ASSESSMENT OF SOIL FERTILITY STATUS OF THREE SOILS AFTER FOUR YEARS OF CONTINUOUS APPLICATION OF DIFFERENT NUTRIENTS

BY

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ABSTRACT

A study was undertaken to assess the fertility status of three soils following four years of continual application of different nutrients. The three soils were from Mlingano, Nkundi and Sasanda, which are classified as *Rhodic Kandiustox*, *Acruoxic Kandiustult* and *Dystrict Haplustand*, respectively. The study was conducted under both field and glasshouse conditions. For the pot experiment conducted at the SUA glasshouse all three soils were used whereas field experiment was conducted only at Nkundi site. Soils for pot experiment were taken from absolute control plots and from plots treated with TSP and MPR at the rate of 120 kg P/ha. Under field study one more treatment, namely control for P was included. The results showed that application of different nutrients, except nitrogen, led to build up in levels of applied nutrients. Application of MPR or TSP increased levels of Bray 1-P from low to medium and high levels, respectively, in Nkundi and Mlingano soils. In Sasanda soil, Bray 1-P remained below 5 mg P/kg despite application of TSP and MPR. This was attributed to high P fixation capacity of Sasanda soil. In Nkundi soil, MPR application raised Bray 1-P from 5.0 mg P/kg to 41.7 mg P/kg whereas in Mlingano soil Bray 1-P was raised from 2.6 mg P/kg to 39.4 mg P/kg. Application of TSP raised Bray 1-P to above 105 mg P/kg in Mlingano and Nkundi soils but only to 4.7 mg P/kg in Sasanda soil. Zinc and copper increased to sufficient levels in all soils due to application of zinc sulphate and copper sulphate fertilizers. Use of TSP or MPR decreased soil pH in Mlingano and Nkundi soils but the decrease was less in soil treated with MPR. For instance in Mlingano soil, pH decreased from 5.5 to 5.4 and 5.0 for soils treated with MPR and TSP, respectively. However in Sasanda soil MPR increased soil pH from 5.0 to 5.3 and there occurred no shift in pH in plots treated with TSP. Residual P increased significantly ($P = 0.05$) the maize dry matter and grain yields in plots treated with TSP and

MPR. The increase in dry matter and grain yields due to residual P from MPR and TSP were comparable. In Mlingano and Nkundi soils, dry matter yields ranged between 7.29 and 64.77 g/pot whereas in Sasanda soil it ranged between 2.12 and 22.10 g/pot. At Nkundi site, residual P from MPR and TSP gave yields of 4.23 and 4.73 t ha^{-1}, respectively. Yield in absolute control and control for P treatments were 1.03 and 1.83 t ha^{-1}, respectively. It was concluded that residual P from MPR and TSP had comparable effects on maize production.

DECLARATION

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

Signature.................................... Date..15TH JULY, 2004..........................

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Rejoice in the Lord always, again I will say Rejoice. Let all men know your forbearance. The Lord is at hand. Not that I complain of want; for I have learned, in whatever state I am, to be content. I know how to be abased, and I know how to abound; in any and all circumstances I have learned the secret of facing plenty and hunger, abundance and want. I can do all things in Him who strengthens me (Philippians 4: 4-5; 11-13). I dedicate this work to God and his only beloved Son Jesus Christ. Even though I am weak in flesh and sprit, they have hiked me to height I could otherwise not reach in my own. Praised is the Holy Trinity.

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LIST OF SYMBOLS AND ABBREVIATIONS

AAS:	Atomic absorption spectrophotometer
aq:	Aqueous
CEC:	Cation exchange capacity
CV:	Coefficient of variation
DTPA:	Diethylenetriaminepentacetic acid
ex:	Exchangeable
MPR:	Minjingu phosphate rock
NH_4OAc:	Ammonium acetate
OC:	Organic carbon
PARP:	Partially acidulated rock phosphate
pH:	Negative logarithm of hydrogen ion concentration
SA:	Sulphate of ammonia
SUA:	Sokoine University of Agriculture
TSP:	Triple superphosphate
USDA:	United States Department of Agriculture
TSP:	Triple superphosphate

CHAPTER ONE

1.0 INTRODUCTION

The soil fertility of fields under cultivation deteriorates from one cropping season to another due to little or no use of fertilizers. It is generally accepted that in practice the removal of nutrients from agricultural ecosystems exceeds natural replenishment and that mineral fertilizers have to play a key role in areas where increased agricultural production is required. Due to continual removal of soil nutrients by crops, soil erosion, leaching and other processes, soils gradually become deficient in one or more nutrients (Tandon, 1994). The reaction of the farmers to the decline in soil fertility has been to practice shifting cultivation where land is not scarce or to supply additional nutrients by using fertilizers and manures. Restoring, maintaining, and increasing soil fertility are major agricultural priorities particularly in the many parts of the developing world where soils are inherently poor in plant nutrients and the demand for food and raw materials is increasing rapidly (FAO, 1998).

Fertilizers that are commonly used worldwide to supplement nutrients in infertile soils are those that supply nitrogen, phosphate, and potash. Farmers prefer fertilizers that exhibit considerable response by crops within a short time after their application. These are usually those that supply mainly nitrogen to the soils. The three nutrients N, P and K are often the most limiting in many soils, in the order N > P > K. Tisdale *et al.* (1993) stated that nitrogen is an important plant nutrient and is the most frequently deficient of all nutrients. The low nitrogen supplying power of soils calls for large additions of nitrogen fertilizer to soils to meet the nitrogen needs of high yielding non legume crops (Foth, 1990). In the early years of use of a soil for agriculture, the first nutrient to be depleted is likely to be nitrogen and for most plants a large supply of nitrogen is needed. Since nitrogen in the soil is normally transient after breakdown of organic matter, external supply of nitrogen is a must except, to some extent, for legumes (FAO, 1995). It is not surprising, therefore, that in many developing countries (Tanzania included), N fertilizers were the first to be used and are still predominant (FAO, 1995).

Phosphorus is the second most limiting nutrient. Phosphorus availability to plants is affected by soil pH. Tisdale *et al.* (1993) stated that in strongly acid or alkaline soils P availability was reduced and that P availability was at a maximum in the pH range 5.5 to 6.5. Highly leached soils such as Oxisols are normally acidic in nature. Oxisols are common in nearly all regions of Tanzania (Uriyo *et al.*, 1979). The Oxisols are characterized by an oxic horizon. Most oxic horizons react with phosphate ions in such a way that they may either adsorb them or chemically bind them on sesquioxidic surfaces (Wambeke, 1992). As for the Andisols, fixation of phosphorus has been reported. According to Miller and Donahue (1995) the efficiency of added fertilizer phosphorus is often less than 10%. They ascribe this phosphorus problem to high content of amorphous Al and Fe clays. In Tanzania, Andisols are found in areas of volcanic activity such as in Mbeya, Kilimanjaro and Arusha regions. Recent attention on studying Minjingu Phosphate Rock (MPR) to be an alternative for highly priced triple superphosphate (TSP) is evidence of the need of phosphorus fertilizers in the soils of Tanzania.

These fertilizers, N, P, and K, are not the only ones needed for good plant growth. Rather, the list of the essential nutrient elements is much longer. Many soils in the tropics are known to be deficient in N and P, and these and other limiting nutrient elements like Cu, Mg, Zn have been continually added in soils at the experimental sites of the Phosphate Rock Utilization Project at Mlingano, Nkundi and Sassanda for the past four years. In the experiments two sources of P, namely TSP and MPR have been used. They have been applied in different plots at varying rates and combinations. The performance of two forms of MPR, namely powder and granulated have been studied and compared to TSP as a standard source. However residual effects of MPR have not been evaluated.

Once applied some of the nutrient elements, like phosphorus and some micronutrients, may remain in soil for a long time and may continue to benefit subsequent crops. It is of interest to determine the quantities of such nutrients in the soil after continual application over several years, so as to record the pattern or trend of nutrient build-up. It is also important to monitor other nutrients that were applied to assess changes that have taken place over the cropping period. The findings from such studies will guide in making subsequent recommendations for proper maintenance and even build-up of soil fertility. Thus, the research was conducted to gauge the extent of changes in the levels of selected nutrients in three soils after application of various nutrients for four years.

The overall objective of this study was to assess changes in soil fertility of three soils, namely an Oxisol, an Ultisol, and an Andisol, that have been fertilised with different nutrients and cropped with maize for four years.

The specific objectives of this study were:

i. to determine the current levels of N, P, K, Ca, Mg, Cu and Zn in the three soils,

ii. to determine the effect of applied nutrients on other soil properties such as soil pH, exchangeable bases, cation exchange capacity, organic carbon, and

iii. to assess the adequacy of these nutrients (N, P, K, Ca, Mg, Cu and Zn) for maize growth.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Levels of N, P, K, Ca, Mg, Zn and Cu in soils and plants

Nitrogen (N) is one of the most important plant nutrients and the most frequently deficient of all nutrients (Tisdale *et al.*, 1993). The low nitrogen supplying power of soils calls for large additions of nitrogen to soils as fertilizers to meet the nitrogen needs of high yielding non leguminous crops (Foth, 1995). The quantity of nitrogen in surface soils generally ranges from 0.02 to 0.25% and is closely related to the amount of soil organic matter which makes up approximately 5% (Bear, 1965). Plants normally contain between 1 and 5% N by weight (Tisdale *et al.*, 1993).

Phosphorus is second only to nitrogen in frequency of use as fertilizer element (Trohel and Thompson, 1993). Plants utilize phosphorus in the forms of HPO_4^{2-} and $H_2PO_4^-$ Soils generally contain 0.02-0.2% mean total P (Brady and Weil, 2000). For most plant species the total phosphorus content of healthy leaf tissue is usually between 0.2 and 0.4% of the dry matter (Brady and Weil, 1996).

Potassium in the soil occurs as potassium ions in mineral structure and as hydrated potassium ions either in solution or adsorbed on cation exchange sites (Trohel and Thompson, 1993). There is a wide range in the potassium content of soils and availability of potassium for plant growth. The potassium content expressed as K_2O, ranges between 0.05 and 3.5% for mineral soils (Bear, 1964). The potassium requirements for optimal plant growth is approximately 2-5% of the dry weight of the vegetative parts, flesh fruits, and tubers (Marschner, 1986). The content of potassium in maize plants ranges between 1.75 and 2.85% (Robert, 1998).

Magnesium constitutes 1.93% of the earth's crust; however, the Mg^{2+} content of soils is variable, ranging from 0.1% in coarse, sandy soils in humid regions to 4% in fine textured, arid or semi arid soils formed from high magnesium parent materials (Tisdale *et al.*, 1993). Magnesium is absorbed by plants as Mg^{2+} from the soil solution (Tisdale *et al.*, 1993). The magnesium requirement for optimal plant growth is in the range of 0.15 to .35% of the dry weight of the vegetative parts (Marschner, 1995). According to Campbell and Plank (2000), magnesium content in maize plants ranges between 0.15 and 0.60%.

Calcium deficiency is uncommon but can occur in highly leached and unlimed acid soils (Tisdale *et al.*, 1993; Foth, 1990). A level of 15 mg/kg in soil is adequate for high maize yields. Plants absorb calcium as Ca^{2+}, and its concentration in plants ranges from 0.25 to 0.80% (Campbell and Plank, 2000).

Total zinc in soils is very variable depending on the nature of parent materials, clay content and soil type. In the soils of India, for example, Tandon (1995) reported total zinc values ranging from 2 to 1600 mg/kg but in most cases it is within 10 to 300 mg/kg. The content of zinc in maize plants ranges between 20 and 70 mg/kg (Campbell and Plank 2000).

Copper exists in soils mostly as cupric ions (Cu^{2+}) and less as cuprous (Cu^{+}) ion (Miller and Donahue, 1995). Its concentration in soils ranges from 1 to 40 mg/kg and averages about 9 mg/kg (Tisdale *et al.*, 1993). The average total copper concentration in the earth's crust has been estimated to be 70 mg/kg and its total content in soils as 2 to 100 mg/kg (Hodgson, 1963). The critical deficiency level of copper in vegetative parts is generally in the range of 3 to 5 mg/kg dry weight (Marschner, 1986). The content of copper in maize plants ranges between 5 to 25 mg/kg at tasseling (Campbell and Plank, 2000).

2.2 Soil factors affecting soil fertility

There are several factors that affect soil fertility. They include soil and climate factors. These are now briefly reviewed.

2.2.1 Soil pH

Soil pH has a profound effect on nutrient availability and, hence, soil fertility (Uriyo *et al.*, 1979). Soil pH influences the rate of plant nutrient release by weathering, the solubility of all materials in soil, and the amounts of nutrient ions on the cation exchange sites (Trohel and Thompson, 1993). Change in soil pH may or may not favour the availability of a given nutrient element. Hynes and Swift (1985) reported a decline in 0.1M HCl and 0.05M DTPA extractable Cu as soil pH increased due to liming. The best pH range for boron availability was reported by Mengel and Kirkby (1982) to be 4.5-6.5. The amount of HPO_4^{2-} and $H_2PO_4^-$ present in soil depends on soil pH (Tisdale *et al.*, 1993) with the pH range of 6.5 to 7.0 being usually optimum for phosphorus availability (Trohel and Thompson, 1993). At extreme pH levels, P is either fixed or precipitated. Studying the response of maize to applied magnesium in strongly acid tropical soils of Australia, Hailes *et al.* (1997) obtained results that showed large responses to magnesium application. They found the pH range suitable for most agricultural crops to be 5.5-7.5.

2.2.2 Soil organic matter

Organic matter influences many soil biological, chemical and physical properties that favourably influence nutrient availability (Tisdale, *et al.*, 1993). Soil organic matter acts as a conditioner, by improving soil structure, moisture content and ion retention, besides being an important source of some nutrient elements (Uriyo *et al.*, 1979). The only important natural source of nitrogen in the soil is organic matter (Davies *et al.*, 1993). The organic fraction of P generally constitutes 20 to 80% of total phosphorus in surface horizons (Brady and Weil, 1996). Organic matter may as well have negative effect on the availability of nutrients to plants. Copper deficiency is often associated with high levels of organic matter (Davies *et al.*, 1993). A large portion of copper is retained in soil organic matter as highly stable organo-copper complexes making this Cu fraction not readily available to plants. Due to this behaviour, Cu availability normally tends to decrease with increase in soil organic matter content (Hodgson *et al.*, 1965). Stevenson and Ardakani, (1972) reported that generally zinc associated with the soluble fraction of organic matter, such as organic acids and amino acids, is readily available whereas that associated with humic acids is less available.

2.2.3 Cation exchangeable capacity

The cation exchange capacity is a measure of the soil's ability to retain cationic nutrients. It measures the quantities of sites on soil surfaces that can retain positively charged ions by electrostatic forces (Riffald *et al.*, 1994). The positively charged ions include Ca^{2+}, Mg^{2+}, K^{+}, NH^{+}, Na^{+}, and Mn^{2+} (Mwinuka, 2001). Also Fe^{2+} and Cu^{2+} are positively charged ions but their quantities are too small to be considered (Biswas, 1987). These positively charged ions are easily exchangeable with other cations in the soil solution and thus readily available for plant uptake. Therefore the exchangeable cations determine, to a large extent, the chemical and physical properties of soils (Biswas, 1987). According to Landon (1991), the higher the CEC the more the fertile and productive the soil is.

Soil texture, organic matter, clay content and type, and soil pH are among factors that affect CEC. Fine textured soil tends to have higher CEC than coarse textured ones. Motavalli *et al.* (1995) reported that CEC increased with increase in soil pH.

2.2.4 Nutrient interactions

The availability of one nutrient may be affected by the amount of other nutrient elements in the soil. It has been reported that the amount of available potassium in soil affects the ability of plants to extract magnesium. Excessive amounts of K reduce its uptake and it is possible to induce or aggravate magnesium deficiency by the liberal use of potash (Davies *et al.*, 1993). Antagonism exists between phosphorus and zinc. Application of phosphorus fertilizers at high rates has been found to reduce zinc availability in soils, especially when levels of zinc are only marginally sufficient (Barow, 1987; Mackenzie and Xie, 1988; Tsidale *et al.*, 1990; Foth, 1990). However some of the antagonistic effects may be used effectively in reducing toxicities of certain micronutrients. For example, adding iron and phosphate fertilizers (Brady and Weil, 1996) may reduce copper toxicity of citrus groves caused by residual copper from fungicidal sprays.

2.2.4 Soil type

Levels of nutrients may differ from one soil type to another. Soils inherit the different minerals from their parent materials. These minerals have a wide variety of chemical compositions and a wide range of weathering rates (Trohel and Thompson, 1993). Total zinc content in basic eruptive rocks (basalt and gabbro) ranges from 70 to 130 mg/kg while metamorphic rocks (schist) and certain sedimentary rocks (clays) have about 30 mg/kg (Aubert and Pinta, 1977). The availability of P in Andosols is likely to be a problem. These soils rapidly adsorb and precipitate phosphorus (Miller and Donahue, 1995). Oxisols on the other hand, are characterized by low exchangeable nutrients (Foth, 1990). Therefore supply and availability of nutrients to plants differ from soil to soil.

2.3 The sources of nutrients in soils

2.3.1 Weathering of rocks and minerals

Nutrient elements are released into the soil following weathering of rocks and minerals. For instance, inorganic phosphorus is released after disintegration of the rocks containing apatites (Uriyo *et al.*, 1979). Biotite, chlorite and olivine minerals are rich in magnesium. On the other hand, disintegration of dolomite, gypsum, calcite, feldspar and amphiboles, apart from other nutrients, contribute a lot to soil calcium (Foth, 1990). However decomposition and disintegration of minerals and organic matter occur slowly over a long period and nutrients are released gradually (Trohel and Thompson, 1993). The rate of nutrient release depends on the nature of parent materials, climate and other soil forming factors. Therefore, levels of nutrients in soils will differ depending on their parent materials and extent of weathering.

2.3.2 Fertilizer additions

The main nutrients applied routinely as fertilizers to agricultural soils are N, P, and K (Hynes and Naidu, 1998). World wide nitrogen fertilizers are more heavily used than the others. This is due to the fact that in most of the agricultural systems, soil N supply is below the minimum requirement of crops, to reach maximum yield (Galvis-spinola *et al.*, 1998). However the nutrient and rate at which it is applied is based on soil testing and the requirement of the crop to be grown. All nutrients ought to be supplied in sufficient levels to meet optimal crop performance. If the soil can not supply them then they are to be supplied through fertilization. According to FAO (2000), application of N, P, and K should include other nutrient elements such as Ca, Mg, S, and micronutrients where necessary.

2.3.3 Crop residues

The harvested crops contain some amount of nutrients extracted from soil. Large quantities of nutrients in harvested parts of crops have been reported. At Lyamungu in Kilimanjaro, Tanzania, Vaje *et al.* (1999) observed that maize stems contained an average of 46 kg N/ha at harvesting. If the same is returned into the soil some of the contained nutrients are released. The release of nutrients will depend on residue management and C: N ratio of the residues. The proportion of phosphorus cycled back to the soil in grain crops, assuming all residues are returned into the soil, is in the order of 40%, in contrast with about 50 to 70% for N and 90% for K (Sanchez *et al.*, 1997).

2.4 Nutrient losses from soils

2.4.1 Crop removal

Declining soil fertility due, largely, to poor crop residue management is a basic agricultural problem in the many developing countries (FAO, 1990). Gebrekidan *et al.* (1999) reported that the harvested produce is the major avenue of nutrient removal, particularly in annual agricultural crops. It is estimated that on average grain crops remove 100 to 150 kg/ha of N, P, and K (FAO, 1990). Smaling and Fresco (1993) found that plant uptake was the main contributor to the loss of 55 kg N ha^{-1} yr^{-1} in Kisii district of Kenya. A typical maize crop in smallholder African farm yields less than 1 t ha^{-1} and requires a plant accumulation of less than 40 kg N ha^{-1}; a crop of 4 t ha^{-1} requires 100 kg N ha^{-1}, and a 7 t ha^{-1} of maize requires 200 kg N ha^{-1} (Sanchez, 1976). Sanchez *et al* (1997 estimated that at least two-third of this nitrogen is contained in the grain and will be exported during harvest.

2.4.2 Leaching

Water percolating through the soil profile carries with it dissolved nutrient elements and this is more prevalent in areas with high rainfall but almost absent in arid areas. Percolation losses are influenced by the amount of rainfall and its distribution, by runoff from the soil, by evaporation, by nature of the soil and vegetation (Brady and Weil, 1996). The form of a fertiliser matters in relation to leaching. Nitrogen in the form of NO_3^- is highly mobile in the soil, and generally follows the flow of water (Benson *et al.*, 1992). Phosphates are more strongly bound to the soil particles and are not generally lost through water movement (Swensen, 1997). Therefore little or no P is leached (Barrow, 1980). Consequently, for most soils, the P applied as fertilisers remains near the soil surface when minimum tillage methods are used to sow crops or it is only incorporated through that portion of the top soil that is cultivated. The extent of loss of nutrients through leaching also depends on the source of fertilizer. Superphosphate is reported to leach more than rock phosphate. This is why phosphate rock and partially acidulated rock phosphate (PARP) fertilizers have been suggested as possible alternative to superphosphate for P leaching soils in high rainfall areas (over 750 mm per annum) of South Western Australian (Yeates *et al.*, 1984). Generally nutrients leach from soil solution having been displaced from exchange sites by other nutrients. In coarse textured soils leaching may be higher than in heavy textured soils.

2.4.3 Soil erosion

Nutrients are lost when the soil is eroded. The extent of nutrient loss depends on its ability to fix on colloidal surface. Ammonia and phosphates are more strongly bound to soil particles and are not generally lost through leaching or surface runoff (Swensen, 1997). The amount of erosion greatly affects the loss of NH_4^+ and P (Vaje *et al.*, 1999). A study in

Kisii, Kenya, showed that leaching caused loss of 41 and 0 kg ha^{-1} yr^{-1} while the erosion losses were 37 and 10 kg ha^{-1} yr^{-1} for N and P, respectively (Vaje *et al.*, 1999). How much is lost depends on the extent of soil erosion. Accelerated soil erosion affects the soil both physically and chemically (Hajek *et al.*, 1990). Increase in nutrient levels may be observed in the site receiving the eroded soil.

2.5 Residual effect of fertilizers

Nutrients applied in fertilizers may not be completely utilized by the current growing crops. Where nutrients have been applied, a certain portion of these nutrients may be left in the soil after harvesting. The amounts remaining depend on the type of fertilizer, the amount added, the yield, the portion of the crop harvested, and the soil. According to Miller and Donahue (1990), in general fertilizer usage, the expected efficiencies are approximately 30 to 70% of added nitrogen, 5 to 30% of added phosphorus and 50 to 80% of added potassium. Results of numerous field and greenhouse experiments, in contrast, have shown that crop recovery values for micronutrients generally range from only 5 to 10% (Mortvedt, 1994).

A marked residual effect has been reported with P fertilizers. When P is applied to the soil, only a small percentage is taken up by plants; the remainder is either permanently or temporarily fixed in forms varying in plant availability (Moughli *et al.*, 1999). The source of a fertilizer is important as far as residual effect is concerned. For instance, Sale and Mokwunye (1993) reported the superiority of residual effects of finely ground phosphate rocks to water soluble phosphate fertilizers in Oxisols of the tropics. At Mlingano in Tanga, Tanzania, Minjingu rock phosphate showed higher residual effect than water-soluble fertilizers (Mowo, 2000). He ascribed the higher residual effects to the continuing dissolution of the phosphate rocks compared to the declining availability of P from the residues and reaction products of the water-soluble P sources over time. However in lateritic soils in south-western Australia, Bolland *et al.*, (1988) reported superiority of residual effectiveness of superphosphate to both granular reactive and partially low reactive phosphate rocks. These soils are sandy and the area is characterized by heavy rain, which causes leaching of highly soluble phosphate fertilizers.

The texture of the soil also has contribution to residual effects. For instance, even though in Australia superphosphate has proved to be better than phosphate rocks, there are some exceptions due to soil textures. Bolland and Gilkes (1990) reported such an exception in sandy and acid soils in areas with over 800 mm annual average rainfall. These soils have extremely low capacities to retain phosphorus. Phosphate rock fertilizers have been considered as substitute for superphosphate on these soils with the aim of reducing losses of phosphorus from the soil due to leaching (Bolland and Gilkes, 1990). The water soluble P from superphosphate is rapidly leached out of reach of plant roots and this P mostly is not utilized by annual plants growing on these soils (Yeats *et al.*, 1984; Yeates *et al.*, 1986).

The duration of crop yield response to P applications depends on the amount of P applied, the soil's P sorption, and cropping intensity. The larger the P application rates the longer the residual effect while low P sorbing soils have short residual effects. The higher the number of crops (cropping seasons) harvested per year the shorter the residual effect (Sanchez *et al.*, 1997). For instance, Adetunji (1994) studying phosphorus requirement of a maize-cowpea sequential cropping on a paleudult found that phosphorus uptake decreased with cropping in plots that received only one application of P, even though there was a significant increase over control. Maize grain yields also decreased with number of cropping. At an application rate of 75 kg P ha^{-1}, in 1990 maize grain yields were 3.04 t ha^{-1} and in 1991 and 1992 were 2.52 t ha^{-1} and 2.38 t ha^{-1} respectively. At an application rate of 30 kg P ha^{-1}, maize grain yields were 2.44, 1.65 t ha^{-1} and 1.10 t ha^{-1} in 1990, 1991 and 1992 respectively. Residual effects decreased with increase in number of cropping and decrease in rate of application. With P applied only in the first year, Adetunji (1994) also observed that Bray 1-P was higher for higher rates of application at the third year of cropping. From an initial of 4.0 mg P/kg, Bray 1-P values at third year were 1.5, 6.5, 8.2 and 8.4 mg/kg for rates of 0, 30, 45 and 75 kg P ha^{-1}.

Residual effects have been observed on micronutrients such as copper and zinc. According to Boawn (1971), residual effects of zinc fertilizers are substantial, with crop responses reported for at least five years after application. Singh *et al.* (1995) found that in control plots zinc declined with number of crops. They also observed that addition of phosphate fertilizers resulted in a build up of soil zinc status. The build up was more at higher rates of application of phosphate fertilizers. However use of nitrogen alone or in combination with potassium at increasing levels decreased the content of available zinc. Accumulation of available zinc generally occurs with annual application of zinc fertilizers (Mortvedt, 1994). In most cropping situations, application of 11.25 kg Zn/ha can be effective for three to five years (Tisdale *et al.*, 1993).

Build up of copper has been observed especially in soils with high content of organic matter. In such soils Cu is strongly complexed by soil organic matter. Leaching of Cu in soils is negligible (Jones and Belling, 1967). Because copper does not leach from soils, copper accumulations are evident with repeated Cu applications. Removal of Cu from soils is small compared to that which may be added in fertilizers (Gartrell, 1981). Therefore Cu would have a long residual effectiveness in soils (Gartrell, 1980). The marked residual effects of Cu fertilizers allow growers to apply higher rates only periodically (Mortvedt, 1994). For example, one application of 3 to 5 kg ha^{-1}of copper as $CuSO_4$ or finely ground CuO will correct deficiencies and may be sufficient for several subsequent years (Kidder and Rhue, 1983).

2.6 Effects of continuous fertilizer use in soils

Continuous use of fertilizer may have both positive and negative effects on some soil properties. Soil acidification caused by routine fertilization has been reported in different parts of the world. Application of ammonium nitrate, ammonium sulphate and urea is known to decrease soil pH (Bowman *et al.*, 1995; Mahler *et al.*, 1985). The pH levels may be lowered to levels deleterious to crop growth (Rasmussen and Rohde, 1989). The use of ammonium based fertilizer may not be avoided especially when phosphate rock is used in low pH soils. This is because phosphate rocks perform well when applied in soils which have low pH (Kanabo and Gilkes, 1987) and high amount of reserve acidity (Bolland and Gilkes, 1990). Phosphate rocks contain 30 to 50% CaO and thus increase the availability of calcium in the soils, increase pH and lower exchangeable Al content (FAO, 1986). Chase *et al.* (1994) indicated that calcium might displace other bases already present on the exchange sites as illustrated below:

$$Ca^{2+}_{(aq)} + 2K_{(ex)} \rightleftharpoons Ca_{(ex)} + 2K^{+}$$

Thus liming can increase the soil solution activity of bases other than calcium (Edmeades *et al.*, 1985). The bases in solution may be lost through leaching in places with high rainfall conditions. High pH leads to increased CEC (Pratt, 1961). If the increase in CEC is appreciable, then net displacement of exchangeable bases is negligible or even negative (Edmeades *et al.*, 1985).

Continuous applications of fertilizers may affect soil organic carbon. Fertilizer additions either as a single or combination of two or three nutrients contribute towards accumulation of root biomass and ultimately maintain or lead to increase in organic carbon (Singh *et al.*, 1995). Kapur *et al.* (1986) reported increase in organic carbon content of the soil with continuous fertilizer application for three years in maize-wheat sequence in a loamy sand soil.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental locations and soil sampling

Soils from three experimental sites, namely Nkundi, Mlingano and Sasanda were sampled for soil analysis and pot experiments. Szilas (2000) classified these soils as *Acruoxic Kandiustult*, *Rhodic Kandiustox* and *Dystric Haplustand*, respectively. Mlingano site is located in Muheza district in Tanga region. Nkundi site is in Nkansi distric in Rukwa region whereas Sasanda site is located in Mbozi district in Mbeya region.

The soil samples were collected from plots that for four years had been treated with the highest levels of triple superphosphate (TSP) and powder Minjingu rock phosphate (MPR) and from absolute control plots. The highest levels of TSP and powder MPR were 120 kg P ha^{-1}. The sampling was done within the rooting depth of up to 20 cm. Sampling points at each site were established at random. The collected samples were air dried and sieved to pass through a 2 mm sieve ready for laboratory analysis and pot experiment.

3.2 Pot experiment

Residual effects of the two sources of P, namely triple superphosphate and powder Minjingu phosphate rock, were determined in the glasshouse at Sokoine University of Agriculture. For all of the three sites, soil samples used were those from absolute control plots and from plots which had been treated with highest levels of TSP and MPR (120 kg P ha^{-1}). Four kilograms of soil samples were weighed into plastic pots. These were then thoroughly mixed with predetermined amount of nutrients to attain their sufficient levels. Nitrogen fertilizer was added to all soils. Zinc was added to Nkundi and Sasanda soils.

Copper and magnesium were added in soil obtained from Sassanda while potassium was added to Nkundi and Mlingano soils. Nitrogen, potassium, magnesium, zinc, and copper were added to the soils at the rates of 200 mg N kg^{-1}, 200 mg K kg^{-1}, 100 mg Mg kg^{-1}, 10 mg Zn kg^{-1} and 10 mg Cu kg^{-1}, respectively. The decision to add some or all of these nutrients and the amount to be applied in a given soil was based on the experience gained in the past four years of study on the adequate levels of the same in these soils. These are the same nutrients that were used in the field studies in respective soils. Nitrogen, potassium, magnesium, zinc and copper were applied as sulphate of ammonia, muriate of potash, magnesium sulphate, zinc sulphate and copper sulphate, respectively.

There were four replications for each treatment. Moisture content of the soils in the pots was maintained at field capacity by timely application of distilled water to replenish that lost due to evapotranspiration. The plastic pots had drainage holes at the bottom, which were plugged with cotton wool to prevent water loss during watering. The experimental design adopted was a completely randomised design with four replications. The treatments were designated as shown below for all three soils:

(i) **Control**: Soil obtained from absolute control plots but all limiting nutrients applied during pot experiment except phosphorus,

(ii) **MPR-P_{120}**: Soil obtained from plot treated with MPR at rate of 120 kg P $ha^{-1}$and all limiting nutrients applied during pot experiment except phosphorus, and

(iii) **TSP-P_{120}**: Soil obtained from plot treated with TSP at rate of 120 kg P $ha^{-1}$and all limiting nutrients applied during pot experiment except phosphorus.

Thinning from four to two maize plants per pot was done at 14 days after sowing. On the same day, first split of nitrogen fertilizer was applied. The second split was applied at 28 days. Harvesting of shoots was done at 42 days after sowing. The maize plants were cut at almost 1 cm above soil level.

3.3 Field experiment

The residual effects of nutrients were studied by growing maize in field plots that had been continually planted with maize and applied with fertilizers at Nkundi site in Rukwa region. The original field experiment had 12 treatments. However, for the purposes of this study, only four treatments were considered for determination of residual effects of phosphorus from Minjingu phosphate rock and triple superphosphate. This was because studies on MPR fertilizers have shown that optimum yields could be obtained when applied at rate of 120 kg P ha^{-1}. Also in pot experiment samples were collected from plots treated with TSP and MPR at this rate and thus it was possible to make comparison. Plots were arranged in a randomized complete block design with four replications. Limiting nutrients were appropriately added except the test nutrient (phosphorus). Treatments at Nkundi site were designated as shown below:

i. Absolute control: No N, P, or any other nutrients,

ii. $N_{120}P_0K_{100}$: Control for P (no P applied, basic N applied at the rate of 120 kg ha^{-1}),

iii. N_{120}TSP-$P_{120}K_{100}$: Triple superphosphate applied at rate of 120 kg P ha^{-1}, and

iv. N_{120}MPR-$P_{120}K_{100}$: Non granulated (powder) Minjingu Phosphate Rock applied at 80 kg ha^{-1}.

- Subscript numbers refer to rates of application of different nutrient elements.

3.4 Plant sampling

Harvesting of maize shoots was done at 42 days after sowing for pot experiment as described in section 3.2. For the field experiment plant sampling was done at 50% tasseling stage. Ear leaves were sampled from 15 randomly selected plants in each plot. Plant samples were cleaned with a moist cloth and oven-dried at temperature of 65°C to constant weight. For the pot experiment, samples were weighed upon attaining a constant weight to record dry matter yields. The samples were then chopped into small pieces and ground to pass through a 1 mm sieve. The powder was packed in polythene bags and stored to await analysis.

3.5 Harvesting of field maize plants for yields

At maturity the field crop was harvested, grains separated from cobs and weighed to determine grains yields. These were taken from all plants except guard rows. Moisture content of the grain was determined. The weight of grain for the considered plot area was determined and appropriately corrected to weight at standard moisture content (12.5%). The yields were expressed in tonnes per hectare (t ha^{-1}).

3.6 Analysis of plant materials

Plant materials were analysed for N, P, K, Ca, Mg, B, Zn and Cu contents. Plant samples were digested using the wet oxidation procedure described by the National Soil Service (1978) 0.5 g of ground plant samples were weighed and placed into digestion tubes. Then 5 mls of 68% HNO_3 were added into each tube and the mixture was left to stand overnight. Thereafter the tubes were placed in a digestion block with temperature set at 125 C and the contents digested for one hour. The digest were allowed to cool, 5 mls of H_2O_2 added into each tube and heated on the digestion block until there was no further reaction and the digest had become colourless. The digest was then heated on the digestion block at 180 C to near dryness. After cooling, 10 mls of 10% HNO_3 were added and the dissolved digest transferred quantitatively to 100 ml volumetric flask, which was filled to the mark with distilled water. Total N was determined by Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982). Calcium and magnesium were determined by atomic absorption spectrophotometer (AAS). Phosphorus was determined spectrophotometrically at 884 nm after colour development using the molybdenum blue method (Murphy and Riley, 1962). Copper and zinc were determined using AAS at 213.9 nm. Potassium was determined using a flame spectrophotometer at 768 nm.

3.7 Soil analysis

The soils collected from field experimental sites were subjected to physico-chemical analysis to determine their fertility status.

3.7.1 Soil texture

Particle size distribution determination in each composite sample soils of each experimental site was carried out by the hydrometer method (Gee and Bauder, 1986). The textural classes were established using the USDA textural triangle (USDA, 1995).

3.7.2 Soil pH

Soil pH was measured potentiometrically in 1:2.5 soil: water suspension following the procedures outlined by McLean (1982).

3.7.3 Organic carbon and total nitrogen

Organic carbon was determined by the wet digestion method of Walkley-Black (Nelson and Sommer, 1982). To a 1 g soil sample, 10 ml of 1M $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 were added to oxidise organic carbon. The amount of dichromate reduced was used to estimate the organic carbon content of the soil. Total N was determined by macro-Kjedahl digestion followed by distillation (Bremner and Mulvaney 1982).

3.7.4 Bray-1 phosphorus

Extractable P was determined according to the Bray-1 method (Bray and Kurtz, 1945), and colour development by the ascorbic acid method of Murphy and Riley (1962).

3.7.5 Exchangeable bases

The cation exchange capacity was determined by the ammonium acetate saturation methods as described by Chapman (1965). The amount of K, Ca, and Mg in the 1M NH_4OAc (pH 7) filtrate was determined using atomic absorption spectrophotometer.

3.7.6 Extractable micronutrients

0.05M DTPA-extractable Zn and Cu were determined by atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

3.7.7 Data Analysis

Analysis of variance (ANOVA) was carried out on nutrient concentrations in soil and plant samples and on the grain and dry matter yields. For soil samples statistical analysis was possible for Nkundi soil since the samples were collected from four treatments with their four replications not mixed. As for Mlingano and Sasanda soils, the analysis on the same was not possible since these were collected as composite soil samples. The MSTATC computer program was used for analysis of variance. The treatment means were compared using the Duncan's New Multiple Range Test at the significance level of 5%.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Some physical and chemical properties of the soils used

4.1.1 Soil texture

The texture of the three soils obtained from Nkundi, Mlingano and Sassanda experimental sites are presented in Table 1.

Table 1: Texture of the three soils in the fifth year of cultivation

Soil	Soil separates (%)			Textural class
	Silt	Clay	Sand	
Nkundi	1	25	74	Sandy clay loam
Mlingano	17	29	54.	Sandy clay loam
Sasanda	4	54	42	Clay loam

The textural classes of the soils were sandy clay loam (medium textured) for Mlingano and Nkundi soils and clay loam (heavy textured) for Sasanda soil. Sand contents in the three soils were above 42% and the highest was observed in Nkundi soil. According to Szilas (2002) the three soils are well drained, due to the fairly high contents of sand.

4.1.2 Soil pH, nitrogen, phosphorus and organic carbon

The pH, total nitrogen, Bray 1-P and organic carbon contents of the soils after four years of amendment are presented in Table 2.

Table 2: Levels of soil pH, organic carbon and total nitrogen in soils from different treatments

Soil	Treatment	Soil pH (in H_2O)	Bray-1 P (mg/kg)	%OC	%Total N
Nkundi	Absolute control	5.5	5.0	1.20	0.08
	N_{120}MPR-$P_{120}K_{100}$	5.4	41.7	1.22	0.09
	N_{120}TSP-$P_{120}K_{100}$	5.0	106.7	1.22	0.09
Mlingano	Absolute control	5.1	2.65	1.25	0.09
	N_{80}MPR-$P_{120}Mg_0$	5.0	39.4	1.39	0.12
	N_{80}TSP-$P_{120}Mg_0$	4.5	115.2	1.48	0.11
Sasanda	Absolute control	5.1	1.0	3.85	0.27
	N_{120}MPR-$P_{120}Mg_{50}$	5.3	3.4	3.94	0.29
	N_{120}TSP-$P_{120}Mg_{50}$	5.1	4.7	3.96	0.28

Note: Subscript numbers refer to application rates (kg/ha) of the respective nutrients

4.1.2.1 Soil pH

Results of soil pH are given in Table 2. Soil pH ranged from 4.5 to 5.5 in Nkundi and Mlingano soils. Fertilization with TSP and sulphate of ammonia intensified soil acidity from strongly to very strongly acid (Msanya *et al.*, 2001). In these two soils, treatment with MPR and SA did not result into any appreciable decrease of soil pH. In Sasanda soil a different trend was observed following treatment with MPR and SA. The treatment with MPR increased soil pH while there was no shift in soil pH following treatment with TSP. TSP did not change pH whereas MPR increased it in Sasanda soil probably because MPR released high amount of Ca, which counteracted the acidification of SA. This soil had low native calcium level (Table 3) and thus a sink for calcium. According to Robinson and Syers (1990), a sink for calcium is an important factor for increasing dissolution of phosphate rock. Low native Ca in this soil probably increased MPR dissolution and thus increased soil pH in Sasanda soil (Hu *et al.*, 1995).

The general findings of this study agree with those of other workers. Studying long-term reactions of phosphate rocks (176 kg P ha^{-1}) in an Oxisol in Colombia, Chien *et al.* (1987) observed an increase in soil pH with all P treatments as compared with the check. The increase was higher with phosphate rocks than with TSP.

The decrease in soil pH in these soils was probably due to use of SA rather than MPR and TSP treatments. In fact the two treatments and in particular MPR minimized the acidification effect of SA. This was verified by the results for Nkundi soil in which control for P (Table 8) had the lowest pH value. Sulphate of ammonia is known for its acidification effect when applied in soil. According to Brady and Weil (2000), ammonium containing fertilizers such as $(NH_4)_2\,SO_4$ and $(NH_4)_2HPO_4$ are oxidised in the soil by microbes to produce strong inorganic acids through reactions such as the one shown below:

$$(NH_4)_2SO_4 + 4O_2 \rightleftharpoons 2HNO_3 + H_2SO_4 + 2H_2O$$

These strong acids provide H^+ that lower soil pH. From the findings of this study, it can be concluded that in soils where SA fertilizers are feared to increase acidity, use of the same in combination with MPR, not TSP can appreciably minimize acidification.

4.1.2.2 Bray 1-phosphorus

Results of Bray 1-P are presented in Table 2. There was an appreciable increase in levels of phosphorus in Nkundi and Mlingano soils after four years of using MPR and TSP. Triple superphosphate increased Bray 1-P from low to high levels and MPR increased it to medium levels in these two soils (Landon 1996). However, in Sasanda soil the increase in Bray 1-P following treatment with the two sources of phosphorus was very slight. Bray 1-P in this soil increased from 1.0 mg/kg in the control to the highest value of 4.7 mg/kg. In control plots for all soils, Bray 1-P values were below 6 mg/kg, which are rated low (Landon, 1996).

These results showed that Bray 1-P increase was considerable in Mlingano and Nkundi soils but not considerable in Sasanda soil. The failure of the two fertilizers to raise P levels in Sasanda (Andisol) was attributed to the very high P fixation capacity of this soil. Szilas (2002) and Tusekelege (1997) found this Sasanda soil to have a phosphorus adsorption maximum of above 2400 mg P kg^{-1} implying very high phosphorus adsorption capacity. By contrast, Mlingano and Nkundi soils had adsorption maxima of only 462 and 181 mg P $kg^{-}1$, respectively (Szilas, 2002), meaning that P concentration in soil solution would be higher as shown in Table 2. According to Brady and Weil (2000), Andisols are usually of high natural fertility, except that phosphorus availability is severely limited by the extremely high phosphorus retention capacity of the andic materials. Andic properties of Andisols include relatively high contents of soluble aluminium and iron (Trohel and Thompson, 1993). Aluminium and iron at high levels react with soluble phosphorus thereby forming insoluble products according to the reaction shown below (Brady and Weil, 2000):

$$Al^{3+} + H_2PO_4^- \text{(soluble)} \rightleftharpoons 2H^+ + Al(OH)_2H_2PO_4 \text{ (insoluble)}$$

The increase in levels of Bray 1-P was very slight in Sasanda soil and it was still far below the critical concentration of 15 mg P/kg (Landon, 1996).

4.1.2.3 Soil organic carbon

Results of organic carbon for the three soils are presented in Table 2. Sasanda soil had the highest organic carbon values compared to Mlingano and Nkundi soils. In all three soils fertilization with phosphate and SA fertilizers increased soil organic carbon slightly. Organic carbon in Sasanda soil was very high for all treatments according to the rating by Msanya *et al.* (2001). For Mlingano soil the value of organic carbon (1.25%) in control plot was low and medium in all plots treated with TSP and MPR in combination with SA and other fertilizers. Basing on rating by Msanya *et al.* (2001), all treatments in Nkundi soil gave low organic carbon ranging between 1.20 and 1.22%. In all three soils absolute control treatments had the lowest values.

The reason for lowest values in control plants could be that MPR and TSP, both in combination with other fertilizers stimulated intensive root growth in fertilized plots. Also crop residues were left on the plots. Decomposition of these roots and tops led to build up in organic carbon in the soils. Singh *et al.*(1995) obtained similar findings. However, looking at the values critically the change in organic carbon with reference to control values was not appreciable. Nevertheless, that slight change was important since organic matter was slowly increasing.

4.1.2.4 The total nitrogen

The results of total nitrogen in soils are presented in Table 2. Values of total nitrogen in the three soils ranged from 0.08 to 0.29%. Levels of total nitrogen were observed to be medium in Sasanda and low in Nkundi and Mlingano soils for the three treatments according to the rating of Landon (1996). In Mlingano and Nkundi soils the highest value of total nitrogen was 0.12%. In Sasanda soil, total nitrogen values ranged from 0.27 to

0.29%. In all soils, fertilization with TSP and MPR in combination with other fertilizers had fairly similar effects on nitrogen levels. Levels of total N in control plots were in all soils slightly lower than those in plots treated with TSP and MPR in combination with other fertilizer.

Generally, application of phosphate fertilizer and sulphate of ammonia in combination with other nutrients resulted into very slight increases in total nitrogen. The observed medium values of total nitrogen in Sasanda (Andisols) soil were attributed to high organic matter as revealed by high soil organic carbon (Table 2). Nkundi and Mlingano soils had low organic matter. According to Bear (1965) the quantity of nitrogen is closely related to the amount of soil organic matter which makes approximately 5% of soil volume. Also low levels of total nitrogen observed in Nkundi and Mlingano soils were attributed to leaching and plant removals. Nitrogen uptake by plants is high and second to potassium (Brady and Weil, 2000). This is clearly demonstrated by results of the pot experiment reported in Table 5. Oxisols are highly leached soils. Nitrogen especially in the form of NO_3^- easily leaches (Benson *et al.*, 1992). At all three experimental sites mean annual precipitation has been estimated to be between 1000 mm and 1400 mm (Szilas, 2002). This amount of precipitation may cause a significant loss of nitrogen through leaching. These results indicated that nitrogen fertilizers have to be applied each time cultivation is done and this is especially evident in Nkundi and Mlingano soils.

4.1.3 Levels of other nutrients and CEC

4.1.3.1 Exchangeable calcium

Results of exchangeable calcium in the three soils are given in Table 3. Treating soil with MPR increased levels of exchangeable calcium in all soils. The increase was highest in

Sasanda soil and least in Mlingano soil. Triple superphosphate increased exchangeable calcium slightly in Sasanda soil and decreased it slightly in Mlingano soil while it had no effect in Nkundi soil.

Table 3: Levels of K^+, Ca^{2+}, Mg^{2+}, CEC, Zn and Cu in soils in fifth year of cultivation

Soil	Treatment	CEC	Ca^{2+}	Mg^{2+}	K^+	Zn	Cu
		........{cmol(+)/kg}.......				....(mg/kg)....	
Nkundi	Absolute control	5.2	1.53	0.95	0.34	0.65	1.17
	$N_{120}MPR_{120}K_{100}$	7.2	2.08	0.22	0.46	5.09	6.65
	$N_{120}TSP_{120}K_{100}$	6.4	1.52	0.45	0.46	6.08	6.17
Mlingano	Absolute control	10.2	1.28	0.19	0.45	0.69	3.08
	$N_{80}MPR\text{-}P_{120}Mg_0$	11.8	1.35	0.29	0.47	10.02	3.72
	$N_{80}TSP\text{-}P_{120}Mg_0$	11.6	1.02	0.32	0.52	9.06	3.32
Sasanda	Absolute control	27.4	1.13	0.38	0.72	1.92	1.41
	$N_{120}MPR\text{-}P_{120}Mg_{50}$	31.2	2.85	0.83	0.75	2.42	3.46
	$N_{120}TSP\text{-}P_{120}Mg_{50}$	28.2	1.24	0.70	0.79	2.98	3.84

Overall the values of exchangeable calcium ranged from 1.02 to 2.85 cmol(+)/kg. These values were very low to low according to the rating of Msanya *et al.* (2001). Overall the levels of exchangeable calcium followed the trend, Absolute control < TSP <MPR in all soils. The results showed that application of MPR increased exchangeable calcium whereas effects of TSP varied for different soils.

The reason for the increased exchangeable calcium in all soils treated with MPR was the release of calcium that is contained in MPR. Minjingu rock phosphate may contain up to 46.4% CaO (Mnkeni *et al.*, 1992). However, the extent of build up of calcium in individual soils could be attributed to their inherent properties. For example oxisols (Mlingano soil) in which nutrients can easily be leached showed lower values of exchangeable calcium.

Sasanda soil, which had highest amount of clay (Table 1) and organic carbon, showed the highest increase in exchangeable calcium. Fine textured soils are known to retain nutrients more than course textured soils. These findings that MPR appreciably increased the levels of exchangeable calcium agree with those of Chien *et al.* (1987). They observed an increase in exchangeable Ca with phosphate rock treatments, but not with triple superphosphate.

4.1.3.2 Exchangeable magnesium

Levels of exchangeable magnesium in the three soils ranged from 0.19 cmol(+)/kg to 0.95 cmol(+)/kg (Table 3). Levels of exchangeable magnesium were high for absolute control treatment in Nkundi soil but medium in plots treated with MPR and TSP (Landon, 1996). In Sasanda soil medium values were observed in control plots and high values were attained in plots treated with MPR and TSP. In Mlingano soil the values ranged from low in absolute control plots to medium in plots treated with MPR and TSP (Landon, 1996).

These results showed that Nkundi soil was inherently rich in exchangeable magnesium but the level was decreased with cropping since there was no supplementation of magnesium. This could be explained by the simple fact that control plot had medium value whereas plots treated with MPR and TSP in combination with other fertilizers such as SA had low values. It was probably due to plant removal, which would increase with growth vigour of plants. Plants in plots treated with MPR and TSP were bigger compared to those in absolute control plots. However, in Sasanda soil the reason for the trend was different. In this soil magnesium fertilizer ($MgSO_4$) was applied at the rate of 50 kg Mg ha^{-1}. This probably led to build up in exchangeable magnesium in plots other than the absolute control plots. As for Mlingano soil, the slight increase was probably due to small amount of Mg contained in MPR and TSP. The results for Sasanda soil have indicated that addition of magnesium feritilzers may lead to build up of exchangeable Mg in soils.

4.1.3.3 Exchangeable potassium

Results of exchangeable potassium in composite sample soils are given in Table 3. Exchangeable potassium levels in the three soils ranged from 0.34 cmol(+)/kg to 0.79 cmol(+)/kg. Based on Landon's (1996) guidelines for rating of exchangeable potassium all values were rated as being high except that of absolute control for Nkundi soil, which was rated as medium. Appreciable increase in levels of exchangeable potassium was observed in Nkundi soil and the differences between control values and values for soils treated with MPR and TSP were small in Mlingano and Sasanda soils. For example, in Sasanda soil exchangeable potassium ranged between 0.72 and 0.79 cmol (+)/kg. This increase was relatively small when compared to a range of between 0.34 and 0.46 cmol(+)/kg soil in Nkundi soil.

Appreciable increase in exchangeable potassium in Nkundi soil was attributed to applied potash fertilizer. This was applied as muriate of potash. Despite high increase of exchangeable K in Nkundi soil, the levels had not reached those in Sasanda soil. Exchangeable potassium levels were highest in Sasanda soil. This was probably due to less leaching given the higher clay content of this soil. Generally, the observed build up of exchangeable potassium in all soils had reached medium to high levels. These levels indicated that production of crops in these soils for sometime could be done without fear of K deficiencies.

4.1.3.4 Cation exchangeable capacity

Table 3 shows the results of CEC in the soils. The values of CEC ranged from 5.2 cmol(+)/kg in Nkundi absolute control soil to 31.2 cmol(+)/kg in Sasanda soil treated with MPR. All levels of CEC in Nkundi and Mlingano soils were low, but were high in Sasanda soil according to the rating by Landon (1996). Treatment with MPR and SA gave highest values of CEC in all soils. These were followed by values in soils treated with a combination of TSP and SA. Soils from control plots gave lowest values of CEC. High values of CEC in soils treated with MPR were attributed to the high content of calcium in this fertilizer. MPR contains about 46.4% CaO and 3.4% MgO, and 1.4% K_2O (Mnkeni *et al.*, 1992) along with its other ingredients. It might as well have been due to other applied fertilizers such as KCl in Nkundi soil and magnesium sulphate in Sasanda soil. The differences in CEC magnitude between the three soils were probably due to the inherent properties of respective soils. While there could be high leaching of exchangeable bases in Mlingano (Oxisol) and Nkundi (Ultisol), relatively low leaching would be expected in Sasanda (Andisol). According to Brady and Weil (2000), Oxisols are the most highly weathered soils in the classification system. In the Sasanda soil higher values of CEC were also attributed to higher organic carbon content. Organic matter is known for its contribution to pH dependent charges. It improves ion retention (Uriyo *et al.*, 1979). This soil (Andisol) was inherently high in CEC as reflected by high value of the same in the absolute control soil.

4.1.3.5 DTPA zinc

The results of DTPA-extractable zinc are presented in Table 3. Extractable zinc ranged from 0.65 mg/kg in Nkundi absolute control to 10.02 mg/kg in Mlingano soil treated with MPR. All values were rated as sufficient for optimum maize growth except those for absolute control in Nkundi and Mlingano soils (Landon, 1996). The build up of zinc levels in Nkundi and Sasanda soils was due to the zinc fertilizers applied. The fertilizer was applied in all seasons of cultivation at the two sites.

4.1.3.6 DTPA copper

DTPA-extractable copper ranged between 1.41 and 6.65 mg/kg in the three soils. Lindsay and Norvell (1978) classify levels of copper in soil as sufficient if they are above 0.2 mg/kg and therefore all the values were sufficient for optimum plant growth. Levels of copper in control soils were smaller than those of fertilized soils. This means that there was build up of levels of copper in all soils. The increase was higher in Nkundi and Sasanda soils than in Mlingano soils. In Nkundi soil the level of copper ranged between 1.17 and 6.65 mg/kg whereas it ranged between 1.41 and 3.84 mg/kg in Sasanda soil. The differences of these ranges were higher than that of Mlingano soil, which ranged from 3.08 to 3.72 mg/kg.

The observed build up of copper in Nkundi and Mlingano soils was attributed to fertilization with copper sulphate. In these two soils copper sulphate was applied annually during the four years of cultivation. This could be the reason for considerable increase of copper in Sasanda soil. In this soil copper sulphate was applied in the fourth year of cultivation. High level of copper that accumulated following one application of copper sulphate was probably due to the high content of organic carbon in Sasanda soil. In soils with high amount of organic matter, copper is strongly complexed and therefore not easily leached (Jones and Belling, 1967). Generally the results indicated that levels of extractable copper were sufficient in all three soils and crops should be successfully grown without encountering copper deficiency for sometimes.

4.2 Pot experiment

4.2.1 Visual assessment of pot maize growth

Maize seeds were completely sprouted after 8 days. The rate of growth of maize plants in all pots was fairly uniform at 14 days but thereafter differences emerged for different treatments. The differences in rate of growth were especially observed with plants grown in Mlingano and Nkundi soils (Plates 1a and b). The rate was high for plants in soils treated with MPR or TSP. In Sasanda soil plants from different treatments continued to grow at almost same rate (Plate 2a). However, on application of the second split of nitrogen, the differences in growth between plants in control and other treatments were clear (plate 2b). The second split application of nitrogen was done at 28 days after sowing. Plants in soils obtained from plots treated with TSP or MPR grew much faster than their counterparts in the control soil. However, generally the performance in terms of growth vigour remained relatively high for plants in Mlingano and Nkundi soils (Plate 1b). Plants in Sasanda soil exhibited stunted growth and purplish leaves in all treatments. Also lower leaves withered. Stunted growth was observed in plants grown in control pots only for Mlingano and Nkundi soils. The observed differences in vigour were attributed to P levels in these soils since other suspected limiting nutrients had been added at sowing.

The stunted growth in the control soils of Mlingano and Nkundi, as well as in all treatments in the Sasanda soil, was due to P deficiency because these soils had low P (Table 2) and the Sasanda soil has an extremely high P fixing capacity (Szilas, 2002).

Plate 1a: Response of maize plants to residual P in Nkundi, Sasanda and Mlingano soils at 25 days

Plate 1b: Response of maize plants to residual P in Nkundi, Sasanda and Mlingano soils at 42 days

Plate 2a: Response of maize plants to residual P in Sasanda soil at 25 days

Plate 2b: Response of maize plants to residual P in Sasanda and soil at 42 days

4.2.2 Effects of residual phosphorus on maize dry matter yields

Results of the effects of residual phosphorus on maize dry matter yields harvested at 42 days after planting are given in Table 4. Dry matter yields of maize plants in the three soils ranged from 2.12 g/pot to 64.77 g/pot. Residual phosphorus significantly ($P = 0.05$) increased dry matter yields in all soils. Higher increase in dry matter yields was observed in Nkundi and Mlingano soils, while, relatively small dry matter yields were observed in Sasanda soil. In all soils TSP and MPR had comparable residual effects on dry matter yields. In all soils the lowest dry matter yields were obtained from control plants.

The increased dry matter yields of maize grown in Nkundi and Mlingano soils was attributed to residual P as other nutrients such as N, K, Mg, Zn and Cu were applied in soil at planting and at different stages of growth thereby making them not limiting. In Nkundi and Mlingano soils the residual P was increased above the critical concentration of 15 mg P/kg (Table 2). In Sasanda and in all control soils dry matter yields were poor. This was anticipated given the low level of residual P in the soils. The P in those soils was below 6 mg P/kg (Table 2) and, therefore, far below the critical concentration of 15 mg P/kg (Landon, 1996). In this study, the results obtained under field study at Nkundi site gave similar results. Maize grain yields due to residual P from MPR and TSP were comparable (Table 10). Generally application of phosphate fertilizers resulted into residual P that was capable of increasing dry matter yields. In order to conclusively confirm if the observed yields were due to residual P, a control for P was subsequently included as independent treatment during the field experiment (section 4.3).

Table 4: Effects of residual P in different soils on dry matter yields of maize shoots at 42 days of growth

Treatment	Dry matter yields (g/pot) in different soils		
	Nkundi	Mlingano	Sasanda
Control	7.29b	7.70b	2.12b
MPR-P_{120}	61.07a	57.35a	22.10a
TSP-P_{120}	64.77a	55.93a	21.44a
CV (%)	9.77	2.87	9.81

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

4.2.3 Effects of residual phosphorus on nutrient uptake by maize plants

4.2.3.1 Phosphorus

Uptake of phosphorus in maize plants is presented in Table 5. The TSP and MPR treatments significantly increased the uptake of phosphorus over the control treatment with uptake being over 120 mg/pot for Nkundi and Mlingano soils but only slightly over 45 mg/pot for Sasanda soil. Uptake of P by plants was relatively small in Sasanda soil and it ranged between 2.68 and 47 mg /pot. In all soils P uptake was lowest in control pots. Phosphorus uptake values were 10.63, 13.84 and 2.68 mg/pot for control plants in Nkundi, Mlingano and Sasanda soils, respectively (Table 5).

The concentration of phosphorus in maize plants grown in the three soils ranged from 0.12% to 0.22% (Table 6). All the concentrations of phosphorus in maize shoots were in sufficient levels (Tandon, 1995). In all the three soils, the lowest P concentrations were observed in plants grown in soils from absolute control plots.

Table 5: Effects of residual P on uptake of N, P, K, Ca, Mg, Zn and Cu by maize plants at 42 days

Soil	Treatment	Uptake (mg/kg)						
		N	P	K	Ca	Mg	Zn	Cu
Nkundi	Control	204.3b	10.63b	283.1b	22.59c	19.8b	0.43b	0.03b
	MPR-P_{120}	599.2a	124.9a	920.9a	167.4a	57.5a	2.59a	0.20a
	TSP-P_{120}	611.4a	135.6a	929.2a	115.8b	50.8a	2.97a	0.21a
	CV (%)	10.75	23.28	10.89	18.77	15.19	12.03	0.22a
Mlingano	Control	248.2b	13.84b	341.4b	17.7c	20.5c	0.55b	0.05b
	MPR-P_{120}	637.4a	120.2a	1001.0a	130.6a	59.6a	2.84a	0.13a
	TSP-P_{120}	651.0a	125.8a	1012.0a	93.0b	49.5b	3.04a	0.14a
	CV (%)	10.19	10.21	9.22	10.64	8.74	14.17	17.64
Sasanda	Control	66.5c	2.68b	75.7b	10.4c	8.2b	0.09b	0.01b
	MPR-P_{120}	584.8a	45.59a	616.0a	71.5a	54.5a	0.80a	0.14a
	TSP-P_{120}	517.1b	47.31a	590.2a	46.1b	51.6a	0.79a	0.11a
	CV (%)	18.82	25.39	12.25	13.29	8.73	7.89	5.76

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

The MPR and TSP treatments in Sasanda soil significantly (P = 0.05) increased P concentration in maize shoots. Statistically significant increase in shoot P concentration in Nkundi soil was only obtained in the TSP treatment. Generally concentrations of phosphorus in maize plants followed the order, control < MPR < TSP.

The explanation for lowest uptake of P by plants in control treatments at all sites and in all treatments for Sasanda soil was the inherently low available P in these soils and the high P fixation capacity of the Sasanda soil. These soils had less than 15 mg P/kg which is the critical concentration of P in soil for optimum maize production (Landon, 1996). On the other hand increased uptake of P in soils treated with MPR and TSP in Mlingano and Nkundi soils was attributed to medium and high levels of Bray 1-P in treated plots (Table 2).

Concentrations of P in maize shoots followed a trend similar to that of uptake by maize plants. Concentrations increased with increased P levels in soils. Concentrations of P were low in control plots and relatively high in plants grown in soils treated with MPR and TSP and other nutrients.

Table 6: Effects of residual P from two sources on concentration of nutrients in maize shoots at 42 days

Soil	Treatment	N	P	K	Ca	Mg	Zn	Cu
		........................(%).....................					....(mg/kg).....	
Nkundi	Control	2.81a	0.14b	3.87a	0.31a	0.27a	58.3a	4.6a
	MPR-P_{120}	0.98b	0.19b	1.51b	0.27a	0.09b	42.7b	3.3b
	TSP-P_{120}	0.94b	0.22a	1.43b	0.18b	0.07b	46.1b	3.5b
	CV (%)	3.2	15.7	5.5	10.2	9.2	10.6	8.6
Mlingano	Control	3.12a	0.18a	4.42a	0.23a	0.26a	71.2a	6.8a
	MPR-P_{120}	1.16b	0.21a	1.74b	0.23a	0.10b	49.6b	2.2b
	TSP-P_{120}	1.11b	0.22a	1.81b	0.17b	0.09b	54.3b	2.5b
	CV (%)	5.8	14.3	7.2	11.2	11.8	17.3	10.6
Sasanda	Control	3.13a	0.12b	3.07a	0.49a	0.33a	37.3a	5.8ab
	MPR-P_{120}	2.59b	0.20a	2.74a	0.32b	0.24b	35.4a	6.8a
	TSP-P_{120}	2.41c	0.22a	2.75a	0.21c	0.24b	37.3a	5.4b
	CV (%)	2.6	12.3	12.5	17.3	17.2	19.1	10.8

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

4.2.3.2 Nitrogen

The uptake of nitrogen ranged from 66.5 to 651.0 mg/pot (Table 5). The uptake of nitrogen was significantly (P = 0.05) higher in soils treated with MPR and TSP in all soils. Residual P from TSP and MPR gave comparable uptakes in Nkundi and Mlingano soils but TSP treatment had significantly higher uptake than MPR treatments in Sasanda soil. Nitrogen uptake by maize plants was comparatively small in Sasanda soil. Control plants had the lowest uptake in all soils.

Nitrogen concentrations in maize appreciably varied for the three soils. It ranged from 0.94% in Nkundi (TSP) maize shoots to 3.13% in Sasanda control maize (Table 6). The concentration of N in maize plants grown in Sasanda soil was adequate for optimum maize growth (Tisdale *et al.,* 1993). Inadequate concentrations of N were observed in maize plants grown in Nkundi and Mlingano soils treated with MPR and TSP. However, control treatments gave the concentrations above 2.81% in the two soils, which were adequate for optimum maize growth. Application of different fertilizers resulted in comparable effects on concentration of nitrogen for plants in Mlingano and Nkundi soils but differed significantly ($P = 0.05$) in Sasanda soil.

Low uptake of N in control plants in all soils was attributed to small dry matter yields (Table 4) of control plants, which resulted from low supply of P (Table 2). Low uptake could not be attributed to low level of N in the soils since 200 mg N/kg soil were applied in all pots at planting. On the other hand, higher uptakes in treated soils were attributed to large dry matter yields due to adequate supply of P in soils treated with MPR and TSP. Overall, the uptakes of N by plants were second largest to potassium uptake. This conforms to Brady and Weil (2000) who stated that these two elements are taken by plants in larger amounts than other elements.

The reasons for lower concentrations in maize plants grown in fertilized soils than those in control treatments could be due to the dilution effect. As dry matter yields increase, nutrients distribute themselves and thus become dilute in tissues (Marschner, 1990). These plants had significantly higher dry matter yields than plants in control treatments. This was explained by the uptakes of nitrogen observed. Control plants had significantly lower uptakes than plants in soils treated with MPR and TSP. Sasanda soil had inherently high level of nitrogen. In addition to its inherent high level of N, it was treated with 200 mg N/kg soil at planting. This and the fact that dry matter yields of maize plants in this soil were smaller were probably the reasons for large concentrations of N in plants grown in Sasanda soil.

4.2.3.3 Calcium

Uptake of calcium ranged from 10.4 mg/pot to 167.4 mg/pot (Table 5). Both MPR and TSP significantly increased calcium uptake (P = 0.05) in all soils. However, there was significant difference in uptake due to applications of the two sources of phosphorus. Calcium uptakes were higher for maize plants in the MPR treatments than those from TSP treatments. Control plants had the lowest uptake in all soils, which ranged from 10.4 to 22.59 mg/pot. Calcium uptake by plants in the MPR treatments ranged from 71.5 to 167.4 mg/pot.

Concentration of calcium in maize plants in the three soils ranged from 0.17% to 0.49% (Table 6). These values fall in the adequate range for maize production (Tandon, 1995). The MPR treatment significantly (P = 0.05) increased calcium concentration in plants over the TSP treatment. However MPR and control treatments had comparable effects on calcium concentration in maize grown in Nkundi and Mlingano soils.

The relatively high uptake of calcium in soils treated with MPR was attributed to high content of CaO in MPR. For instance Mnkeni *et al.* (1992) found MPR to contain 46.4 % CaO. Also TSP supplies calcium to plants but it is lower than that supplied by MPR (Semoka, J.M.R. personal communication, 2003). It therefore contributed to the concentrations observed in plants in TSP treatments. They were able to utilize available calcium in soils.

High concentrations of calcium in control plants were attributed to small dry matter yields of these plants. On the other hand high concentration of calcium in plants grown in soil treated with MPR was attributed to high supply of calcium in soils released by MPR fertilizers. Levels of exchangeable calcium were highest in plots treated with MPR in all soils (Table 3).

4.2.3.4 Magnesium

Uptake of magnesium ranged between 8.2 mg/pot and 59.6 mg/pot (Table 5). Application of MPR and TSP significantly ($P = 0.05$) increased uptake of magnesium. Uptakes of magnesium due to MPR and TSP application were comparable ($P = 0.05$) for Nkundi and Sasanda soils. In Mlingano soil, the uptake of magnesium was significantly higher for MPR than TSP treatments. Lowest uptake in each soil was observed in control plants. Unlike for other nutrients, magnesium uptake in Sasanda soil treated with TSP and MPR were similar to uptakes in other soils. It ranged between 51.6 and 54.5 mg Mg/pot whereas in Nkundi and Mlingano soils it ranged between 49.5 and 59.6 mg Mg/pot.

Magnesium concentration in plants ranged from 0.07% in Nkundi soil (TSP) to 0.33% Sasanda control plants (Table 6). Concentrations of magnesium in plants in MPR and TSP treatments were low whereas in control treatments were adequate for all soils (Campbell and Plank 2000). In Sasanda soil, all plants had adequate magnesium concentrations for maize production. Treatments with MPR and TSP had comparable effects on the concentration of magnesium in maize shoots in all three soils. Increased magnesium uptake in MPR and TSP treated Sasanda soil was probably due to added magnesium sulphate at the rate of 50 kg Mg/ha during field experiment phase which increased the level of exchangeable Mg in this soil (Table 3). Also during the pot study magnesium sulphate was added to Sasanda soil at the rate of 100 mg/kg soil. Uptakes in other soils were comparable to uptakes for plants in Sasanda soil probably due to their healthy growth and thus high dry matter yields (Table 4).

The relatively lower magnesium concentrations in plants in MPR and TSP treated soils as compared to magnesium concentrations in control plants were attributed to dilution effect due to increased dry matter yields. However, this was compensated by increase in uptake of magnesium. Also the relatively high concentration of magnesium in plants grown in Sasanda soil was mainly due to applied magnesium sulphate during field and pot studies. These results indicated that application of magnesium fertilizer led to increase in magnesium concentration in soils and plants and increased uptake of magnesium by maize plants. This was evident in Sasanda soil.

4.2.3.5 Potassium

Uptake of potassium was the largest of all considered nutrient elements. It ranged from 75.7 mg/pot to as large as 1012.0 mg/pot (Table 5). Lowest potassium uptake was observed in maize plants grown in Sasanda soil. It ranged from 75.7 mg/pot to 590.2 mg/pot. The MPR and TSP treatments significantly ($P = 0.05$) increased potassium uptake by plants in all soils. However, no statistically significant differences in uptakes of potassium were observed due to the two sources of phosphorus. In all soils the lowest uptakes were found in plants grown in control pots.

Potassium concentration in maize shoots ranged from 1.43% to 4.42% for Nkundi and Mlingano soils, respectively (Table 6). Basing on rating of Jones and Eck (1973) these values of potassium concentration were sufficient for optimum maize growth. However, in Nkundi soil, potassium concentrations in treated plants were deficient. The concentrations in control maize plants were significantly higher than that for plants grown in soils treated with MPR and TSP except in Sasanda where concentrations were comparable. Significantly higher uptake of K by plants in Mlingano and Nkundi plots treated with TSP and MPR was attributed to large dry matter yields.

The relatively lower potassium concentrations in plants in plots treated with MPR and TSP as compared to potassium concentrations in control plants were attributed to dilution effect due to increased dry matter yields. However, this was compensated by increase in uptake of potassium. The low potassium concentration in plants in Nkundi soils was also due to decreasing exchangeable K in this soil (Table 3). The general high concentrations of potassium in maize shoots were probably due to excessive uptake of the same. According to Brady and Weil (2000), plants absorb potassium far in excess of their needs if sufficiently large quantities are present.

4.2.3.6 Zinc

Uptake of zinc in maize plants varied from 0.09 mg/pot to 3.04 mg/pot (Table 5). There was significant ($P = 0.05$) increase in uptake of zinc in plots treated with MPR, TSP and zinc fertilizer. Zinc uptake was smallest in control plots. In all soils zinc uptakes by maize plants in plots treated with TSP and MPR in combination with other fertilizers including zinc sulphate were comparable.

Zinc concentrations in maize shoots ranged from 35.4 mg/kg to 71.2 mg/kg (Table 6). These concentrations were rated as sufficient for optimum maize growth (Tandon, 1995). Control plants had highest concentration of zinc. The concentrations of zinc in plants in Mlingano and Nkundi soils followed the order, control > TSP > MPR. In Sasanda the order was control = TSP >MPR. Concentrations of Zn in plants grown in control soils were significantly different (P = 0.05) from those in plants. The MPR and TSP treatments had comparable effects on concentration of zinc in maize shoots. Significantly increased uptake of zinc in plants grown in soils treated with TSP, MPR and zinc fertilizers were due to high levels of Zn in soils (Table 3) following treatment with zinc sulphate. The fact that no significant difference was observed for soils treated with MPR and TSP implied that the two sources of P had similar effects on the uptake of zinc.

Relatively higher zinc concentrations in control plants were attributed to small dry matter yields of these plants. According to Kumar *et al.* (1992), in particular the concentrations of micronutrients in plant materials generally decrease as plant weight increases in response to provision of micronutrients and this is known as dilution effects (Jarrell and Beverly, 1982). Therefore small dry matter yields of control plants were the reason for the highest concentration of zinc observed in control plants for all soils. Zinc concentrations in plants grown in treated plots were comparable, as were dry matter yields of maize grown in same plots.

4.2.3.7 Copper

Uptake of copper in these soils ranged from 0.01 mg/pot to 0.22 mg/pot (Table 5). The highest uptake (0.22 mg/pot) was observed in plants grown in Nkundi soil treated with TSP. The lowest value (0.01 mg/pot) was for maize grown in control Sasanda soil.

Residual P from MPR and TSP significantly (P = 0.05) increased the uptakes of copper and for all soils the uptake was lowest in control plots. Residual P from MPR and TSP fertilizers had comparable effects on uptake of copper.

Concentrations of copper in maize shoots ranged between 2.19 and 6.84 mg/kg (Table 6). According to Kumar *et al.* (1992), minimum adequate concentration of copper in maize is 5 mg/kg. Based on this standard, only plants grown in Sasanda soil had adequate amount of copper. Concentrations of copper in control maize shoots were significantly different from that in maize grown in Mlingano and Nkundi soils treated with TSP and MPR. In Sasanda soil residual P from MPR significantly (P = 0.05) increased zinc concentrations in maize shoots over residual P from TSP. Overall the uptake of copper by plants was highest in Nkundi soil and this was probably due to relatively high levels of Cu in this soil (Table 3). Even though Cu was added in Sasanda soil, its uptake was small compared to Nkundi soil probably due to high organic matter of this soil. Copper is strongly complexed by organic matter. The observed significantly lower concentration of copper in plants grown in soils treated with phosphate and other fertilizer than those of control plants was attributed to dilution effect (Jarrell and Beverly, 1982). Small dry matter yields for plants in Sasanda soil was the reason for observed high concentration of copper.

4.2.4 Residual phosphorus in pot experimental soils

Results of levels of residual P in soils after pot experiments are presented in Table 7 and those of other nutrients in Appendix 1. Bray 1-P ranged between 0.7 mg/kg and 80 mg/kg. Before pot experiment, Bray 1-P ranged from 1.0 to 106.7 mg/kg (Table2). There was therefore an appreciable decrease in P levels especially in Nkundi and Mlingano soil. In all soils the decrease was largest with TSP treatments. For example, in Nkundi soil it decreased from 106.7 (Table 2) to 47.1 mg/kg (Table 7). In this soil the P level for the MPR treatment decreased from 41.7 to 40.4 mg/kg.

Table 7: Level of residual available P in soils after pot experiment

Treatment	Bray 1-P in different soils (mg/kg)		
	Nkundi	Mlingano	Sasanda
Control	5.3c	5.1c	0.7c
MPR-P_{120}	40.4b	37.6b	1.6b
TSP-P_{120}	47.1a	80.4a	2.1a
CV (%)	15.96	4.98	14.5

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

It was also observed that decrease in residual P was highest and least in Nkundi and Sasanda soils, respectively. The little change in levels of residual P in soils treated with MPR as compared to TSP was attributed to the low dissolution of MPR (Di *et al.*, 1994). Relatively high P uptakes were observed in Nkundi soil whereas the least was in Sasanda soil (Table 5). Nkundi and Sasanda soils showed highest and least decrease in residual P, respectively. Therefore the extent of decrease in P in these soils was attributed to plant uptake. The uptake of P was lowest for plants grown in Sasanda soil. However, these results may not be extrapolated to field conditions. In pots plants utilize nutrients more extensively because small volumes of soils are used.

4.3 Field experiment

4.3.1 Effects of residual phosphorus on soil chemical properties of Nkundi soil

The effects of MPR and TSP applied at the rate of 120 kg P ha^{-1}on soil chemical properties for Nkundi soil are presented in Tables 8 and 9.

Table 8: Levels of pH, organic carbon, phosphorus and nitrogen in Nkundi soil in the fifth year of cultivation

Treatment	pH (in H_2O)	Bray-1 P (mg/kg)	Total N	OC
			............(%)..........	
Abs control	5.5a	7.2c	0.07a	1.45c
$N_{120}P_0K_{100}$	4.8c	7.1c	0.07a	1.47bc
$N_{120}TSP_{120}K_{100}$	5.0b	109.8a	0.10a	1.64a
$N_{120}MPR_{120}K_{100}$	5.4a	46.5b	0.08a	1.67a
CV (%)	1.89	16.09	10.93	4.84

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

4.3.1.1 Soil pH

Soil pH varied between 4.8 and 5.5 (Table 8). There was no statistically significant ($P = 0.05$) difference between the pH of the absolute control treatment and that for soil fertilized with MPR. However, statistically significant difference was observed for the values of soil pH in soil fertilized with MPR in combination with SA and that which received SA, but without phosphate fertilizer. Moreover, application of a combination of TSP and SA resulted in significant decrease in soil pH. With this treatment soil pH decreased significantly by 0.5 units and the soil changed from strongly acid to very strongly acid (Msanya *et al.*, 2001). A decrease following treatment with MPR and SA combination was very slight (0.1 unit) and the soil remained strongly acidic. Soil pH value (4.8) for soil without P was rated as strongly acid (Msanya *et al.*, 2001).

Decrease in soil pH in all treatments was attributed to the effect of sulphate of ammonia that was applied in soil. This was evident in control treatment, which resulted into largest decrease in soil pH. This experiment was part of the main experiment. In the main experiment there was an increase in soil pH when MPR was applied without SA. Soil pH increased from 5.5 to 5.9 (Kadogholo, E. M. personal communication, 2003). These results indicated that MPR had neutralization effects when applied in combination with SA. A bit of neutralization effect was also observed with TSP fertilizer but it was not as much as that of MPR. The findings of this experiment conforms to those of Chien *et al.* (1987) who found that both phosphate rock and superphosphate increased soil pH and that the increase was more for phosphate rock than for triple superphosphate. In general, MPR has a higher buffering capacity than TSP. Where ammonium-containing fertlizers are feared to increase soil acidity, the use of such fertilizer in combination with MPR would minimize the risk of acidification appreciably.

4.3.1.2 Soil organic carbon

Soil organic carbon ranged from 1.45 to 1.67% (Table 8). These values are considered very low (Landon, 1996). However there was significant (P = 0.05) build up of organic carbon in plots fertilized with phosphate fertilizers in combination with other fertilizers such as sulphate of ammonia and muriate of potash. The results of increased organic carbon following treatments with MPR and TSP were comparable. There was no significant difference (P = 0.05) between values of organic carbon in absolute control and treatment control. The results, therefore, indicate that the differences in observed values of organic carbon did not result from direct application of fertilizers. They rather resulted from other factors influenced by application of phosphate fertilizers. One of such factors could be stimulated root growth. According to Singh *et al.* (1995), fertilizer additions either as a single or combination of two or three nutrients contribute to proliferation of roots and ultimately maintain or lead to increase in organic carbon. Kapur *et al.* (1986) reported an increase in organic carbon content of the soil with continuous fertilizer application for three years in maize-wheat sequence in a loamy sand soil. The other reason for significant increase in soil organic carbon could be the decomposition of stover. At harvest stover were left in field to decompose. Plots fertilized with all nutrients gave significantly higher yields (Table 10) and thus a larger amount of stover. Overall, the results indicated that the levels of organic carbon in Nkundi soil were very low and so was organic matter. Soil organic matter plays a number of roles in the soil. It influences many soil biological, chemical and physical properties that favourably influence nutrient availability (Tisdale *et al.*, 1993). It acts as a conditioner by improving soil structure, moisture and ion retention besides being an important source of nutrient elements (Uriyo *et al.*, 1979) such as nitrogen (Davies *et al.*, 1993). All these would then contribute to increased plant growth and yields.

4.3.1.3 Total nitrogen

The results of total nitrogen are presented in Table 8. Total nitrogen ranged from 0.07% to 0.10%. Based on Landon's guidelines for rating of total nitrogen, all values were rated as low (Landon, 1996). There was no significant (P = 0.05) difference between values of different treatments.

Nitrogen is one of the highly leachable nutrients and it is associated with organic matter. The only important source of nitrogen in the soil is soil organic matter (Davies *et al.*, 1993). As shown by the results of organic carbon (Table 8), this soil lacked adequate organic matter. Low levels of nitrogen were probably due to leaching, removal by plants and small amount of organic matter in this soil. It was therefore not surprising that this soil had inherently low soil nitrogen as revealed by the value of total N for absolute control treatment. According to Benson *et al.* (1992), nitrogen in the form of NO_3^- is highly mobile in the soil and generally follows the flow of water. Large removal of nitrogen through plants uptakes has been reported (Vaje *et al.*, 1999). For example, a typical maize crop in smaller African farm yielding 4 t ha^{-1} requires 100 kg N ha^{-1} while a less than 1 t ha^{-1} maize yield requires 40 kg N ha^{-1} (Sanchez *et el.*, 1997). Pot experiment results for this study have also shown that nitrogen removal (uptake) from soil by maize plants was large (Table 5). The findings of this study showed that whenever cultivation is done, application of nitrogen is necessary if optimum production is to be attained.

4.3.1.4 Bray 1-phosphorus

Bray 1-phosphorus results are given in Table 8. Extractable phosphorus in Nkundi soil for different treatments ranged from 7.1 mg/kg soil to 109.8 mg/kg. Application of both MPR and TSP in combination with other fertilizers increased significantly ($P = 0.05$) levels of Bray1-P. Minjingu rock phosphate and triple superphosphate increased Bray 1-P to 46.5 mg/kg and 109.8, respectively. Based on Landon's guidelines for Bray 1-P, these values were rated as medium and high, respectively. The values for absolute control and control for P treatments were rated as low.

The higher level of P due to treatment with triple super phosphate was attributed to high solubility of this fertilizer as compared to the solubility of MPR. That notwithstanding both sources of P increased Bray-1 P above critical concentration of 15 mg P/kg. Unlike the case of total nitrogen; P had increased to levels that could support growing crops without a need to apply P in the fifth and probably several years to come. Phosphate accumulation has been reported elsewhere and reasons given for the same. According to Moughli *et al.*

(1999) when P is applied to the soil, only a small percentage is taken up by plants, the remainder is either permanently or temporarily fixed in forms varying in plant availability.

4.3.1.5 Exchangeable calcium

Exchangeable calcium ranged from 0.71 cmol(+)/kg to 1.93 cmol(+)/kg (Table 9) in Nkundi soil. All values are considered low (Landon, 1996). There was significant (P = 0.05) increase in level of exchangeable calcium when MPR was applied. Triple superphosphate slightly increased exchangeable calcium in this soil.

Table 9: Effect of residual P from TSP and MPR on levels of Ca^{2+}, Mg^{2+}, K^+, CEC, Zn and Cu in Nkundi soil in the fifth year of cultivation

Treatments	Ca^{2+}	Mg^{2+}	K^+	CEC	Zn	Cu
	................{cmol(+)/kg}			....	......(mg/kg)........	
Absolute control	1.27b	1.23a	0.32c	4.62c	0.52b	0.92b
$N_{120}P_0K_{100}$	0.71c	0.33b	0.36bc	4.90c	5.38a	6.66a
N_{120}TSP-$P_{120}K_{100}$	1.44b	0.43b	0.56a	6.13b	5.43a	7.42a
N_{120}MPR-$P_{120}K_{100}$	1.93a	0.49b	0.45b	8.17a	4.71a	6.99a
CV (%)	12.47	26.20	14.10	10.63	15.0	14.3

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

There was a significant decrease in level of exchangeable calcium in the soil that was not fertilized with MPR and TSP but treated with sulphate of ammonia. For this treatment, exchangeable calcium decreased from 1.27 to 0.71 cmol(+)/kg. Overall, use of MPR as source of P significantly increased levels of exchangeable calcium whereas TSP increased it just slightly. Elevated levels of exchangeable calcium were attributed to the high amount of calcium contained in MPR. Minjingu rock phosphate contains about 46.4% CaO. These results conformed to the findings by Chien *et al.* (1987). Studying long-term effects of phosphate rock applied in Oxisols, they observed that exchangeable calcium increased with phosphate rock but not with TSP applications. A significant decrease in exchangeable calcium in soil used for P control was attributed mainly to plant removals. There was no external supply of calcium to plants growing in Nkundi soil.

4.3.1.6 Exchangeable magnesium

Exchangeable magnesium values ranged from 0.33 cmol(+)/kg to 1.23 cmol(+)/kg in Nkundi soil (Table 9). These values were rated as medium to high (Landon, 1996). The highest value 1.23 cmol(+)/kg of exchangeable magnesium was observed in absolute control treatment. Therefore, there was significant ($P = 0.05$) decrease in levels of exchangeable magnesium in soil obtained from plots treated with MPR and TSP. Values of exchangeable magnesium due to treatments other than the absolute control were comparable.

Decrease in levels of exchangeable magnesium in Nkundi soil was attributed to depletion of magnesium through plant removal and leaching. There was no important external supply of magnesium to this soil. The results indicated that one could not rely on phosphate and nitrogenous fertilizers to supply magnesium to plants. Unless it is applied, with years magnesium would decrease to even lower levels. In five years time it has already decreased from high to medium levels. This means that in the future there will be a need to apply magnesium rich fertilizers to avoid its deficiency.

4.3.1.7 Exchangeable potassium

Exchangeable potassium in the soil ranged from 0.32 cmol(+)/kg to 0.56 cmol(+)/kg in Nkundi soil (Table 9). The values were rated as low to medium (Msanya *et al.,* 2001). Low values were for soils in absolute control and treatment control and the medium values were in soil treated with TSP and MPR, both in combinations with SA and potassium chloride. Treatment with MPR and TSP, both in combinations with SA and KCl resulted into comparable significant ($P = 0.05$) increase in exchangeable potassium. Results for absolute control and control for P treatments were slightly different. The observed build up of exchangeable potassium was attributed to applied potash fertilizers in the past four years. Also the fact that there was no increase in exchangeable potassium in plots used for control of P indicated that phosphate fertilizers contributed in build up of potassium in other treatments. Minjingu rock phosphate may sometimes contain as much as 1.4% K_2O (Mnkeni *et al.,* 1992).

4.3.1.8 Cation exchange capacity

Cation exchange capacity ranged from 4.62 cmol(+)/kg to 8.17 cmol(+)/kg in Nkundi soil (Table 9). These values of CEC were all rated as low (Landon, 1996). There was significant ($P = 0.05$) increase in CEC in soil treated with TSP and MPR in combination with SA and KCl. Absolute control and treatment control gave comparable levels of CEC. However, in terms of magnitude the treatment control had higher value of CEC than that of absolute control treatment.

Significant increase in CEC in Nkundi soil was attributed to application of MPR and KCl. Minjingu rock phosphate increased the level of exchangeable calcium and other exchangeable cations whereas KCl increased level of exchangeable of potassium. It is worthwhile to note that level of exchangeable Mg in this soil was on decrease (Table 9). Therefore any increase in CEC could reasonably be attributed to elevation in levels of exchangeable potassium and calcium. In general, CEC of this soil was low. The results of this study indicated that treatment with fertilizers did not elevate CEC from low to medium values. This was probably due to leaching. This is because this soil (sandy clay loam) is found in the area that receives high amount of rainfall. It receives annual mean precipitation of between 1000 and 1400 mm (Szilas, 2002). Since exchangeable bases are easily leached, those added amount from MPR and other fertilizers were probably lost through leaching.

4.3.1.9 DTPA zinc

Results of extractable zinc in Nkundi soil are presented in Table 9. The values of extractable zinc ranged from 0.52 mg/kg to 5.43 mg/kg. The values were rated as insufficient in absolute control plots and as sufficient in plots treated with fertilizers (Landon, 1996). There was statistically significant ($P = 0.05$) increase in levels of extractable zinc in treated soil but not in the absolute control plots. However, there was no any significant ($P = 0.05$) differences observed among treatments other than the absolute control.

Build up of levels of zinc in soils where zinc fertilizers are used has been reported. According to Mortvedt (1994), accumulation of available zinc generally occurs with annual applications of zinc fertilizers. Therefore increase in levels of zinc was largely attributed to the applied zinc fertilizers. The results of this study indicated that both types of phosphate fertilizers (MPR and TSP) had similar effects, if any, on contents of zinc in soil since they did not show any significant difference ($P = 0.05$) between them.

4.3.1.10 DTPA copper

The values of extractable copper ranged from 0.92 mg/kg to 7.42 mg/kg in Nkundi soil (Table 9). These values were all rated as sufficient (Lindsay and Norvell, 1978). There was statistically significant build up of copper level in the soil with reference to the absolute control treatment. No significant difference ($P = 0.05$) was observed between fertilized treatments.

Build up of copper levels was attributed to copper application. Copper sulphate was added to this soil in the fourth year of cultivation. Plants remove small amount of copper and accumulation occurs with application of copper fertilizers (Gartrell, 1981). It is also known that leaching of copper in soils is negligible (Jones and Belling, 1967). These could also be the reasons for sufficient levels of copper observed in absolute control.

4.3.2 Effect of residual phosphorus on maize grain yields at Nkundi site

Data on maize grain yields due to residual P from MPR and TSP obtained in the fifth year of cultivation at Nkundi site are presented in Table 10. Maize grain yields ranged from 1.03 t ha^{-1} to 4.73 t ha^{-1}. There was significant ($P = 0.05$) increase in maize yields in fertilized plots.

Table 10: Effects of residual P on maize grain yields at Nkundi site in the fifth year of cultivation

Treatments	Maize grain yields (t/ha)
Absolute control	1.03b
$N_{120}P_0K_{100}$	1.83b
$N_{120}TSP_{120}K_{100}$	4.23a
$N_{120}MPR_{120}K_{100}$	4.73a
CV (%)	12.8

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

The MPR and TSP treatments gave comparable yields and were significantly larger than yields from the absolute control and from treatment control. The absolute control treatment gave the lowest yields. Significantly higher yields in plots treated with MPR and TSP were attributed to residual P effects. This was because yields for plants grown in plots supplied with all nutrients except phosphorus had significantly lower yields. Also levels of Bray 1-P were higher for MPR and TSP treated soils than for absolute control and treatment control (Table 8).

4.3.3 Effects of residual phosphorus on nutrient concentrations in maize leaves

4.3.3.1 Phosphorus concentration

Concentrations of phosphorus in maize ear leaves are given in Table 11.

The concentrations of phosphorus at tasseling ranged from 0.12% to 0.22%. These concentrations were rated as insufficient for maize production (Campbell and Plank, 2000).

Table 11: Effects of residual P on concentrations of nutrients in maize shoots at tasseling for Nkundi site

Treatments	N	P	K	Ca	Mg	Zn	Cu
	……………………(%)……………………					…….(mg/kg)…..	
Absolute control	2.01a	0.14b	1.96c	0.19b	0.19a	9.2c	7.3b
$N_{120}P_0K_{100}$	2.17a	0.12b	2.33a	0.23b	0.13b	23.3a	10.2a
$N_{120}TSP_{120}K_{100}$	1.98a	0.22a	2.06b	0.34a	0.16a	12.3bc	8.9ab
$N_{120}MPR_{120}K_{100}$	2.00a	0.19a	2.06b	0.37a	0.18a	12.4bc	10.7a
CV (%)	6.81	8.95	5.12	10.05	17.05	26.8	13.9

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

However, treatment with MPR and TSP significantly (P = 0.05) increased concentration of P in ear leaves. Also the increase in P due to treatment with MPR and TSP were comparable.

The results indicated that phosphate fertilizer did not result in sufficient concentrations of P in maize plants and that TSP and MPR had comparable effects on concentrations of P in maize ear leaves. However, the soils in which the maize plants were grown had medium to high P levels. This suggest that the observed inadequate levels in plants were not due to low available P in soil but rather due to factors affecting phosphorus uptake in soils. According to Mahimairaja *et al.* (1995) most of the P dissolved from phosphate rocks undergoes immediate adsorption and immobilization reactions and only a fraction becomes available for plant uptake. Short terms experiments have shown that depending on the adsorption capacities of the soils, only 30 to 50% of dissolved P is taken up by plants (Kanabo and Gilkes, 1987). Also it has been reported that uptake is not reflective of P dissolution in soil (Mahimairaja *et al.*, 1995).

4.3.3.2 Nitrogen concentration

Nitrogen concentration in maize shoot ranged from 1.98 to 2.17 %. All values were rated as insufficient for optimum maize growth (Robert, 1998). There was no any significant difference ($P = 0.05$) between treatments. The observed insufficient concentration of nitrogen in all maize plants and for all treatments was attributed to low level of total N in Nkundi soil (Table 8). The relatively lower values in treated plants was probably due to dilution factor (Marschner, 1990).

4.3.3.3 Calcium concentration

Results of concentrations of calcium in maize ear- leaves are given in Table 11. The concentrations of calcium in the maize ear-leaves ranged from 0.19% to 0.37%. Concentrations of calcium in plants grown in soil treated with phosphate fertilizers were rated as sufficient and those in plants grown in control plots were rated as insufficient for optimum maize growth (Robert, 1998). Treatment with phosphate fertilizer significantly ($P = 0.05$) increased concentration of calcium in plant leaves. The effects of MPR and TSP on concentrations of calcium in plants were comparable.

Concentration of calcium in plants in the control treatment was similar to that from absolute control. Therefore, increased concentration of calcium in maize plants in soils treated with phosphate fertilizer was due to increased exchangeable calcium supplied by the phosphate fertilizers.

4.3.3.4 Magnesium concentration

The concentrations of magnesium in maize plant leaves are given in Table 11. The values of magnesium in maize plants at tasseling stage ranged from 0.13% to 0.19%. These values were rated as sufficient based on Robert's guidelines for rating concentration of magnesium in maize plants (Robert, 1998). Plants grown in soils treated with fertilizers other than magnesium had significantly lower concentration of magnesium.

The results indicated that treatment with phosphate fertilizers did not increase concentrations of magnesium in maize plants. Relatively lower concentrations of magnesium in maize plants grown in treated soil, were attributed to low levels of exchangeable magnesium in Nkundi soil. This was because no magnesium containing fertilizers were applied to this soil.

4.3.3.5 Potassium concentration

The results of potassium concentrations in maize leaves are given in Table 11. Its concentration ranged from 1.96% in absolute control plants to 2.33% in the treatment control. The concentrations of potassium were sufficient for optimum maize growth in all treatments (Robert, 1998). Fertilization significantly ($P = 0.05$) increased concentration of potassium in maize plants. Increased concentrations of potassium in maize plants were attributed to the applied KCl. Levels of potassium in Nkundi soil treated with phosphate and potash fertilizers were adequate for maize production.

4.3.3.6 Zinc concentration

Zinc concentrations in maize leaves ranged from 9.2 to 23.3 mg/kg (Table 11). Zinc concentrations were rated as sufficient only in maize plants in treatment control and the rest were rated as insufficient (Robert, 1998). There was no significant difference ($P = 0.05$) between concentrations of zinc in plants grown in treated soil and absolute control plots.

The soil from plots treated with MPR and TSP in combination with zinc and other nutrients had sufficient concentration of zinc (Table 5). Therefore, the observed insufficiency could not be attributed to lack of adequate zinc in the soil but rather to other factors that limited its availability to plants. This could also be explained in the light of antagonistic relationship that exists between P and Zn. Application of phosphorus fertilizers at higher rates has been found to reduce zinc availability in soils (Tisdale *et al.*, 1990 and Foth, 1990). In this study, the treatment for phosphorus control had the highest value of 23.3 mg/kg whereas those for MPR and TSP gave the lowest values of 12.4 and 12.3 mg/kg, respectively. Insufficient concentration of zinc in plants grown in soil fertilized with phosphate was also attributed to dilution effects. The concentrations of micronutrients generally decrease as plant weight increases in response to the provision of macronutrients (Kumar *et al.*, 1992).

4.3.3.7 Copper concentration

The concentrations of copper in maize at tasseling ranged from 7.3 mg Cu/kg to 10.7 mg/kg (Table 11). These concentrations were rated as sufficient for maize production (Campbell and Plank, 2000). Copper concentrations were significantly ($P = 0.05$) higher in plants grown in plots treated with MPR and for control of phosphorus. Minjingu rock phosphate, TSP and the treatment control had comparable effects on concentration of copper. These results indicated that plants had sufficient levels of copper and cultivation of maize could be continued for sometime without fear of copper deficiency

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and conclusions

The results indicated that use of MPR and TSP led to build up of residual available phosphorus in the three studied soils. The results also showed that application of these fertilizers had an implication on other soil properties and in particular soil pH and levels of exchangeable bases. However the extent that these fertilizers influenced soil properties and yields did also depend on the nature of these soils.

From the results of the present study, it was concluded that:

1. Application of MPR or TSP for four seasons resulted in substantial residual effects and can substitute each other.
2. The effectiveness of these sources of phosphorus was soil specific. Their agronomic performance, from the yield perspective, varied in different soils. Sasanda soil gave poor dry matter yields. The residual available P from MPR and TSP ranged from low for high P fixing Sasanda soil to medium and high levels in Mlingano and Nkundi soils with relatively low P fixing capacities. The level of residual available P in Sasanda soil was inadequate for optimum plant growth.
3. Use of MPR as source of phosphorus in areas where nitrogen fertilizers must be used but feared to increase acidity could be of added advantage over TSP since MPR counteracted the acidification effects of sulphate of ammonia.
4. Overall, production of maize could be done for sometime with entire dependency on residual P from the two studied sources after four years of their continued applications.

5.2 Recommendations

In accordance with the findings obtained in this study the following recommendations are made:

1) Studies should be carried out to establish for how long a crop would continue to benefit from the observed residual P in the soil resulting from treatment with MPR and TSP.
2) Studies should be done to include more soils in which MPR is being or is intended to be used in the future.
3) The findings of this study may not cut across other crops. It would, therefore, be rational to extend this study to other field crops

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7.0 APPENDICES

Appendix 1: Levels of N, K, Ca, Mg, Zn and Cu in soils after pot experiment

soil	treatment	N	Ca^{2+}	Mg^{2+}	K^{+}	Zn	Cu
		%	…….{cmol(+)/kg}……			……(mg/kg)…..	
Nkundi	Control	0.09a	1.18b	0.68a	0.46a	4.99c	5.90a
	MPR$_{120}$	0.07a	2.23a	0.13b	0.23b	7.74b	5.74a
	TSP$_{120}$	0.09a	2.24b	0.20b	0.08c	10.55a	1.28a
	CV (%)	15.96	15.53	31.02	17.8	18.02	8.79
Mlingano	Control	0.09a	1.70b	1.16a	0.62a	4.26b	2.97a
	MPR$_{120}$	0.10a	3.97a	0.50b	0.15b	10.43a	3.22a
	TSP$_{120}$	0.11a	1.22b	0.48b	0.17b	10.29a	2.96a
	CV (%)	6.30	28.45	23.14	26.61	4.48	14.28
Sasanda	Control	0.28a	0.39c	1.06b	0.77a	1.41b	5.85a
	MPR$_{120}$	0.25a	3.99a	1.29a	0.41b	4.04a	6.07a
	TSP$_{120}$	0.29a	0.87b	0.18c	0.44b	4.09a	3.47b
	CV (%)	18.82	13.29	8.76	12.25	7.89	5.76