadu and Sasanda soils,

respectively. The rates of applied P, also had significant effect on the concentration of N in the plants in which lower rates of applied P has higher N concentration in the plants in all soils than the higher rates of P applications. The decrease in N concentration in plants with increasing P rates may be attributed to dilution effect caused by the large increase in dry matter yields as a result of P application. In fact the highest rate of P decreased N concentration to deficient levels. This means that application of high rates of P called for higher rates of N to maintain adequate levels

Table 7: Effects of rates and sources of P on plant nitrogen concentration and uptake in Nkundi soil

| P source and rate (mgP/kg soil) | N concentration (%) | N uptake (mgN/pot) |
|------------------------------------|------------------------|-----------------------|
| Absolute control | 2.30b | 85.1c |
| Treatment control | 3.60a | 149.5c |
| MPR (40) | 2.26b | 476.3b |
| MPR (80) | 1.59cd | 672.8a |
| MPR (160) | 1.32cd | 681.8a |
| TSP (40) | 1.72c | 485ab |
| TSP (80) | 1.22d | 592.9ab |
| TSP (160) | 1.27d | 677.7a |
| CV (%) | 12.88 | 22.69 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

of both nutrients in the plants. On the other hand, the sources of P had slight effect on N concentration in plants but comparable. The treatment controls had N concentration close to the adequate range, but P treatments resulted in deficient levels of N according to Okalebo *et al.* (1993) and Chapman (1965). The N uptake ranged from 85.4 to 685.3, 54.4 to 611.8 and 48.9 to 782.8 mg N/pot Nkundi, Magadu and Sasanda soils, respectively. Phosphorus treatment significantly ($P = 0.05$) increased nitrogen uptake over the treatment controls in all soils. Sources of P had comparable effect on N uptake by maize plants.

Table 8: Effects of rates and sources of P on plant nitrogen concentration and uptake in Magadu soil

| P source and rate (mg P/kg soil) | N concentration (%) | N uptake (mgN/pot) |
|-------------------------------------|------------------------|-----------------------|
| Absolute control | 1.38c | 56.9c |
| Treatment control | 2.72a | 113.4c |
| MPR (100) | 1.83b | 550.5ab |
| MPR (200) | 1.39c | 590.8ab |
| MPR (400) | 1.45c | 595.6ab |
| TSP (100) | 1.81b | 615.9a |
| TSP (200) | 1.39c | 536.9b |
| TSP (400) | 1.39c | 556.8ab |
| CV (%) | 9.15 | 8.60 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

The higher N uptake in P treated soils than treatment controls in all soils may be due to increased availability of P in the soil solution following the dissolution of applied P fertilizers which enhanced N uptake.

Table 9: Effects of rates and sources of P on plant nitrogen concentration and uptake in Sasanda soil

| P source and rate (mg P/kg soil) | N concentration (%) | N uptake (mgN/pot) |
|-------------------------------------|------------------------|-----------------------|
| Absolute control | 1.81c | 48.9c |
| Treatment control | 2.85a | 95.8c |
| MPR (800) | 2.24b | 497.5b |
| MPR (1600) | 1.86c | 689.5a |
| MPR (3200) | 1.48d | 782.8a |
| TSP (800) | 1.37d | 686.1a |
| TSP (1600) | 1.23d | 723.8a |
| TSP (3200) | 1.22d | 782.9a |
| CV (%) | 10.58 | 11.48 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

4.2.5 Calcium concentration and uptake

The effects of rates and sources of P on calcium concentration and uptake are presented in Tables 10, 11 and 12. The concentration of calcium ranged from 0.30 to 0.55, 0.27 to 0.52 and 0.32 to 0.67% for Nkundi, Magadu and Sasanda soils,

respectively. Plants in control treatment had significantly ($P = 0.05$) higher Ca concentrations than those in P treated soils. The rates and sources of applied P affected the Ca concentration in plants differently.

Table 10: Effects of rates and sources of P on calcium, potassium and magnesium concentration and uptake by plant in Nkundi soil

| P rates and sources (mg P/kg soil) | Nutrient concentration | | | Nutrient uptake | | |
|---------------------------------------|------------------------|---------|--------|--------------------|---------|---------|
| | Ca | K | Mg | Ca | K | Mg |
| |(%)..... | | |(mg/pot)..... | | |
| Absolute control | 0.55a | 5.10a | 0.45ab | 20.4d | 188.7c | 16.7c |
| Treatment control | 0.46ab | 5.82a | 0.53a | 18.9d | 242.7c | 22.1c |
| MPR (40) | 0.43abc | 3.50b | 0.28cd | 90.1c | 737.5b | 58.9bc |
| MPR (80) | 0.44abc | 3.17bc | 0.23d | 181.8a | 1341.2a | 97.5ab |
| MPR (160) | 0.39bcd | 2.88bcd | 0.23d | 200.4a | 1487.5a | 118.8a |
| TSP (40) | 0.38bcd | 2.59cd | 0.38bc | 105.3bc | 730.4b | 107.2ab |
| TSP (80) | 0.32cd | 2.28d | 0.28cd | 155.2ab | 1108.1a | 136.1a |
| TSP (160) | 0.30d | 2.22d | 0.22d | 165.5a | 1184.6a | 117.4a |
| CV (%) | 18.20 | 17.82 | 23.43 | 27.01 | 17.1 | 31.5 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

Increase in P rates slightly decreased Ca concentration in plants for Nkundi soil while for Magadu and Sasanda soils a significant decrease was realized for both TSP and MPR. The concentration decreased slightly due to dilution effect, but uptake

increased significantly implying that the dilution effect was partially compensated by release of Ca from MPR. Triple super phosphate gave slightly less Ca content but statistically comparable results to MPR.

Table 11: Effects of rates and sources of P on calcium, potassium and magnesium concentration and uptake by plant in Magadu soil

| P rates and sources (mg P/kg soil) | Nutrient concentration | | | Nutrient uptake | | |
|---------------------------------------|------------------------|--------|-------|--------------------|-----------|--------|
| | Ca | K | Mg | Ca | K | Mg |
| |(%)..... | | |(mg/pot)..... | | |
| Absolute control | 0.45ab | 4.63a | 0.39a | 18.6c | 190.9d | 16.1c |
| Treatment control | 0.52a | 4.89a | 0.40a | 21.7c | 203.9d | 16.7c |
| MPR (100) | 0.27b | 3.48b | 0.19b | 81.1b | 1045.4c | 57.1b |
| MPR (200) | 0.28b | 3.14bc | 0.17b | 119ab | 1334.5a | 72.3a |
| MPR (400) | 0.34ab | 3.00bc | 0.19b | 139.8a | 1233.9ab | 78.2a |
| TSP (100) | 0.30b | 3.43b | 0.17b | 102.1ab | 1167.3abc | 57.9ab |
| TSP (200) | 0.32b | 3.38b | 0.17b | 123.6ab | 1306ab | 65.7ab |
| TSP (400) | 0.27b | 2.85c | 0.16b | 108.2ab | 1141.7bc | 64.1ab |
| CV (%) | 18.60 | 7.63 | 9.55 | 24.26 | 9.9 | 17.1 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

All the Ca concentration values fall in the adequate range on the basis of guidelines proposed by Tisdale *et al.* (1993).

The application of P significantly increased Ca uptake over the control. Calcium uptake ranged from 18.9 to 200.4, 18.6 to 139.8 and 18.1 to 275.9 mg Ca/pot for Nkundi, Magadu and Sasanda soils, respectively.

Table 12: Effects of rates and sources of P on calcium, potassium and magnesium concentration and uptake by plant in Sasanda soil

| P rates and sources (mg P/kg soil) | Nutrient concentration | | | Nutrient uptake | | |
|---------------------------------------|------------------------|---------|-------|--------------------|----------|---------|
| | Ca | K | Mg | Ca | K | Mg |
| |(%)..... | | |(mg/pot)..... | | |
| Absolute control | 0.67a | 5.10a | 0.33b | 18.1c | 137.7d | 8.9e |
| Treatment control | 0.66a | 5.82a | 0.39a | 23.5c | 207.2d | 13.9e |
| MPR (800) | 0.53b | 3.50b | 0.20c | 117.7b | 777.4c | 44.3d |
| MPR (1600) | 0.45b | 3.17bc | 0.19c | 166.8b | 1175.1b | 70.4c |
| MPR (3200) | 0.51b | 2.88bcd | 0.22c | 269.9a | 1524.7a | 116.5b |
| TSP (800) | 0.32c | 2.59cd | 0.24c | 160.3b | 1297.1ab | 120.2ab |
| TSP (1600) | 0.43bc | 2.28d | 0.21c | 253.1a | 1341.8ab | 123.6ab |
| TSP (3200) | 0.43bc | 2.22d | 0.21c | 275.9a | 1424.8ab | 134.8a |
| CV (%) | 12.96 | 12.35 | 13.84 | 21.97 | 13.3 | 14.3 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

Calcium uptake significantly increased with increasing P rates and was highest at the highest rate of P from both sources. Non-significant differences between MPR and TSP at a rate equal to the standard P requirement was realised in Nkundi and Magadu

soils. However, at the highest rates of 160, 400 and 3200 mg P/kg for Nkundi, Magadu and Sasanda soils, respectively, MPR performed better than TSP. These results concur with findings reported by Mnkeni *et al.* (1991) and Nsenga (2001).

For instance, Nsenga (2001) found a Ca concentration of 0.28 and 0.25% at the rate of 50 and 150 kg/ha, respectively.

4.2.6 Potassium concentration and uptake

The results for concentration and uptake of potassium are presented in Tables 10, 11 and 12 for Nkundi, Magadu and Sasanda soils, respectively. The concentration of potassium ranged from 2.22 to 5.82, 2.85 to 4.89 and 2.22 to 5.82% K and the uptake values ranged from 188.7 to 1487.5, 190.9 to 1334.5 and 137.7 to 1524.7 mg K/pot for Nkundi, Magadu and Sasanda soils, respectively. The treatment control had significantly ($P < 0.05$) higher K than plants from P treatments. The data show general decreases in K concentration with increasing P rates. A significant decrease in K concentration was realized at the rates of 80, 160, 400, 1600 and 3200 mg P/kg for Nkundi, Magadu and Sasanda soils, respectively for TSP. However, K concentrations were within the adequate range of 1.8 to 5.0% K (Tandon, 1995; Tisdale *et al.*, 1993). The decrease in K concentration with increasing rate of P application was attributed to dilution effect because dry matter increased with increasing rate of P application. However, the dilution effect was partially compensated for by improved K supply from P sources leading to increase in K uptake. Furthermore, at all rates of applications in all soils MPR was found to be associated with higher K concentrations than TSP. This may be attributed to higher

potassium content of MPR (0.5% K₂O) than in TSP (0.06% K₂O) (Tusckelege, 1997).

There was a significant increase in K uptake over the control in all soils tested. A significant increase in K uptake was realised at the rates of 200 and 3200 mg P/kg for Magadu and Sasanda soils, respectively with MPR. However, although not statistically significant there was a general increase in K uptake with rates of application for both sources in Nkundi and Sasanda soils. These results indicate that MPR and TSP improved K uptake and their effects were comparable.

4.2.7 Magnesium concentration and uptake

The concentration of Mg in maize earleaves as influenced by P rates and sources are presented in Tables 10, 11 and 12. Magnesium concentration values ranged from 0.22 - 0.53, 0.16 to 0.40 and 0.19 to 0.39% for Nkundi, Magadu and Sasanda soils, respectively. In Nkundi and Sasanda soils, Mg concentration in maize leaves was significantly higher in the treatment controls than in P treatments. With the exception of Magadu soil, the absolute and treatment controls had equal effects and significantly higher Mg concentrations than the other treatments. Minjingu PR and TSP were comparable in influencing Mg concentration in maize earleaves. In Sasanda and Magadu soils, P rates and sources had no significant effect on Mg concentration in plants. In Nkundi soil TSP at the rate of 40 and 80 mg P/kg and MPR at the rate of 40 mg P/kg had slightly higher Mg concentration than the other rates. All soils gave Mg concentration values falling in the critical range of 0.15 -

0.80 % given by Tandon (1995) and Tisdale *et al.* (1993). Therefore, all the three soils had adequate levels of Mg.

Magnesium uptake ranged from 16.7 to 138.6, 16.1 to 78.2 and 8.9 to 134.8 mg Mg/pot. There was a significant increase in Mg uptake over the control in all soils tested. For both P sources an increase in P rates, significantly increased Mg uptake in all soils. A slight increase in Mg uptake was realised at the rates of 160, 3200 and 200 mg P/kg for Nkundi, Sasanda, and Magadu soils, respectively for TSP and MPR, respectively. At lower rates of 40, 100 and 800 mg P/kg for Nkundi, Magadu and Sasanda soil, respectively TSP performed slightly better than MPR. However, MPR and TSP had comparable performance in Mg uptake.

4.2.8 Zinc concentration

The results of zinc concentration in maize plants as influenced by rates and sources of P are presented in Tables 13, 14 and 15. Zinc concentration values ranged from 20.70 to 30.30, 18.40 to 49.20 and 10.90 to 28.73 mg/kg for Nkundi, Magadu and Sasanda soil, respectively. Zinc concentrations were inconsistent with the dry matter yields. A significant increase in Zn concentration was observed for the treatment controls for Magadu and Sasanda soils. In Nkundi soil a significant increase in Zn concentration was realised at the 40 mg P/kg MPR and TSP. The decrease in Zn concentration with increasing P rates in all soils may probably be due to dilution effect. For Nkundi and Magadu soils, P application decreased Zn concentration significantly but all Zn values were in the adequate range. In Sasanda soil, high rates

of P decreased Zn to deficient levels. This is probably due to antagonistic relationship between P and Zn. Such antagonist effects have been observed by others when very high rates of P are used (Lisuma, 2002; Barrow, 1987).

Loneragan *et al.* (1979) reported that P induced Zn deficiency may be due to; (i) dilution of zinc in plants by increased growth caused by P fertilizer, (ii) inhibition of Zn uptake by cations added with P fertilizers and (iii) phosphorus induced zinc adsorption in soils due to hydroxides and oxides of Fe and Al.

Table 13: Effects of P rates and sources on zinc concentration in maize shoots grown in Nkundi soil

| P rates and sources (mg P/kg soil) | Zinc concentration (mg Zn/kg) |
|---------------------------------------|----------------------------------|
| Absolute control | 25.6ab |
| Treatment control | 24.8ab |
| MPR (40) | 29.5a |
| MPR (80) | 27.2a |
| MPR (160) | 20.7b |
| TSP (40) | 30.3a |
| TSP (80) | 25.8ab |
| TSP (160) | 21.0b |
| CV (%) | 12.4 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

For Sasanda soil, except for the treatment control, all treatment tested had low Zn concentration based on ratings by Tandon, (1995), and Tisdale *et al.* (1993) who suggested the sufficiency range to 20 – 60 mg Zn/kg for maize plants. Pasricha *et al.* (1987) reported that P fertilization resulted in decreased utilization of Zn by growing plants and P induced deficiency can be severe in soils that are low or marginal in available Zn such as Sasanda.

Table 14: Effects of P rates and sources on zinc concentration in maize shoots in Magadu soil

| P rates and sources (mg P/kg soil) | Zinc concentration (mg Zn/kg) |
|---------------------------------------|----------------------------------|
| Absolute control | 21.7b |
| Treatment control | 49.2a |
| MPR (100) | 25.3b |
| MPR (200) | 23.7b |
| MPR (400) | 18.4b |
| TSP (100) | 25.3b |
| TSP (200) | 23.6b |
| TSP (400) | 20.6b |
| CV (%) | 17.6 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

Table 15: Effects of P rates and sources on zinc concentration in maize shoots in Sasanda soil

| P rates and sources (mg P/kg soil) | Zinc concentration (mg Zn/kg) |
|---------------------------------------|----------------------------------|
| Absolute control | 20.1bc |
| Treatment control | 28.7a |
| MPR (800) | 20.5b |
| MPR (1600) | 16.6bcd |
| MPR (3200) | 12.9cd |
| TSP (800) | 13.5bcd |
| TSP (1600) | 15.6bcd |
| TSP (3200) | 10.9d |
| CV (%) | 22.0 |

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

4.2.9 Bray 1 P after harvest

The amounts of available P after harvest are presented in Tables 16, 17 and 18 below. The application of P significantly increased the amounts of available P in all soils. There was a significant ($P = 0.05$) increase in available P with increasing P rates from both sources. A significant increase was realised at the rates of 160, 400 and 3200 mg P/kg TSP in all soils. Generally there was a significant difference

between TSP and MPR in available P at each rate of application in all soils tested with TSP performing better than MPR at each rate.

Table 16: Bray 1 P and exchangeable calcium in Nkundi soil after harvest

| P sources and rates(mg P/kg soil)..... | Bray 1 P | Exchangeable Ca (cmol+)/kg soil) |
|---|----------|-------------------------------------|
| Absolute control | 2.34e | 1.47d |
| Treatment control | 2.60e | 1.53d |
| MPR (40) | 9.65d | 1.63d |
| MPR (80) | 16.40c | 2.22b |
| MPR (160) | 26.86b | 2.65a |
| TSP (40) | 11.76d | 1.38d |
| TSP (80) | 24.30b | 1.40d |
| TSP (160) | 49.72a | 1.89c |
| CV (%) | 11.25 | 8.04 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

This implies that P source was also a significant factor on the amount of available P in soil. The low available P values in MPR treated soils as compared to those in TSP treated soils at all rates were probably attributed to low solubility of MPR (Khasawneh and Doll, 1978). The increase in available P indicates that MPR and TSP have undergone considerable dissolution thereby releasing P in the soil solution. In case of Nkundi soil, P application at and above the standard P requirement increased P levels to and above adequate levels according to rating by Landon (1991)

and Singh and Uriyo (1979) where Bray 1 P > 15 mg/kg soil is considered adequate. While in Magadu soil P application increased soil available P from 2.0 to 95.46 and 2.0 to 53.50 mg/kg soil for TSP and MPR, respectively which are above the critical levels on the basis of rating by Landon (1991) and Singh and Uriyo (1979). This is an increase of 98 and 96% for TSP and MPR, respectively.

Table 17: Bray 1 P and exchangeable calcium in Magadu soil after harvest

| P source and rate(mg P/kg soil)..... | Bray -1 P | Exchangeable Ca (cmol(+)/kg) |
|---|-----------|---------------------------------|
| Absolute control | 2.00f | 3.27e |
| Treatment control | 2.56f | 3.34e |
| MPR (100) | 15.03e | 4.22d |
| MPR (200) | 34.39c | 5.47b |
| MPR (400) | 53.50b | 6.80a |
| TSP (100) | 24.68d | 3.56e |
| TSP (200) | 52.43b | 4.02d |
| TSP (400) | 95.46a | 4.63c |
| CV (%) | 8.12 | 4.16 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

Sources of P had significant effect on the amounts of available P remained in the soil in which TSP gave higher amounts than MPR at the same rate at Nkundi and Magadu sites. The low amounts of available P for MPR as compared to TSP may be

attributed to low dissolution of MPR. This implies that if other factors will not be limiting the next crop will benefit from the residual P.

For Sasanda soil low levels of extractable P remained in the soil after harvest. This situation is attributed to high P fixation capacity of this soil. Mwakisimba (1999) reported that Sasanda soil has a very high P adsorption capacity.

Table 18: Bray 1 P and exchangeable calcium in Sasanda soil after harvest

| P sources and rates(mg P/kg soil)..... | Bray 1 P | Exchangeable Ca (cmol(+)/kg) |
|---|----------|---------------------------------|
| Absolute control | 2.57e | 2.79f |
| Treatment control | 1.93f | 2.84f |
| MPR (800) | 6.17d | 8.09c |
| MPR (1600) | 7.44cd | 9.76b |
| MPR (3200) | 9.82c | 12.47a |
| TSP (800) | 7.52cd | 4.66e |
| TSP (1600) | 15.80b | 6.41d |
| TSP (3200) | 53.62a | 9.77b |
| CV (%) | 11.71 | 5.44 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

Therefore, this implies that a large one-time P application may not be an appropriate approach for maximizing P availability in soils with high P fixing capacities.

4.2.10 Exchangeable Calcium

The amounts of exchangeable calcium are presented in Tables 16, 17 and 18. The application of P significantly ($P = 0.05$) increased the amount of exchangeable calcium over the treatment control. There was a significant increase in the amount of exchangeable calcium with increasing P rates for both MPR and TSP in all soils. A significant increase in the content of exchangeable calcium in the soil was observed at the rates of 160, 400 and 3200 mg P/kg MPR in Nkundi, Magadu and Sasanda soils, respectively. In addition, MPR performed significantly better than TSP at each rate. This is attributed to the higher content of calcium in MPR (27.86% CaO) compared to TSP (16.79% CaO) (Tusekelege, 1997). The results of this study conform to those reported by Nsenga (2001); Mkeni *et al.* (1991) and Ikerra (1986). Increased Ca contents result in its availability to plants. On the other hand increased Ca contents may decrease or limit availability and uptake of P, respectively. According to Landon (1996) Ca-Mg ratio greater than 5:1 leads to reduced P availability and if less than 3:1 P uptake by plants is inhibited. Also increased Ca contents may increase soil pH which in turn may have negative effect on the dissolution of MPR.

4.2.11 TSP and MPR dissolution after harvest

The extent of dissolution of TSP and MPR in Sasanda soil as estimated by sodium hydroxide extraction is given in Table 19. The results show that there were differences in the extent of dissolution between TSP and MPR. The amount of NaOH P increased with increasing rate of application for each source. The net dissolution (Δ

NaOH-P) was determined from the difference between P applied at each rate and the absolute control.

Table 19: Soil pH, TSP and MPR dissolution in Sasanda soil pot experiment after harvest

| P rates and sources | NaOH-P(mg/kg)..... | Δ NaOH-P | NaOH-P (% of applied) | Soil PH |
|---------------------|-----------------------------|-----------------|---------------------------|------------|
| Absolute control | 151.8e | 0 | ... | 5.6d |
| Treatment control | 168.6e | 16.8 | ... | 5.6d |
| MPR (800) | 413.3d | 261.5 | 32.7 | 5.8c |
| MPR (1600) | 493.4cd | 341.6 | 21.4 | 6.2ab |
| MPR (3200) | 938.3b | 786.5 | 24.6 | 6.3a |
| TSP (800) | 484.6cd | 332.8 | 41.6 | 5.9bc |
| TSP (1600) | 557.8c | 406.0 | 25.4 | 6.0b |
| TSP (3200) | 2015.0a | 1863.2 | 58.2 | 6.0b |
| CV(%) | 10.11 | | | 2.56 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

The net dissolution at the rate of 3200 kg P/ha was 24.6 and 58.2% for MPR and TSP, respectively. Of the dissolved P only 1.3 and 2.9% of P from MPR and TSP, respectively was extractable by the Bray-1 method (Table 19). Therefore, a large proportion of the dissolved P became fixed. Tusekelege (1997) found that 28.9 and 59% of the applied MPR and TSP, respectively were dissolved in Sasanda soil. The

low amount of extractable P may probably be due to the high P fixation capacity of the soil. Sasanda soil being volcanic in origin is dominated by allophane which has high affinity for P (Moberg, 1981a). A comparison of the two amounts of P extracted by the two methods namely NaOH and Bray 1, indicated that NaOH extracted higher amounts than Bray 1 method (Tables 18 and 19). The differences in the amounts of extracted P by the two methods is due to fact that Bray 1 extracts only a fraction of soluble P considered to be available to plants while NaOH extract non occluded Al-P and Fe-P from the soil (Syers *et al.*, 1972). NaOH is used to estimate the amount of P dissolved from the applied P materials (Mackay *et al.*, 1986).

4.2.12 Change in soil pH after harvest

The effects of P sources and rates on soil pH are presented in Table 19. The soil pH values ranged from 5.2 to 6.3. Phosphorus application significantly increased soil pH over the control. The sources and rates of P application significantly affected soil pH. Minjingu PR significantly increased soil pH over TSP. Minjingu PR application increased soil pH while TSP application had slight effect on soil pH. The increase in soil pH with the application of MPR was attributed to MPR's liming effect. These results conform to those observed by Chien *et al.* (1987) who found an increase in soil pH in all PR treatments in an Oxisol as compared to the control.

4.3 Field experiment

4.3.1 Maize grain yield

Maize grain yield results for the field experiment are presented in Table 20. Phosphorus application significantly ($P = 0.05$) increased maize grain yield over the treatment control. All P rates and sources increased grain yield significantly and the trends were similar. Grain yield increased with increasing rate of P up to the standard P rate (1600 kg P/ha) for both sources of P. The rate of P 1600 kg P/ha gave less grain yield compared to the rate of 1600 kg/ha from both sources. Phosphorus application at the rate of 1600 kg/ha gave the highest grain yield of 2.97 t/ha, which was an increase of 77% when compared to treatment control. The slight decrease in grain yield at the highest rate of P may be attributed to nutrient imbalances. Further, the low grain yield despite the heavy dose of P could probably be due to the high P fixing capacity of the soil as indicated by low extractable P after harvest (Table 22). The results of the current study concur with those reported by (Semoka, J.M.R., 2003, personal communication; Mzee, 2001; Kadogholo 2001).

4.3.2 Phosphorus concentration

The results for the effects of phosphorus application on P concentration in maize leaves (earleaves at silking) are given in Table 20. Phosphorus concentration values

Table 20: Effects of P rates and sources on maize grain yield and P, N, K and Ca concentrations in ear leaf samples at Sasanda field experiment

| P rates and sources (kg/ha) | Grain yield (t/ha) | Nutrient concentration | | | | |
|--------------------------------|-----------------------|------------------------|---------|-------|-------|-------|
| | | P | N | Ca | K | Mg |
|(.....)(%)..... | | | | | | |
| Treatment control | 0.69d | 0.16b | 1.86a | 0.21a | 1.52e | 0.18a |
| MPR (800) | 2.16bc | 0.21ab | 1.7abc | 0.18a | 2.37b | 0.14a |
| MPR (1600) | 2.66ab | 0.22ab | 1.51cd | 0.22a | 2.37b | 0.14a |
| MPR (3200) | 2.50abc | 0.24a | 1.54bcd | 0.21a | 2.99a | 0.12a |
| TSP (800) | 2.00c | 0.21ab | 1.45d | 0.18a | 2.22b | 0.12a |
| TSP(1600) | 2.97a | 0.21ab | 1.75ab | 0.20a | 2.33d | 0.13a |
| TSP (3200) | 2.59abc | 0.24a | 1.54bcd | 0.22a | 2.41b | 0.12a |
| CV (%) | 14.87 | 4.85 | 7.25 | 11.12 | 13.33 | 10.28 |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

ranged from 0.16 to 0.24%P. Phosphorus application from sources, TSP and MPR slightly increased phosphorus concentration in maize leaves over the control. A significant increase in the content of phosphorus was observed at the rates of 3200 kg P/ha. Other P rates increased phosphorus concentration in plants slightly. There was no significant difference between sources of P on their effects on the concentration of P in plants. This indicated that, MPR was as effective as TSP despite their differences in composition. The content of P in plants was close to the adequate range of 0.2 to 0.3% P for ear leaf samples at silking (Tisdale *et al.*, 1993). Hence, plants were marginally supplied with P. The results are comparable to the findings

reported by Kadogholo (2001) and Babili (1999) that TSP and MPR are equally effective in increasing P content in plant leaves.

4.3.3 Nitrogen concentration

The data for nitrogen concentrations in leaves are presented in Table 20. The concentration ranged from 1.45 to 1.86%N. The treatment control had significantly higher nitrogen concentration compared to other treatments. Generally there was inconsistency in nitrogen concentration in plant leaves following P application for both sources. Further, the rate of 6400 kg P/ha from both TSP and MPR had equal effects on nitrogen concentration. This is consistent with the trend for P concentration indicating that the sources were equally effective. To some extent this is consistent with the grain yield. The low nitrogen concentration at the highest rate of P applied could probably be due to dilution effect and losses of N by leaching. The results of the current study conform to those reported by Kadogholo (2001). However, the nitrogen concentration for all treatments was below the sufficiency range of 2.8 to 3.5% N (Tisdale *et al.*, 1993).

4.3.4 Potassium concentration

The results for potassium concentration are presented in Table 20. The concentration ranged from 1.52 to 2.99% K. A significant increase in potassium concentration was realised at the rate of 6400 kg P/ha MPR. The rate of 6400 kg P/kg from MPR significantly increased the concentration of potassium in plants compared to the same rate of P from TSP. Furthermore, at all rates although not significant, MPR was

superior to TSP. This was attributed to the higher content of K in MPR than in TSP. Also better plant growth due to P supply exploited soil K more efficiently probably due to better root growth. However, plants from all experimental plots were adequately supplied with potassium (1.8 to 5.0%) in accordance with the rating of Marschner (1995) and Tisdale *et al.* (1993).

4.3.5 Calcium concentration

The data for calcium concentration are presented in Table 20. There was a general non-significant increase in calcium concentration in the earleaves. At the same rate of application, MPR was found to supply slightly higher Ca concentration than TSP. This was expected because MPR has high calcium content compared to TSP. These results conform to those found by Mnkeni *et al.* (1991). According to the rating by Tisdale *et al.* (1993) the plants were adequately supplied with calcium with critical range of 0.2 to 1.2%.

4.3.6 Magnesium concentration

The results of Mg concentration in maize plant as influenced by P rates and sources are presented in Table 20. The ranges of Mg concentration were 0.12 - 0.18%. Magnesium concentration value was slightly higher for treatment control than for the P treatments. Rates and sources of P had no effect on the concentration of Mg in maize earleaves. In general, all the Mg concentration values were within the lower part of the critical range of 0.15 - 0.45 % given by Tandon (1995).

4.3.7 Zinc concentration

The results for zinc concentration are presented in Table 21. The concentration ranged from 7.77 to 13.23 mg/kg. There were no significant differences in Zn concentration in maize earleaves between sources and rates of P. The treatment control has significantly higher zinc concentration than other treatments. Phosphorus application decreased zinc concentration further and all Zn concentration values were in the deficiency range (<20 mg/kg) basing on rating by Tisdale *et al.* (1993) and Tandon, (1995). The rate of 6400 kg/ha P decreased zinc levels to deficiency levels. Zinc deficiency might be one of the factors that limited maize grain yield. These results imply that application of nutrients in the right proportion is vital for optimising crop yield. Also these results indicate that P is not the sole limiting nutrient for crop production at Sasanda.

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Table 21: Effect of rates and sources of P on zinc concentration in plants in Sasanda soil

| P rates and sources (kg/ha) | Zinc concentration (mg/kg) |
|--------------------------------|-------------------------------|
| Treatment control | 13.2a |
| MPR (1600) | 9.7b |
| MPR (3200) | 8.7b |
| MPR (6400) | 8.1b |
| TSP (1600) | 7.8b |
| TSP (3200) | 8.7b |
| TSP (6400) | 8.6b |
| CV (%) | 16.7 |

Means followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

4.3.8 Residual Bray 1 P after harvest

The results for residual extractable P are presented in Table 22. Notable differences in available P status of the soil with different treatments of applied P were observed. Phosphorus application generally increased the level of available P content of the soil over the treatment control. This observation indicates an increasing availability of soil P with increased P rates. Triple super phosphate application at the rate of 6400 kg P/ha TSP significantly increased the amount of available P in the soil. The level of available P was significantly affected by the source of P. TSP gave a significant

higher residual value than MPR at the same rate of application. This could be attributed to its fast dissolution compared to MPR. The levels of extractable P from all treatments were very low according to Landon (1991) and Singh and Uriyo (1979). The low level of extractable P despite the high rates of P application might be attributed to many factors. These may include; uptake by plants, immediate fixation due to high affinities of soil colloids for phosphate ions. The amount of P remaining in soil is deficient according to Landon (1996) and Singh and Uriyo (1979) such that P application is necessary for the next cropping season. The results of the current study indicated that a large one-time P application might not be effective for correcting P deficiency and P capitalization on high P fixing soils. Therefore, a seasonal P application may be an alternative strategy for correcting P deficiencies in Sasanda than a one heavy dose of application.

4.3.9 Change in soil pH after harvest

The data for the effect of rates and sources of P on soil pH are presented in Table 22. Soil pH values ranged from 5.9 to 6.2. Phosphorus application significantly increased soil pH. As in the case of the pot experiment, the sources and rates of P affected soil pH. Minjingu PR influenced soil reaction more than TSP. This was attributed to high liming effect of MPR compared to TSP due to their differences in Ca contents (27.86 and 16.79% CaO for MPR and TSP, respectively) (Tusekelege, 1997).

4.3.10 MPR and TSP dissolution after harvest

The sodium hydroxide extractable P results are presented in Table 22. The amount of phosphorus extracted by sodium hydroxide indicates the extent of dissolution of the applied P fertilizer was very low despite the inability of NaOH to dissolve substantial amount of the P fertilizer applied (Syers, 1972). The extent of dissolution of residual P from the highest rate (6400 kg/ha) of P applied was 15.63 and 34.01% while the corresponding Bray 1 P levels were 1.39 and 2.31 mg P/kg soil for MPR and TSP, respectively.

Table 22: Bray 1 P, Soil pH and TSP and MPR dissolution at Sasanda field experiment determined after harvest

| P rates and sources (kg/ha) | Bray-1 P (mg/kg soil) | Soil pH | NaOH-P (mg/kg) | Δ NaOH-P (mg/kg) | NaOH- P (% of applied P) |
|--------------------------------|--------------------------|---------|-------------------|----------------------------|------------------------------|
| Treatment control | 0.56d | 5.9b | 168.4c | 0 | |
| MPR (1600) | 0.73cd | 6.0ab | 242.3bc | 73.8 | 18.5 |
| MPR (3200) | 0.86cd | 6.1ab | 224.7bc | 56.3 | 7.0 |
| MPR (6400) | 1.39b | 6.2a | 250.1bc | 81.7 | 5.1 |
| TSP (1600) | 1.05bc | 6.1ab | 305.2b | 136.8 | 34.2 |
| TSP (3200) | 1.35b | 6.1ab | 307.0b | 136.6 | 17.1 |
| TSP (6400) | 2.31a | 5.9b | 544.2a | 375.6 | 23.5 |
| CV (%) | 20.55 | 2.27 | 16.38 | | |

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test at 0.05 level of significance.

This indicates that 94.9 and 76.5% of the dissolved P was not in available form. Mwakisimba (1999) found that 92.7% of the residual P from MPR in Sasanda soil was also not extractable by the Bray 1 method. Furthermore, Tusekelege (1997) found that only 12.6% of the applied MPR was extracted by NaOH for Sasanda soil while Wright *et al.* (1992) reported a value of 22.3% in one soil to which North Carolina PR was applied. The low extent of dissolution of the residual P might be attributed to many factors such as P rates, soil pH, soil moisture, soil solution P, soil solution Ca and properties of the P applied. In addition increase in soil pH might have also contributed to low dissolution of MPR. It has been reported by Hammond *et al.* (1986) that PR fertilizers dissolve more in acid soils than in neutral or alkaline soils. Joos and Black (1955) reported that more P was released from PR in soil with pH 4.6 and 5.6 than at pH 6.6. Also several studies have indicated that soil Ca concentration is an important factor controlling the dissolution of PR in soils. Mnkeni *et al.* (1992) and Sale and Monkwenye (1993) reported that low Ca concentration in the soil solution enhances PR dissolution. This is due to the law of mass action whereby low Ca in the soil solution favours release of P from PR. Mwakisimba (1999) working on eleven soils reported a decrease in the dissolution of Minjingu PR from 92.4% at pH 4.8 to <30% at pH 5.8 after 56 days of incubation. Most of the dissolved P was fixed as shown by the very low amount of P extracted by Bray 1 (Table 20). The low amount of extractable P may probably be due to high fixation capacity of the soil. Sasanda soil being volcanic in origin is dominated by allophanes which has high affinity for P (Moberg, 1981a). Nsenga, (2001), Syers *et al.* (1992) and Mackay and Syers (1986) reported that soils with high adsorption

maxima had low available P from PRs in agreement with the results of the current study.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results obtained in this study, have shown that,

1. Both TSP and MPR were equally effective and good sources of P for the studied soils except that MPR was found to be less effective on increasing extractable P in Sasanda soil in glasshouse conditions. Under field conditions both TSP and MPR gave low levels of available P as it was below the established critical levels. Also in the high P fixing Sasanda soil, even the high rate of P failed to optimise grain yield. This was attributed to the high P fixing capacity of Sasanda soil.
2. Both TSP and MPR significantly increased DM yield, P concentration and uptake and grain yield. Rates of 160, 400 and 3200 mg P/kg soil of MPR and TSP performed better than the low rate in all the three soils tested in this study for pot experiment. However, TSP was superior to MPR in Nkundi and Sasanda soils while for Magadu soil, MPR at standard P rate gave significantly high DM yield than TSP.
3. A large, one-time application of P on severely P deficient soils with high P fixing capacity corrected P deficiency for the current crop but it did not result in increased residual P for the next crop.
4. In the field experiment, application of MPR and TSP at a rate equal to the standard P requirement significantly increased grain yield over half this rate or double this rate.
5. Soil properties and climatic factors have significant effect on the effectiveness of P sources particularly MPR.

5.2 Recommendations

From the results of this study it is recommended that;

1. MPR should be used as an alternative source of P to TSP because of the possibility of better economic returns and better effects on some soil properties such as pH and exchangeable calcium.
2. Application of 320 and 400 kg P/ha on Nkundi and Magadu, respectively can be used for optimum crop yield on the basis of pot experiment results. However, these rates should be confirmed under field conditions.
3. A large, one-time application of P is not an appropriate strategy of P capitalization in soils with high P fixing capacities. Gradual seasonal P application can be a good strategy for correcting P deficiency in soils.
4. Further studies should be undertaken to find out the most affordable and economically justifiable rate for Sasanda soil.

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