

**COMPARATIVE EFFECTS OF MINJINGU PHOSPHATE ROCK AND
TRIPLE SUPER PHOSPHATE ON RESIDUAL P IN AN ULTISOL**

BY

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ABSTRACT

The use of relatively high rates of phosphorus (P) is known to result in a build up of P in soils and there are frequent claims that the use of phosphate rocks results in higher residual effects than water soluble sources. Thus the objective of this study was to assess residual P in treatments where relatively larger amounts of P from triple super phosphate (TSP) and Minjingu phosphate rock were applied. Total amount of P applied was 480 kg P /ha applied to *Kanhaplic Haplustult* at the Sokoine University of Agriculture farm. Residual P was assessed by Bray I extraction, sequential P extraction and growth of maize plants on soil samples collected from the treated soils as well as from the control treatment. The assessment of residual P was done seven years after P application was stopped. The results indicated that Bray I-P increased from 3.4 mg /kg in the control to 26.1 and 33.1 mg /kg in the MPR and TSP treatments, respectively indicating that MPR and TSP had comparable effects on residual available P. The total labile P increased by 45.3 and 50.2 mg /kg in TSP and MPR, respectively. The moderately labile P increased by 104.3 mg /kg and 77.0 mg /kg in TSP and MPR, respectively indicating that the residual P fractions from the two sources were different in P being held strongly by chemisorptions to Fe and Al components of soil surfaces. The increase in total recalcitrant P fraction was relatively higher in the MPR (114.4 mg/kg) than TSP (49.5 mg /kg) treatment. The pot experiment results showed that the P uptake from residual P in MPR and TSP treatments were comparable with 123.2 and 121.2 mg /pot, respectively but were significantly higher than the control treatments. Addition of fresh P applications into soil with residual P resulted in higher extractable P and P uptake than residual P alone. Recommended P applications from fresh TSP and MPR were comparable in

maize P concentration and uptakes. The contributions of total labile P, moderately labile and HCl- P on P uptake were 58 %, 64 %, and 49 %, respectively.

It was concluded that application of a relatively large rates of P either as MPR or TSP resulted in relatively high levels of residual available P seven years after P application was stopped but the levels achieved were below optimum under pot conditions.

DECLARATION

I, Asheri Mwamba Kalala do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor being currently submitted for a degree award in any other institution.

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The above declaration is confirmed

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Stay blessed by God!

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LIST OF SYMBOLS AND ABBREVIATIONS

%		percent
°C	-	Celsius Centigrade
<		less than
=		equal to
>		greater than
±		plus or minus
AAS	-	Atomic Absorption Spectrophotometer
Al	-	Aluminium
ANOVA	-	Analysis of Variance
B	-	Boron
Ca	-	Calcium
CaCl ₂	-	Calcium chloride
CaSO ₄	-	Calcium Sulphate
CEC		Cation exchange capacity
cm	-	Centimetre
cmol (+) /kg		Centimol per kg
CRBD	-	Completely randomized block design
Cu		Copper
DAP	-	Di-ammonium phosphate
DAS	-	Days after sowing
DM	-	Dry mater
DMRT	-	Duncan's Multiple Range Test
DMY	-	Dry mater yield

DTPA	-	Diethylenetriaminepentacetic acid
<i>et al.</i>		and others
Fe	-	iron
FeCl ₃	-	ferric chloride
FeO	-	iron oxide
FeO-Pi		iron oxide extractable inorganic P
g	-	gram
H		hydrogen
H ₂ O ₂	-	hydrogen peroxide
H ₂ SO ₄	-	sulphuric acid
HCl	-	hydrochloric acid
HNO ₃	-	nitric acid
hrs		hours
K		potassium
K ₂ Cr ₂ O ₇	-	potassium Dichromate
KCl	-	muriate of Potash
kg / ha -		kilogram (s) per hector
kPa	-	kilo Pascal
L.		Lineus
M	-	molar mass
Mg	-	magnesium
mg/kg		milligram (s) per kilogram
mg.	-	milligram
ml	-	millilitre

mm	-	millimetre
Mn	-	manganese
Mo	-	molybdenum
MPR		Minjingu phosphate rock
MSTAT-C		Michigan state University of Agricultural Statistical Centre
N	-	nitrogen
Na		sodium
$\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$	-	sodium Molybdate
$\text{Na}_2\text{B}_4\text{O}_8 \cdot 10\text{H}_2\text{O}$	-	Di-sodium tetraborate decahydrate
NaCl		sodium chloride
NaHCO_3^-	-	sodium bicarbonate
NaOH	-	sodium hydroxide
$\text{NaOH}^- \text{Pi}$	-	sodium hydroxide extractable inorganic P
NaOH-P_o		sodium hydroxide extractable organic P
NH_4F	-	ammonium fluoride
NH_4OAc		ammonium acetate
P		phosphorus
pH	-	negative logarithm of hydrogen ion activity
Pi	-	inorganic P
P_o	-	organic P
PR	-	phosphate rock
R^2		determination of coefficient
S	-	sulphur

SSP		single super phosphate
SUA	-	Sokoine University of Agriculture
TSP	-	triple Super Phosphate
USDA	-	United States Department of Agriculture
yrs	-	years
Zn	-	zinc
ZnSO ₄ .7H ₂ O)	-	zinc Sulphate

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CHAPTER ONE

1.0 INTRODUCTION

Good quality and optimal production of crops is influenced by the ability of soils to supply nutrients which include Phosphorus (P). Phosphorus is an essential nutrient for plants and often the first limiting element in acid tropical soils (Buehler *et al.*, 2002). Sharpley *et al.* (1994) argued that low P in soils contributed greatly to declining food production. Therefore, a good understanding of the P dynamics in the soil–plant system and especially of the short- and long-term fate of P fertilizer in relation to different management practices is essential for the sustainable management of tropical agro ecosystems (Friesen *et al.*, 1997).

Although P is very stable, immobile, and not easily leached in soils, still many acidic soils do not supply sufficient P in the available forms and proportions for optimal plant growth; because they have a potential of fixing phosphorus. In Tanzania, over 50% of cultivated soils are estimated to be deficient in P (Semoka and Kalumuna, 2000). These soils are characterized by low total and available P contents and high phosphate retention (fixation) capacities (Msolla *et al.*, 2005a). Other factors which contribute to low soil P availability include crop harvests without replenishing the uptaken nutrients, sub-optimal applications of fertilizer and loss through erosion.

Different measures have been taken to revamp the problem of low P in soils; so as to supply adequate amount of P for crop production. Researching on the factors contributing to low P and how to supply or replenish the depleted P from soils are some of the measures taken.

The use of chemical fertilizers is often considered to be an immediate solution to correct nutrient deficiencies in soils (Woomer *et al.*, 1997). P in soils can be replenished either immediately with a large, one-time P application or gradually with moderate seasonal applications of P at rates sufficient to increased availability of available P. Tanzanian farmers have been using water – soluble phosphate fertilizers especially triple super phosphate (TSP), and di-ammonium phosphate (DAP). It was reported that between 1994 and 95 season only 15 % of Tanzanian farmers were found to use some mineral fertilizers with very low application of phosphate fertilizers at an average rate of 1.9 kilograms per hectare of cultivable land (ICRA, 2001).

Kimbi *et al.* (1996) reported that water soluble fertilizers are expensive to resource poor farmers, so these farmers could benefit more by using phosphate rock (PR) fertilizers which are less expensive. There are a number of PR deposits in Tanzania some of which are sufficiently reactive to serve as good sources of P (Woomer *et al.*, 1997). Currently in Tanzania the fertilizer strategy is to use water insoluble Minjingu Phosphate Rock (MPR) as an alternative to water soluble sources in suitable soils (i.e. acidic soils with pH less than 6.5). For example in 2008/ 09 Tanzania annual budget, about 24 160 tones of MPR were supplied compared with 2000 tons of DAP under subsidy scheme by the Government to be used by farmers (Lugendo, 2009).

Depending on soil conditions the amount of P applied might have residual effect. Sanchez and Palm (1996) defined residual P as a stock of soil P that gradually supplies plant available P for about 5 to 10 years. Buresh *et al.* (1997) argued that the

residual benefit from added P increases with increasing P sorption capacity, except for soils with allophane. Two scenarios of build up in residual P in soils are distinguished depending on the fertilizer source. Hughes and Gilkes (1986) argued that soils that have been fertilized with PR fertilizers may contain un-dissolved PR that can persist for many years after application.

This is because only a portion of the PR dissolves quickly (within weeks) and the remainder dissolves slowly (over several years). Consequently appreciable amounts of P may be present in soil for many years after application. Additionally, Zapata and Roy (2004) portrayed with water soluble P sources the residual effects are derived from the soil phosphate reaction products and the reaction of prime importance is the conversion of P from labile to non labile form. Different from PR's where PR-P need to be released into the solution before any residual effect can manifest itself. Residual P determination is very important and much have been done in studying fractions of residual soil P in relation to yields either as grain or dry matter yields (DMY). According to Mutuo *et al.* (1999) levels of residual P depend on the fractions analyzed. The residual P fractions often analyzed are Resin- extractable Pi, NaHCO₃ extractabe, NaOH extractable Pi and dilute HCl -extractable Pi.

1.1 Objectives

The general objective of the study was to assess residual P in an Ultisol seven years since fertilizer application ceased and its effect on maize dry matter yield and P uptake.

1.2 Specific Objectives

- (i) To determine the residual P levels in experimental plots previously (seven years) treated with a total of 480 kg P/ha from either TSP or MPR in an Ultisol at Magadu, SUA farm
- (ii) To identify P fractions which contain the residual P and their relationships to maize growth
- (iii) To assess adequacy or otherwise of the residual P levels for maize growth

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Assessment of Residual P in Soils

Chemical sequential extraction procedures have been and still are widely used to divide extractable soil P into different inorganic and organic fractions (Hedley *et al.*, 1982; Mutuo *et al.*, 1999). The underlying assumption in these approaches is that readily available soil P is removed first with mild extractants, while less available or plant-unavailable P can only be extracted with stronger acids and alkali (Pierzynski *et al.*, 2000). Residual phosphorus in soils can be determined by assessing the available pool using chemical extractants e.g. Bray 1-P in acidic soils (Mbanzibwa, 2004; Sotomayor-Ramrez *et al.*, 2004). The Olsen test is used for soils with pH values higher than 7 and is not recommended for PR treated soil as it underestimates the available P for plants because it does not extract un-dissolved PR which sometimes contributes to plant available P.

Secondly, residual P can also be assessed by determining different P fractions in soils treated with P sources after a certain period of soil and P fertilizer contact. Kosia (2003) used deionised water (H_2O -P) and $NaHCO_3$ - extractable P_i as a readily available P fraction. The common method used for P fractionation is a sequential P extraction method developed by Hedley *et al.* (1982) followed by some modifications (Tiessen *et al.*, 1984; Linquist *et al.*, 1997; Mutuo *et al.*, 1999). The sequential P fractionation method removes progressively less available soil P with each subsequent extraction, and also provides details about the organic portion of soil P. Most researchers have grouped the P fractions into labile, moderately labile and

recalcitrant P fractions (Mtengeti, 2008). The labile P fraction is the P loosely sorbed and in rapid equilibrium with soil solution. There is equilibrium between labile and non labile P pools in the soil which controls the ability of the soil to supply P to plants (Buresh *et al.*, 1997). The highly labile P fraction is thought to be readily available to plants and is commonly determined by either resin method (Amer *et al.*, 1955) or iron oxide impregnated filter paper (Pi) method (Linguist *et al.*, 1997; Habib *et al.*, 1998; Pierzynski *et al.*, 2000). Both of these methods give closely related results. Normally highly labile P fraction is depleted during crop uptake after P fertilization is stopped which indicates that it is a potential source of P for plants. The other fraction constituting the labile P fraction is the NaHCO_3 -extractable Pi and Po (Mutuo *et al.*, 1999). NaHCO_3 -extractable Po represent the most easily mineralizable pool of Po consisting organic compound like ribonucleic acid, glycerol-phosphate and some microbial P which contribute to plant available P (Anderson, 1980). The NaHCO_3 -extractable Pi is a labile inorganic pool thought to consist of P adsorbed on more crystalline compound surface of sesquioxides or carbonates. Normally the sum of NaHCO_3 -extractable Pi and FeO-Pi constitute the inorganic labile pool.

The moderately labile P fraction is made up of NaOH-Pi and NaOH-Po representing P strongly sorbed onto Fe and Al oxides and clay edges and is slowly available to plants (Guo *et al.*, 2000). The NaOH-Po is associated with stable organic compounds such as fulvic and humic- acids as well as inositol phosphates sorbed to Al and Fe hydroxide (Anderson, 1980). The NaOH also removes Pi and soil organic P (Po) associated with amorphous hydrous oxides of Al and Fe (Hedley *et al.*, 1982).

Moderately labile P acts as a sink of P during P fertilization and increases with P applications (Msolla, 2005a).

The hydrochloric acid (HCl)- P extracts P associated with apatite or octacalcium phosphate (Frossard *et al.*, 1995). This fraction comprises undissolved portion of phosphate rock as well as octacalcium phosphate which comprises a large portion of P in young soils (Cross and Schlesinger, 1995). This fraction is generally thought to be of low availability to plants (Tiessen *et al.*, 1984; Mtengeti, 2008).

Strong sulphuric acid P (H_2SO_4 -P) sometimes termed recalcitrant P fraction is determined at the end by reacting the remained soil used in the preceding steps with $\text{H}_2\text{SO}_4 + \text{H}_2\text{O}_2$ (Guo *et al.*, 2000). This fraction is thought to consist of P_i occluded by sesquioxides (Hedley *et al.*, 1982) P in resistant primary minerals and very stable P_o possibly associated with humic and fluvic acids and sesquioxides- stabilized inositol. The recalcitrant P fraction does not shortly contribute to the available P for the plants.

2.2 Effects of P Sources on Residual P Fractions

There is a remarkable effect of P sources on residual P fractions when the soil is treated with either soluble or water insoluble fertilizers. According to Mutuo *et al* (1999) in an experiment where an Ultisol was treated with 250 kg P/ha of either TSP or MPR there was a gradual decrease of extractable P following TSP application. After one week 34 % of the added P was extracted with anion resin, 38 % was extracted with mixed resin, and 22 % was extracted with bicarbonate. In the same trial at 18 months, only 10% of the added P was extracted with anion resin, 12% was

extracted with mixed resin, and 6 % was extracted with bicarbonate. Other researchers like Linquist *et al.* (1997) have reported similar trends of rapid decline in extractable P following a large application of water soluble P fertilizer.

In the case of MPR application at 250 kg P /ha, Mutuo *et al.* (1999) reported that anion resin P decreased between 7 and 18 months whereas 6 % was extracted as bicarbonate P throughout 18 months period. At 18 months, anion resin P and bicarbonate P were comparable for PR and TSP application. Msolla *et al.* (2005b) reported differences in the distribution of P fractions in soils treated with TSP and MPR. Studying four soils differing in P sorption capacities, he found the TSP treatment to have higher labile fraction ranging from 127 to 141.2 mg P /kg while MPR treated soil ranged from 91 to 118 mg P /kg. He further found that the HCl-P fraction was significantly higher in the MPR than TSP treatments, ranging from 56 to 132 and from 47 to 79 mg P /kg respectively. Msolla *et al.* (2005b) suggested that the higher HCl-P fraction may indicate Ca-P from apatite that was not yet dissolved.

A significant increase in total labile P fraction was reported by Mtengeti (2008) when an Acrisol was treated with either TSP or MPR at 200 mg P /kg in a pot experiment. Total labile P was significantly higher in the TSP treatments than MPR treatments. Higher labile P under TSP than MPR was also reported by Msolla (2005a) in the same soil type. When P is applied with plant residues it affects P fractions. Kolawole and Tian (2007) studying the effects of Sokoto phosphate rock (PR) and plant residues on soil phosphorus fractions in an Alfisol in Nigeria found that when PR was applied with plant residues, maize P uptake was positively correlated with resin

P having coefficient of determination (R^2) of 0.53, while when it was combined with *Crotalaria* the coefficients of determination (R^2) were 0.60 and 0.49 for dry matter and P uptake, respectively, showing that those parameters were positively correlated with NaOH-Po. Application of PR alone did not affect yields and P uptake of *Crotalaria* and maize.

2.3 Effectiveness of Residual P in Soils

Effectiveness of residual P sometimes depends on the amount of fertilizer applied. Kamprath (1967) reported that a single large application of 680 kg P/ha from TSP maintained maize yield at 90% of maximum yield for nine years without further P applications while 340 kg P/ha had low residual effects which indicated further that high rates of P have higher residual effects than lower P rates. In both acidic and basic soils, substantial benefits from residual P can persist for as long as 5 to 10 years or more and of course the duration of response will be influenced by the amount of residual P (Tisdale *et al.*, 1993). Studying P fractions Nziguheba *et al.* (2002) found that the effectiveness of P declined when applications were stopped. Where P was applied at 150 kg ha⁻¹ once at the beginning of the study, resin P declined from 54.9 to 22 kg P/ha from fourth to eighth crop. Ibrikci *et al.* (2005) reported changes in soil P values where the initial P levels of 24 mg /kg declined to 10 mg /kg after 3 years in a calcareous soil. Msolla *et al.*, (2005b) reported that in the first year, performance of MPR was low but in the second and third years the performance of MPR approached that of TSP and the relative agronomic effectiveness of MPR increased from 50–70% in the first year to 80 – 95% in the third year. The results implied that MPR can replace TSP on acidic soils with low available Ca and P. Kosia

(2003) reported increases in all P fractions over the control after an application of MPR, while an application of TSP increased significantly NaOH-Pi over MPR indicating that TSP has higher solubility.

Effectiveness depend on both the amount P applied but also the P adsorption capacity of the soil. It was reported (Satell and Morris, 1992) that when the soil with high adsorption capacity applied with 98 mg P /kg to maintain adsorption of 0.2 mg P /L, during fractionation the soil constituted 45% moderately P while the soil applied with 29 mg P /kg constituted 27 % of moderately labile P and 54 % of labile P. This indicates that the presence of 2:1 layer silicate in the soil and low amount of P sorbing minerals (Fe and Al oxides) influences the amount sorbed and available P to plants.

2.4 P Concentrations in Plants

Nutrient sufficiency levels (in percentage) for P at different stages of development were recorded to range from 0.4 to 0.6 % for shoots at 24 -45 days, 0.35 to 0.5 % for the third leaf at green silks, and 0.25 to 0.4 for third leaf at brown silks (Tisdale *et al.*, 1993). One unit of levels below these values are considered low or deficiency and can cause deficiency symptoms. Low levels of P concentration results in deficiency symptoms which are purpling or reddening of leaves which affect lower leaves initially while leaf tips may turn dark brown and die (Tisdale *et al.*, 1993). Steinhilber and Salak (2009) have reported different P sufficiency levels for maize crop at different stages by grouping them into seedling stage: 0.3- 0.5 %, prior to tassel stage: 0.25- 0.45 and at silking stage: 0.25-0.50 %. Below these values the

plants are said to be low in P concentration and deficiency symptoms may appear on plants.

2.5 Adequacy of Residual P in Soils

Sometimes water soluble and water insoluble P sources can have comparable residual P effects. In five year experiment, a single application of single super phosphate (SSP) and Algerian rock phosphate (APR) at 175 kg P/ ha resulted into high residual available P and maintained high crop yield for five years. After the five years period, there were still high P balances of 51 to 65 kg P / ha in soils with both SSP and APR (Nemeth *et al.*, 2002).

Adequacy of P sometimes depends on the initial amount of fertilizer applied, as soluble fertilizers can be easily changed from readily available to less available. Ibrikci *et al.* (2005) after initial year's fertilization (0, 33, 66 and 99 kg P /ha) followed by subsequent years applications of 0, 9, 18, 27 and 36 kg P /ha to a Typic Xerofluvent found that soil P values increased from the initial P levels of 8 to 24 mg /kg but declined after 3 years to 6–10 mg /kg. Only the lowest subsequent annual P application rate (9 kg P /ha) produced an available P level that was not in the sufficiency range. Grain yields across the main and subplots and years ranged from 6.6 to 13.2 t /ha. Overall corn yield averaged over the years increased by 8–33% compared with the control as the rates of applied P increased. In that experiment it was found that a residual P effect on grain yield occurred with application of higher P levels of 99 kg P /ha. For example, the recovery was at 33 kg P /ha,

ranged between 10.8 and 46.4%. The researchers indicated that adequate plant available P levels can be maintained by modest P fertilizer application rates.

Abekoe and Sahrawat (2003) reported that a single application of different levels of TSP in an Ultisol followed by continual rice cropping for five years was not adequate to increase P levels for optimal rice production as Bray I at the end of project was less than 15 mg P/kg. The labile P_i was reduced from 10.8 mg P /kg in the uncultivated soil to 7.62 mg P /kg in the control. The treatment in which 90 kg P/ha was applied had labile P_i level of 10.7 mg P /kg. In the treatments in which 135 kg P/ha and 180 kg P/ha were applied had labile P_i increased by 1.3 and 2.7 mg P /kg, respectively above that of the uncultivated one. The NaOH- P_i and H_2SO_4 -P fractions increased with increasing rates of P application. After five years of experiment NaOH- P_i was 7.62 mg P /kg in the control compared to 13.5 mg P /kg at 180 kg P/ha. Moderately labile P in the control treatment was 24.7 mg P /kg compared to 60.5 mg P /kg in the 135 kg P/ha treatment. Therefore the researcher suggested that adequacy might be attained by frequent supply of P and not only a single application.

2.6 Fractions of Soil P in Relation to P Plant Availability

Several studies have related different P fractions in tropical soils to plant growth. Application of inorganic P fertilizers can increase bicarbonate and hydroxide P when the rate of P addition exceeds P uptake by plants (Linquist *et al.*, 1997). Most researchers have reported that when inorganic P sources are added to the highly weathered soils NaOH-P becomes a dominant pool. Kosia (2003) reported higher NaOH- P_i fraction (67.6 %) in TSP treatment than that in MPR treatment (55.7 %)

meaning higher soil P capital was in TSP treated soil than MPR. The NaOH-P_i fraction is a sink for soluble P fertilizer added in excess of plant uptake and is subsequent source of plant available P (Beck and Sanchez, 1994). Iyamuremye *et al.* (1996) reported that addition of manure or alfalfa (*Medicago sativa* L.) residues to acid low-P soils of Rwanda increased resin-P_i, NaHCO₃-P_i and -P_o, as well as NaOH-P_i. In the study of Guo and Yost (1998) resin-P_i, NaHCO₃-P_i, and NaOH-P_i were most depleted by plant uptake on highly weathered soils indicating that NaOH-P_i was important in buffering available P supply to the plants. Satell and Morris (1992) reported that in the green house experiment, applying sufficient P to elevate soil solution concentrations to 0.2 µg P / g, phosphorus concentration in foxtail millet (*Setaria italica* (L)) was significantly related to 58% of labile inorganic P while resin extractable P was found to contribute 53 % of P taken up. Also the moderately labile organic fraction was significantly related to P uptake. NaOH was a dominant pool with an average of 45 % of total soil P and of this 72 % was in organic form.

There is evidence that plant uptake produces an imbalanced state in soil solution by depleting different P forms surrounding the root zone. The reactions related to soil P transformations varies depending on soil type, climatic conditions and management practise (Zhang and Mackenzie, 1997). The fractions of P in relation to plant P availability might vary with different soil orders. Mdahir *et al.* (2007) found the largest pools of NaOH-P_i and H₂SO₄-P_i in the rooting zones of an Aridisol, followed by Inceptisol, Mollisol and Entisol. Residual-P amounted to 19-26% of total P in the Mollisol, 32-51% of total P in Aridisol, 30-34% in the Inceptisol and 39-54% in the

Entisol with a higher percentage in the deepest horizons for each of the soil orders. The researcher suggested that the readily plant available soil P pools of Mollisol were sufficiently large to support crop production. On the other hand, in the Aridisol, Inceptisol and Entisol the labile P pools were small. In the Aridisol, re-supply from more stable P fractions (NaOH and H₂SO₄ -Pi) might contribute to P availability over time. However, in the Inceptisol and Entisol, re-supply of the labile P fraction from the more stable pools will not be sufficient given small pool sizes, and so regular P applications will be needed to sustain crop production for these soil orders.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Soil Sampling and Sample Preparation.

The long term residual effects of the two sources of P, namely triple super phosphate (TSP) and powder Minjingu phosphate rock (MPR) were determined in a green house experiment at Sokoine University of Agriculture.

Bulk composite topsoil (to a depth of 15 cm) samples were collected from experimental plots that were fertilized with TSP or MPR with a total of 480 kg P/ha at the rate of 120 kg P/ha in each year for four years consecutively from 1998 to 2002. The experimental site is located at Magadu area of Sokoine University of Agriculture farm. Another soil sample was collected from the absolute control plots of the same experimental site. Each sample was collected from replicates of the treatments selected. The composite samples were air –dried and ground to pass through an 8mm sieve for a pot experiment. One sub-sample of one kilogram from each treatment was taken from the bulk sample, ground and sieved to pass a 2 mm sieve for laboratory routine analysis and P sequential fractionation.

3.2 Pot Experiment

3.2.1 Phosphorus sources and treatments

Four kilograms of each composite air- dried soil were weighed into a clean five litres plastic pot. Ten designated treatments which are described below in Table 1 were applied to potted soils and replicated three times and their details are in Appendix 1. The choice of P levels used in the treatments based on the need to compare the

effectiveness of residual P from TSP and MPR fertilizers. Residuals were also compared with fresh applications of both TSP and MPR. Another consideration was the performance of residual P when combined with fresh application of either TSP or MPR when added with the same rate found in the soil or applied fresh at the recommended rate.

Table 1: The treatments used in pot experiment

Treatments no.	Rates applied (mg P/kg soil)	Treatments description/ abbreviation of rates used
1	$P_0N_0K_0Zn_0S_0B_0Mo_0$	Absolute Control
2	$P_0N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P treatment control
3	$P_{26.1}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	$P_{26.1}$ (Residual MPR)
4	$P_{33.2}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	$P_{33.2}$ (Residual TSP)
5	$P_{66.4}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	$P_{66.4}$ (Residual + fresh TSP)
6	$P_{66.4}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	$P_{66.4}$ (Residual + fresh MPR)
7	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P_{160} (Residual + fresh MPR)
8	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P_{160} (Residual + fresh TSP)
9	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P_{160} (Fresh MPR)
10	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P_{160} (Fresh TSP)

Key:

- 1: No nutrients were applied
- 2: No P was applied, other nutrients applied at recommended rate
- 3: Received P from residual MPR, other nutrients at recommended rate
- 4: Received P from residual TSP, other nutrients at recommended rate
- 5: Received P as residual TSP added with the same amount fresh TSP (i.e. 66.4 mg P/kg)
- 6: Received P from residual MPR and fresh application made to 66.4 mg P/kg
- 7: Received P from residual and fresh MPR to recommended P rate(160 mg P/kg)
- 8: Received P from residual and fresh TSP to recommended P rate (160 mg P/kg)
- 9: Received P from fresh MPR only to recommended P rate (160 mg P/kg)
- 10: Received P from only fresh TSP to recommended P rate (160 mg P/kg)

3.2.2 Other nutrients applied in the pot experiment

In addition to phosphorus, other nutrients were applied to all treatments except the absolute control to correct their possible deficiencies. The nutrients added were nitrogen at 400 mg /kg from Urea, potassium at 50 mg /kg from KCl, sulphur from Calcium sulphate (CaSO_4); Zinc at 10 mg /kg from Zinc Sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), sulphur was supplied at 20 mg /kg from both Calcium Sulphate and Zinc Sulphate. Other supplied nutrients were Boron at 2 mg /kg from Di-sodium tetraborate decahydrate ($\text{Na}_2\text{B}_4\text{O}_8 \cdot 10\text{H}_2\text{O}$) and molybdenum at 1 mg /kg from Sodium molybdate ($\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$).

3.2.3 Planting and management of pot experiment

Maize (*Zea mays* (L) variety TMV₁) was used as the test crop in the pot study. The designed treatments (Table 1) were replicated three times and arranged in complete randomized block design (CRBD) in the green house at Sokoine University of Agriculture. Four seeds were sown in the moistened potted soils. Moisture content of the soils in the pots was determined by the Salvage method (Appendix 2) and was maintained at $\pm 90\%$ field capacity by timely application of distilled water to replenish moisture 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. Also plates were placed underneath to collect any solution with nutrients that leached out which was later returned into the pots. Seedlings were thinned to two plants per pot, 12 days after sowing (DAS). The first dose of N was applied at 12 DAS and the second dose of N was applied at 21 DAS. The plants were grown for 35 days after which shoots were harvested by cutting at 1 cm above the soil surface.

Shoots were dried in the oven at 65 °C to constant weight, ground using a cyclone mill to obtain powder which was used for laboratory analysis.

3.3 Laboratory Analysis

3.3.1 Routine soil analysis

Physical-chemical properties of each sample were determined to get the general fertility status of the soils in each plot. Also soils used in pot experiment were analysed for physical-chemical properties after shoots harvesting.

3.3.1.1 Soil Texture

Particle size analysis was determined by the hydrometer method after dispersing the soil samples in sodium hexametaphosphate solution (National Soil Service, 1987).

Soil textural classes were determined using the USDA textural class triangle (USDA, 1995).

3.3.1.2 Soil pH

Soil pH was determined using a pH electrode in 1:2.5 soil: water suspension as described by Page *et al.* (1982).

3.3.1.3 Cation exchange capacity

Cation exchange capacity (CEC) was determined by using the ammonium acetate (NH₄OAc, pH 7) saturation method (National Soil Service, 1987). Exchangeable Ca and Mg in the ammonium acetate leachate were determined by atomic absorption

spectrophotometry, while exchangeable K and Na were determined using the flame photometer method.

3.3.1.4 Organic carbon and total nitrogen

Organic carbon was determined by the Walkey and Black method as described by 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 nitrogen was determined by the semi-micro Kjeldahl procedure (Page *et al.*, 1982).

3.3.1.5 Extractable micronutrients

Available Zn, Cu, Fe and Mn were extracted by 0.05 M DTPA and levels determined using atomic absorption spectrophotometer (National Soil Service, 1987).

3.3.1.6 Bray -1 phosphorus

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

using a Spectrophotometer at a wavelength of 884 nm. The absorbance was then used to calculate P (National Soil Service, 1987).

3.4. Fractionation of Soil Phosphorus

Residual P analysis followed the sequential fractionation procedure described by Mutuo *et al.* (1999) with some modifications. Five fractions were sequentially extracted using the same soil sample. The extracted fractions were Iron Oxide impregnated filter paper inorganic P fraction (FeO-Pi), NaHCO₃- P, NaOH-P, HCl-P, and H₂SO₄- P.

The soils used for P fractionation and pot experiment were obtained by mixing thoroughly three replicates of each treatment to have the composite subsoil samples for the treatments of interest. Then the obtained composite sample of each treatment was used to determine the P fractions in duplicates.

The first fraction was extracted by Iron Oxide impregnated filter paper (FeO-Pi) procedure (Pierzynski *et al.*, 2000) instead of resin extraction. Preparation of FeO paper strips and phosphorus extraction procedure is detailed in Appendix 3. Sharpley (1994) reported that P extracted by FeO strips was closely correlated with P extracted by anion exchange resin. The FeO-Pi procedure is simple and cheap compared with anion exchange resin but is also a very suitable method for estimating plant available P in PR treated soil (Zapata and Roy, 2004). In the same soil sample the sequential extraction for the subsequent fractions was conducted as presented in Fig 1. After each step of the sequential extraction soil residues were washed twice using 10 ml

portions of saturated sodium chloride (i.e. 3 M NaCl). The washings were added to the decanted supernatant. Aliquots of the NaHCO_3 and NaOH solution were digested in an autoclave (103.4 kPa, 121 °C for 1 hour) by acidified ammonium persulphate oxidation and analyzed for total P. Organic P (Po) for each fraction was calculated as the difference between total P in the respective extracts (NaHCO_3 or NaOH) and the inorganic P (Pi) in the extracts. The sequence of the sequential extraction and the fraction extracted by each step is summarized in Fig.1.

3.5 Plant Sample Preparation and Analysis

Plant shoots were weighed, ground with a cyclone mill, and sieved through a 1-mm sieve ready for plant analysis. Leaf samples were analyzed following the HNO_3 - H_2O_2 wet digestion procedure. The extracted and determined nutrients were N, P, K, S, Mg Ca and Na. Also micro nutrients Fe, Zn, Cu and Mn were determined in the same digests by DTPA method.

3.6 Statistical Analysis

Data generated in the experiment was subjected to analysis of variance (ANOVA) using MSTAT-C (1990) package and treatment means were separated by Duncan's Multiple Range Test (DMRT) at the significance level of 5%. Correlation analysis was performed for plant P concentration in maize tissues from different P sources against fractions of extracted P in soils.

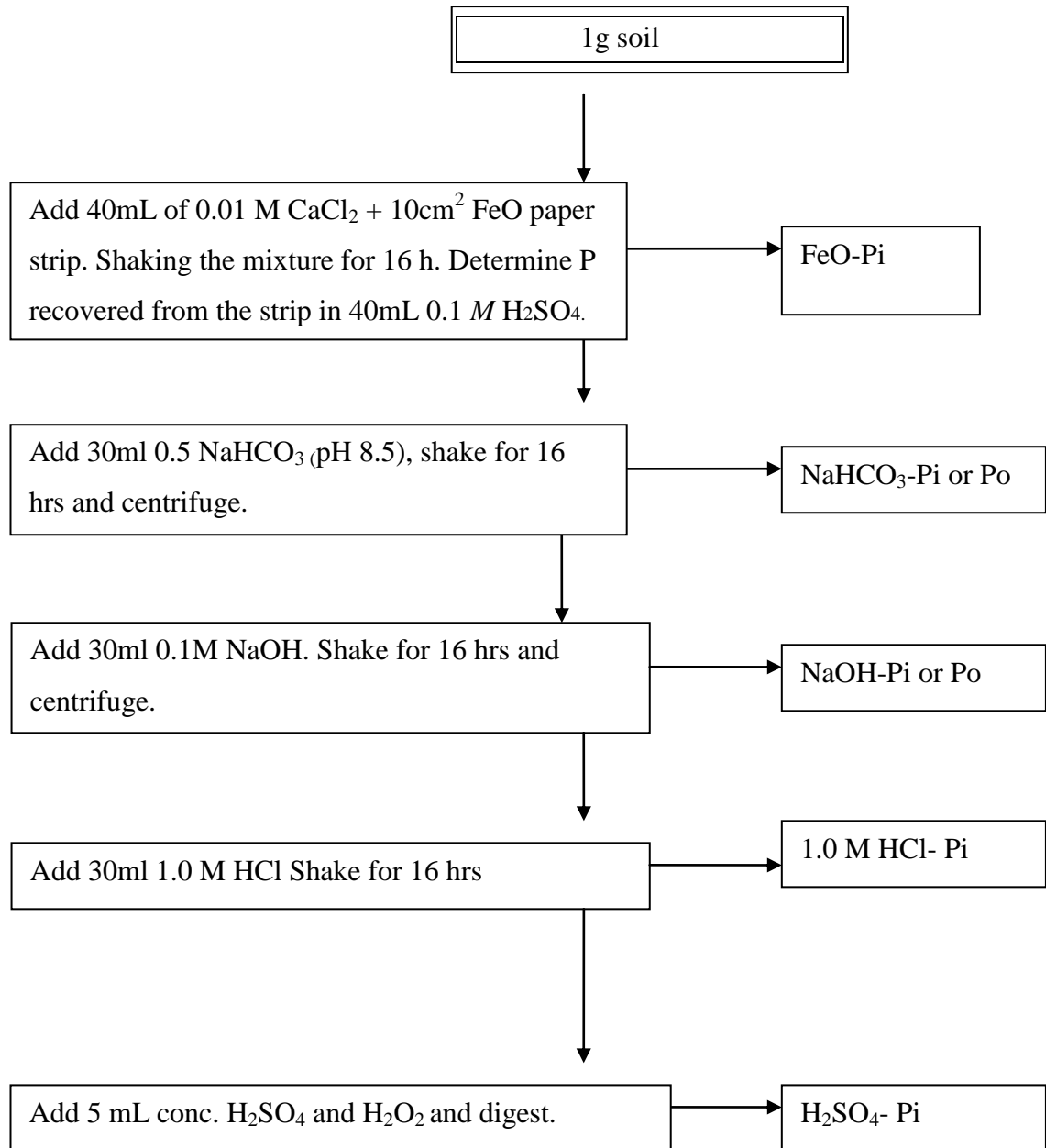


Figure 1: A schematic presentation of the Phosphorus fractionation procedure.

A Modified procedure of (Mutuo *et al.*, 1999; Pierzynski *et al.*, 2000).

Statistical model $Y_{ij} = \mu + T_i + B_j + E_{ij}$ (i)

Where,

Y_{ij} = Observed response value for treatment in block j

μ = General effect

T_i = Treatment effect on value for treatment i

B_j = Block or replication effect (mean value for block j)

E_{ij} = Random error where, $i = 1, 2, \dots, t$ and $j = 1, 2, \dots, j$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Chemical and Physical Properties of Magadu Soil Sampled Seven Years after P Application Ceased

Physical and chemical properties of soils collected in an experimental site from Magadu farm are presented in Table 2.

4.1.1 Physical properties of soils

Results of physical properties of soils collected from Magadu farm after seven years since P application ceased are summarized in Table 2. Soil texture classes of the three treated soils were clay. Minjingu PR treated soil had clay values 55 % which was relatively higher to the TSP treated soil and an absolute control soil both with values 53 %. The bulk density was relatively higher in MPR treated soil 1.5 g cm^{-3} compared to 1.2 g cm^{-3} of the TSP and the absolute control soil. The relative higher values of clay and bulk density noted in MPR treated soil compared to TSP and absolute control soils likely was caused by Ca released from MPR fertilizer. Calcium acts as the cementing material of soil colloids (Zapata and Roy, 2004) and was found relatively higher in MPR compared to TSP and absolute control treated soils

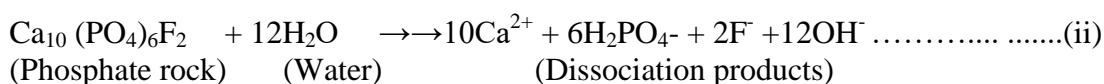
4.1.2 Chemical properties of Magadu soil sampled seven years after P application ceased

Chemical parameters of Magadu soil sampled seven years after P application ceased are presented in Table 2. These parameters includes soil pH, exchangeable

acidity, cation exchange capacity, micronutrients, organic carbon, total nitrogen, and extractable phosphorus

4.1.2.1 Soil pH and exchangeable acidity

Soil pH was 4.3, 4.4 and 4.3 for the absolute control, MPR and TSP treated soils, respectively. These pH values are rated as very strong acidic soils (Landon, 1991). Exchangeable acidity was 3.1 for absolute control soil, 1.9 for MPR and 2.3 for TSP treated soil. The relatively higher values of pH and low exchangeable acidity in MPR treated soil might be contributed by the release of Ca from MPR. Kosia (2003) reported increases in pH of Suluti and Sasanda acidic soils treated with MPR for three seasons of cultivation although there was an application of sulphate of ammonium which has an acidifying effect. The pH and total exchangeable acidity of the treated soils from Magadu farm shows high ability of MPR dissolution because they can supply appreciable hydrogen ions to neutralize the hydroxyl ions released during the process. Generally the dissolution of phosphate rock can be presented by the equation



The use of PRs, depending on their reactivity is generally recommended in soils with pH of 5.5 or less and the dissolution diminishes as with increasing pH up to 5.5. When considering a large number of soils, titratable acidity may be a better indicator of PR dissolution (Zapata and Roy, 2004). Soil pH shows the magnitude of hydrogen ion supply at a given time, whereas titratable acidity indicates the supply of hydrogen ions in the longer time.

Table 2: Chemical and physical properties of the experimental soils collected from Magadu farm seven years after P application ceased

Parameters (units)	Absolute control	MPR plot	TSP plot	Methods of analysis
Chemical properties				
pH	4.3	4.4	4.3	1: 2.5 soil: water
Organic Carbon (%)	1.1	1.1	1.2	(Nelson and Somers, 1982).
Total (N %)	0.1	0.1	0.1	Kjeldahl. (Bremner and Mulvaney, 1982).
Extractable P (mg/kg)	3.4	26.1	33.2	Bray I (Bray and Kurtz, 1945).
Extractable SO ₄ -S (mg/kg)	15.7	22.1	26.8	Turbid metric spectrophotometer
Exchangeable cations (cmol (+) /kg)				
Ca	1.3	2.3	1.5	Ammonium acetate. (National Soil Service, 1987).
Mg	1.7	1.7	1.8	-do-
K	0.3	0.2	0.3	-do-
Na	0.1	0.1	0.1	-do-
Exchangeable H ⁺	0.4	0.2	0.4	1 M KCl (Van Ranst <i>et al.</i> , 1999).
Exchangeable Al ³⁺	2.7	1.7	1.9	
Total Exchangeable acidity	3.1	1.9	2.3	
CEC (cmol (+) /kg)	15.0	17.4	16.8	Ammonium acetate. (National Soil Service, 1987).
Micronutrients (mg/kg)				
Cu	0.7	0.8	0.8	DTPA method (Lindsay and Norvell, 1978).
Fe	34.3	39.4	49.5	-do-
Zn	1.1	5.6	4.3	-do-
Mn	60.5	50.6	54.4	-do-
Physical properties				
Sand (%)	40	38	40	Hydrometer method (Gee and Bauder, 1986).
Silt (%)	7	7	7	
Clay (%)	53	55	53	
Textural class	clay	Clay	clay	(USDA, 1975)
Bulk density (g/cm ³)	1.2	1.5	1.2	

4.1.2.2. Cation exchange capacity and exchangeable cations sampled seven years after P application ceased

The CEC for MPR treated soil had values (17.4 cmol (+) /kg) which was relatively higher than the absolute control and TSP treated soil with 15.0 and 16.8 (cmol (+) /kg) respectively. The CEC in all treatments were medium (Landon, 1991; Szilas *et al.*, 2005). The relatively high CEC values observed in the MPR treated soil was probably due to its relatively high content of clay fraction. The soils with CEC below 15 (cmol (+) /kg) are considered to have low fertility status (Landon, 1991). The indicated CEC of these soils might be attributed to the soil mineralogy as they were dominated by low activity clay minerals such as kaolinite and aluminium and iron oxides (Szilas *et al.*, 2005).

The determined exchangeable cations were Sodium (Na), Potassium (K), Calcium (Ca), and Magnesium (Mg). According to Landon (1991) and (Tisdale *et al.* 1993) the values of exchangeable bases in cmol (+) /kg are rated as follows: for Ca < 4 as low and > 10 (cmol (+) /kg) as high; for K the values are rated as < 0.2 as low and > 0.6 (cmol (+) /kg) as high; for Mg < 0.5 as low and > 4.0 (cmol (+) /kg) as high.

The Ca values were 1.3, 2.3 and 1.5 in cmol (+) /kg for an absolute treated soil, MPR and TSP treated soils, respectively which are rated as low levels (Tisdale, 1993; Landon, 1991). The relatively high value of Ca in MPR treated soil was contributed by MPR dissolution releasing Ca in the soil solution. These soils had adequate levels of K and Mg. Perrot *et al.* (1993) suggested that high exchangeable magnesium in soils may enhance PR dissolution as Mg is held by soils more strongly than Ca, the

presence of Mg on the soil exchange sites may block adsorption of Ca released on dissolution of PR and thereby facilitate its removal from the soil fertilizer system.

4.1.2.3.1 Micronutrients after seven years since P application ceased

The micronutrients determined were copper, iron, zinc and manganese (Table 2). According to Sims and Johnson (1991), the critical range of copper is 0.1 to 0.25 mg Cu /kg. The determined copper was above that critical range (0.71 mg Cu /kg for control, 0.79 and 0.83 mg Cu /kg for MPR and TSP treated soil respectively. These levels of Cu indicate the soil to be adequate in Cu. The critical range of Zn in soils (Sims and Johnson, 1991) is 0.2 to 2.0 mg Zn /kg suggesting the soil to be adequate in Zn. The critical range for iron is 2.5 to 5.0 mg /kg and 1.0 to 5.0 mg /kg for manganese (Mn) (Sims and Johnson, 1991). It was suggested (Landon, 1991) that Mn is being considered high when more than 2000 mg /kg are found in soil. Therefore the levels of Mn were not to toxic level. The relatively higher levels of Mn would be attributed to high solubility as the soils are very strongly acidic.

4.1.2.3.2 Soil organic carbon and total nitrogen after seven years of P application

The total organic carbon (OC) was 1.2 % for TSP and 1.1 % for both an absolute control and MPR treated soil. These values are rated low as are less to 2 % (Landon, 1991). Total N was 0.11% for non treated soil, 0.12 % and 0.13 % for both MPR and TSP treated soils, respectively. These values are rated as low according to (Tisdale *et al.*, 1993).

4.1.2.3 Extractable phosphorus after seven years since P application ceased

The levels of Bray I for soils collected from Magadu farm after seven years since P fertilizer application ceased are presented in Table 2. The levels were 3.4, 26.1 and 33.2 mg P /kg for an absolute control, MPR and TSP treated soils, respectively. The Bray I P was very low in the absolute control soil which indicates P deficiency (Landon, 1991). The levels of extractable P in TSP and MPR treated soil were above the suggested critical level (Singh *et al.*, 1977) of 25 mg P /kg which has been rated as adequate for maize in Morogoro soils. But the value of extractable P from TSP treated soil was slightly comparable to that in the MPR treatment which is contrary to claims by most researchers who suggest that phosphate rock gives higher residual effects than TSP (Guo *et al.*, 2000; Zapata and Roy, 2004). This may indicate that long time residual effects do not depend only on water solubility characteristics of the fertilizer but also the capacity of a soil to fix P.

The Ultisol used in this study has medium P fixing capacity which might have resulted in small quantity of soluble P from TSP to be fixed. Mbanzibwa (2004) reported an increase in Bray I P after four years of MPR and TSP application in Nkundi and Mlingano soils which have moderate P fixing capacity compared to low levels in Sasanda soil having high P fixing capacity in which both TSP and MPR did not show increases in extractable P. It can be suggested from this study that for an Ultisol in similar conditions like Magadu the effect of residual P in extractable P from both MPR and TSP is comparable.

4.1.3 Effects of P sources on P fractions in Magadu soils collected seven years after fertilizer application ceased

4.1.3.1 Total labile P fractions

The Iron Oxide Pi fraction (FeO-Pi) and NaHCO_3 -P fractions in the experimental soils which constitute the labile P fraction are presented in Table 3 and appendix 5.

The iron oxide impregnated paper (FeO-Pi) Pi values were 5.6mg /kg for an absolute control; 25.2 mg /kg and 14.0 mg /kg for TSP and MPR treated soils, respectively. These values indicate that TSP treated soil had relatively higher (FeO-Pi) than MPR treated soil meaning the potential to supply P for plants was higher in TSP than MPR treated soil. The potential of the native soil (absolute control) to supply P was low. Zapata and Roy (2004) suggested the critical level for FeO-Pi in acidic soils to be 14 mg /kg.

Table 3: Labile P fractions of Magadu soil collected seven years after P application ceased

Treatment	P fractions (mg /kg)			
	FeO-Pi	Total NaHCO_3 - P	Total labile P	ΔP
Control	5.6	7.4	13.0	0.0
TSP	25.2	33.1	58.3	45.3
MPR	14.0	49.1	63.2	50.2

ΔP = The difference in total labile P fraction of the treated soil and an absolute control soil

Total NaHCO_3 values were 7.4 mg /kg for absolute control soil, 33.1 mg /kg and 49.1 mg /kg for TSP and MPR treated soil. These two fractions in combination give the total labile P in respective treatments. The total labile fractions were 13.0mg /kg in

absolute control soil, 58.3 mg /kg and 63.1 mg /kg for TSP and MPR treated soils. The MPR treated soil had slightly higher total labile P than that in TSP treated soil but may have similar performance in terms of plant growth and therefore MPR and TSP may have comparable potential to release P for plant growth. This finding is contrary to Msolla (2005b) and Mtengeti (2008) who reported higher labile P fraction under TSP than MPR in an Acrisol three years subsequent to P fertilizer application.

Table 4: Moderately labile P fraction in Magadu soil collected seven years after P application ceased

Treatments	P fractions (mg /kg)			ΔP
	NaOH-Pi	NaOH-Po	Total NaOH -P	
Control	69.1	45.2	114.3	0.0
TSP	119.2	99.4	218.6	104.3
MPR	107.6	83.6	191.2	77.0

ΔP = The difference in Total NaOH –P fraction of the treated soil and an absolute control soil

4.1.3.2 Moderately labile P fractions

The NaOH-Pi and NaOH- Po fractions in the experimental soils which constitute the moderately labile P fraction are presented in Table 4 and Appendix 6. These two fractions in combination give total NaOH-P which constitute moderately labile P fraction (Mutuo, 1991). The difference in moderately labile P (Total NaOH –P) fraction in the TSP treatment (104.3 mg/kg) was slightly higher than in MPR (77.0 mg/kg) treated soils. This indicates that the treatments had different characteristics of

P being held strongly by chemisorption to Fe and Al components of soil surfaces (Guo *et al.*, 2000). Kosia (2003) suggested that the transfer of different P fractions was strongly dependent on the degree of P saturation of soil Al and Fe hydroxides. Furthermore from these obtained results it can be suggested that these treatments had different potential in increasing the moderately labile P pool. Similar effects was reported by Mtengeti (2008) after treating an Acrisol with 1580 mg P /kg, that moderately labile P fraction was higher in TSP (26.6 %) than MPR (22.6 %) treatments.

Table 5: Total recalcitrant P fraction in Magadu soil collected seven years since P application ceased

Treatment	P fractions (mg /kg)			ΔP
	1M HCl-P	H ₂ SO ₄ -P	Total recalcitrant P	
Control	11.9	232.9	244.8	0.0
TSP	34.6	259.8	294.3	49.5
MPR	46.8	312.4	359.2	114.4

Note: ΔP = The difference in total recalcitrant P fraction of treated soil and an absolute control soil

4.1.3.3 Recalcitrant P fractions

Both P sources increased hydrochloric acid P (HCl- P) with MPR treated soil having slightly higher HCl- P (46.8 mg P /kg) than TSP treated soil (34.5 mg /kg.).

This indicates the presence of higher undissolved portion of apatite in MPR than in TSP treated soil. Mtengeti (2008) reported higher values of HCl-P in MPR 12 to 13 times higher than that of TSP in an Andosol suggesting that application of high

rates of MPR may result in a large portion of undissolved PR, apatite and that the proportion of undissolved PR increase with increasing P rates.

The values of H₂SO₄ fraction had similar trend to HCl in that the highest value was in MPR treated soil which indicates the presence of resistance minerals to dissolution during subsequent reagent extractions. The relative lower values for TSP were associated with high solubility in preceding reagents.

The highest total recalcitrant fractions were relatively higher in the MPR treated soil with a value of 359.2 mg /kg or ($\Delta P = 114.4$ mg /kg) compared to TSP and an absolute control soil with values of 294.2 or ($\Delta P = 49.5$ mg /kg) and 244.8 mg /kg or ($\Delta P = 0.0$ mg /kg) respectively (Table 5). This indicates that a large portion of Ca bound P or undissolved apatite was in MPR treated soil than TSP. Kosia (2003) found similar trend with MPR having higher values of HCl-Pi than TSP. The fraction estimates active soils Pi in undissolved PR that can supply plant available P (Buresh *et al.*, 1997). Kosia (2003) reported that out of 180 mg P/kg applied as MPR about 112.7 mg P/kg were not dissolved after three years.

4.2. Comparative Effects of Residual P from Two Different Sources and Their Combination with Different P Rates of MPR and TSP on Soil pH and Selected Nutrients

The effects of residual P from two different sources and their combination with different P rates of MPR and TSP on some important soil and plant parameters after pot experiment are presented in Table 6 and 7.

4.2.1 Soil pH after pot experiment

The results for pH in soils after the pot experiment are presented in Table 6. Different P rates influenced pH significantly with MPR treatments resulting in higher pH levels than TSP. Statistically there was a slight difference of about pH 0.4 units between TSP and MPR treatments. Comparing the treatments used the control soil by applying either fresh TSP or MPR to recommended P rates, MPR treatment increased pH from 4.4 to 4.6 while TSP lowered pH from 4.4 to 4.2. The higher values of pH in MPR to TSP treatments could have been caused by the release of Ca from MPR as a result decreased levels of hydrogen ions in soils. An absolute control treatment was fairly comparable to pH values of MPR than TSP treatments which are contrary to the expectations that would have been lower because no Ca was applied to that treatment. The increase in pH due to MPR application agree with the study in long-term reactions of phosphate rocks (176 kg P/ha) in an Oxisol in Colombia (Chien *et al.*, 1987) in which there was an increase in soil pH with all treatments compared to the control. Mtengeti (2008) reported an increase of 0.3 units for MPR and a decrease of 0.2 units for TSP after applying 200 mg P /kg of fertilizer in Acrisol. It was also reported (Kosia, 2003; Mbanzibwa, 2004) that there was an increase in pH of MPR treated soil compared to TSP which had no shift.

4.2.2. Bray I P after pot experiment

The results for Bray I P in soils after pot experiment are presented in Table 6. The application of both MPR and TSP increased Bray I- P levels significantly in the treated soils. The P treatment control and absolute control were not significantly

Table 6: Effects of residual P from two different sources and their combination with different P rates of MPR and TSP on soil pH, nitrogen, Bray I-P and exchangeable bases.

Treatments	pH	Total N (%)	Bray I- P (mg/kg)	Exchangeable bases (cmol(+)/kg)		
				K	Ca	Mg
Absolute Control	4.4 abc	0.12a	6.3 g	0.1d	1.4 f	1.0 a
P treatment control	4.5 ab	0.13a	6.3 g	0.6 a	1.4 f	1.0 a
P _{26.1} (Residual MPR)	4.5ab	0.12a	28.5 f	0.2 c	2.2 c	0.9a
P _{33.2} (Residual TSP)	4.2 bc	0.12a	30.2 f	0.3 b	1.2 g	0.9 a
P _{66.4} (Residual + fresh TSP)	4.1 c	0.12a	65.3 a	0.3 b	1.6 e	0.9 a
P _{66.4} (Residual + fresh MPR)	4.5 ab	0.11a	40.7 de	0.2 c	2.5 b	0.9 a
P ₁₆₀ - (Residual + fresh MPR)	4.4 ab	0.13a	53.4 bc	0.2 c	3.1 a	0.9 a
P ₁₆₀ (Residual + fresh TSP)	4.2 bc	0.13a	60.4 ab	0.2 c	1.6 e	0.9 a
P ₁₆₀ (Fresh MPR)	4.6 a	0.12a	36.4 ef	0.2 c	2.5 b	1.0 a
P ₁₆₀ (Fresh TSP)	4.2 bc	0.12a	47.6 cd	0.2 c	1.7d	1.0 a
CV (%)	3.7	4.4	12.7	9.4	4.2	4.4

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

different both having Bray I- P values 6.3 mg P/kg. These values are very low according to (Landon, 1991; Singh *et al.*, 1997).

Both the MPR and TSP residual P treatments and fresh application treatments of both TSP and MPR were above the critical level of 25 mg P/kg established by Singh *et al.* (1997). Residual MPR and TSP treatments had comparable Bray I P levels of 28.5 and 30.2 mg P/kg, respectively. This indicates that TSP and MPR had similar effect on residual P found in these soils after maize growth. The treatment that contained P from residual TSP plus an equal amount from fresh TSP had 65.3 mg/ P kg and was significantly higher than the treatment that contained P from residual MPR plus fresh MPR to attain 66.6 mg P/kg which had Bray I 40.7mg /kg. This was attributed to the higher solubility of TSP than MPR resulting in the higher amount of extractable P in TSP than in MPR treated soil. Treatment received P to recommended P rate from fresh and residual MPR treatment with a value of 53.4 mg P/kg was slightly comparable to the treatment that received P to recommended P rate from fresh and residual TSP from fresh and residual TSP with a value 60.4 mg P /kg. The same reason that TSP is soluble in water and supply high quantity of P in soil solution accounted for this trend. A similar trend was observed for the treatments which received recommended P from fresh MPR (36.4 mg /kg) compared to the one which received recommended P from fresh TSP (47.6 mg /kg). This finding suggests that all fresh application of either TSP or MPR increased plant available P but the TSP applications resulted into higher values than MPR. Mtengeti (2008) reported the same that in all TSP treatments Bray I P was high compared to MPR although the recommended rates had higher P values than lower rates.

4.2.3 Exchangeable calcium

The results for exchangeable Calcium (Ca) in soils after the pot experiment are presented in Table 6. Fresh application of both MPR and TSP increased Ca levels in all the treatments over the control. Statistically all MPR rates increased exchangeable Ca over the control and TSP treatments. MPR treated soil had higher levels of Ca than TSP treated soil. The recommended P rates of MPR were statistically higher in Ca content than those which received recommended P from TSP. The higher increase in exchangeable Ca in MPR treatments is attributed to its higher content of Ca than TSP. Minjingu phosphate rock contains up to 46.4 % CaO (Mnkeni *et al.*, 1992; Szilas, 2002) while TSP contains 12 to 14 % Ca (Tisdale *et al.*, 1993). Although calcium was applied as Calcium sulphate in the P treatment control there was no significant increase in Ca compared to the absolute control may be because the applied Ca was taken by plants. The finding from this study is that MPR application results in an increase in Ca levels when applied in soils compared to inorganic mineral fertilizer like calcium sulphate.

4.2.4 Total nitrogen

The results for total N in soils after the pot experiment are presented in Table 6. There was no increase in total N statistically regardless that the nutrient was applied in all the pot soils except the absolute control. The levels of N were low (Landon, 1991) ranging from 0.11 to 0.13 (%). It can be suggested that most of applied N was used by plants for growth. In both control treatments N was not used optimally by plants because P was limiting. Mbanzibwa (2004) reported an increase in N for Sasanda soil compared to that of Nkundi and Mlingano which had higher available P

levels. The reason is that the decrease of N levels in soil due to plant uptake depends on the availability of P where small plants due to lack of P takes small amount of N and reduce negligible amount of N in soils as high amount would remain in soil.

4.2.5 Exchangeable K and Mg

The results for exchangeable K and Mg in soils after the pot experiment are presented in Table 6. Despite that KCl was applied at the same rate in all potted soils except in an absolute control there was a significant difference for levels of exchangeable K in these treated soils. Higher level was in the P treatment control with a value of 0.6 cmol(+)/kg which is rated as very high according to Landon (1991). This was a result of small plants due to low soil P availability and therefore small quantity of K up taken by plants and much left in soil. This might imply that for K to be taken up by plants will require sufficient P supply in soil. The absolute control had low levels of K because K was not applied; indicating that in this Ultisol K can contribute to poor plant growth. Statistically, all potted soils treated with recommended P rates were comparable in K taken up indicating that when P is applied as either MPR or TSP at the recommended rate then K taken from the soil is comparable.

Magnesium levels were not significant different ($P=0.05$). This may indicate that an application of either TSP or MPR does not influence magnesium in soil therefore for a Mg deficient soil it would be better to add a mineral fertilizer containing Mg before application of these two P sources. Mbanzibwa (2004) reported appreciable decrease

Mg for poor inherent Mg soils when MPR and TSP were used without mineral fertilizer application.

4.3 Comparative Effects of Residual P from Two Different Sources and Their Combination with Different P Rates of MPR and TSP on Crop Performance

4.3.1 Visual assessment of maize growth

Maize seeds were completely sprouted at day seven. In the first 12 days maize plants were growing at uniform rate and no symptoms could be clearly observed in either P applied fertilizer or control treatments indicating that seeds were still capitalizing on their reserved nutrients (Plates 1: (a), (b), (c) and (d)). After the nutrient reserve in seeds were exhausted and plants started to depend on external supply from the soils, deficiency symptoms due to P and N became obvious in absolute control and purpling due to P deficiency in P treatment control and absolute control. This suggested that in absolute control treatment both P and N were limiting plant growth but only P was limiting after the supply of N in P control treatment. In treatments which received P either as fresh or residual and other recommended nutrients, stems were big, leaves were green and plants showed vigorous growth at 21 DAS (Plates 2: (a), (b), (c) and (d)).

An assessment made for plants at day 35 before shoots harvesting showed remarkable visual differences within the treatments. In absolute control treatment plant stems were very thin, pale in colour indicating N deficiency, also irrigated water in these pots was little indicating low evapotranspiration, purplish colour

indicating severe P deficiency and almost all the lower leaves had senesced. In P treatment control only P deficiencies symptoms observed, indicating P was limiting after N supplied. Plants grown in residual P of either TSP or MPR had comparable performance and no deficiency symptoms were observed. Only two lower leaves were necrotic compared to five leaves on the control treatments. The stems of plants grown in either residual P treatments or fresh applications were big and plants were very big compared to control pots suggesting adequate supplies of the test nutrients.

4.3.2 Dry matter yield and shoot length of pot maize

Dry matter yield and plant shoots length results are presented in Table 7. It can be generalized that DMY of both P treatment and absolute control treatments were low and statistically comparable. This might be attributed to the fact that P and N are very important nutrients for better accumulation of dry matter in plants. Much more emphasis is put in P because even after application of all necessary nutrients including N in the P treatment control still the DMY was not statistically increased indicating that P limit the plants to utilize other nutrients unless it is supplied above critical level. The dry matter yields for both TSP and MPR residual P treatments were fairly comparable, and both of them had lower yields than fresh P application treatments. The relative lower DM yields in residual P treatments to fresh application indicates that the available P to plants in P treatment control was not enough to accumulate higher dry matter as fresh applications could have resulted.



Plate 1a: Showing plants without nutrient deficiency symptoms in P treatment control at 12 DAS.



Plate 1b: Showing plants without nutrient deficiency symptoms in an absolute control treatment at 12 DAS



Plate 1c: Showing growing plants in residual P from TSP added with fresh TSP treatment at 12 DAS.



Plate 1d: Showing growing plants in residual P from MPR added with fresh MPR treatment at 12 DAS.



Plate 2a: Showing plants growing vigorously in residual P of MPR and TSP treatments compared with unhealthy plants grown in absolute control treatment and P- treatment at 21 DAS.



Plate 2b: Showing maize plants grown in residual P of MPR and TSP treatments compared with plants in residual P added with the same amount of fresh MPR at 21 DAS.



Plate 2c: Showing plants grown in residual P of MPR and TSP treatments compared with plants grown in recommended P from fresh MPR at 21 DAS.



Plate 2d: Showing plants grown in residual P of MPR and TSP treatments compared with plants grown in recommended fresh application of TSP at 21 DAS.

Table 7: Effects of residual P from two different sources and their combination with different P rates of MPR and TSP on plant DMY, shoot length, P uptake and concentrations

Treatments	DMY (gm/pot)	Shoot length (cm)	P concentration (%)	P uptake (mg/pot)
Absolute Control	4.3 d	59.5 d	0.24e	10.3 c
P treatment control	6.7 d	78.8 c	0.26 e	17.4 c
P _{26.1} (Residual MPR)	36.8 bc	129.0 b	0.34 d	123.2 b
P _{33.2} (Residual TSP)	34.8 c	133.7 b	0.35 d	121.2 b
P _{66.4} (Residual + fresh TSP)	45.9 a	137.3 b	0.38 c	174.4a
P _{66.4} (Residual + fresh MPR)	40.7 abc	139.7 b	0.40 b	162.8 a
P ₁₆₀ (Residual + fresh MPR)	44.0 ab	140.0 b	0.40 b	175.9 a
P ₁₆₀ (Residual + fresh TSP)	44.9 a	134.0 b	0.41 ab	186.2 a
P ₁₆₀ (Fresh MPR)	41.3 abc	141.3 b	0.43 a	177.3 a
P ₁₆₀ (Fresh TSP)	45.3 a	160.0 a	0.41 ab	180.0 a
CV (%)	12	5.5	4.4	10.7

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

The trend of shoot length was comparable to DM yields. The absolute control plants were significant different from other treatments that were applied with other nutrients. As it was in DMY the plants in the P control were significantly taller than those in the absolute control but shorter than plants in the residual P and fresh P application treatments indicating that the shoot length depends on P and other nutrients availability. Recommended P from fresh application of TSP treatment had relatively taller plants compared to plants in other which treatments received either P

as fresh or residual P. The findings indicate that fresh application of P from TSP sources increased more plant height and DMY compared to the treatments received only residual P. Mbanzibwa (2004) reported an increase of DMY for plants grown in residual P of either MPR or TSP applied at 120 kg/ha for four years.

4.3.3 Phosphorus uptake and concentrations in maize plants

Concentrations and uptake of P in maize plants are presented in Table 7. The concentrations in plants ranged from 0.24 to 0.43 (%). It was suggested by Tisdale *et al.* (1993) and Steinhilber and Salak (2009) that the P sufficiency levels to be 0.3 to 0.6 % for maize plants prior tasselling. The absolute control and P treatment control were not significant different ($P=0.05$) and had low levels of P concentration in shoots. This indicates that the native soil could not supply enough P for plant growth and P was limiting plant growth in these treatments, therefore farmers using similar soils for maize cultivation are likely to get poor harvests due to P limitation. Residual P and fresh P application from both MPR and TSP increased phosphorus concentration in the shoots significantly and the P concentration values for these treatments were above the sufficiency range. This indicated that application of P from either of the source in these soils is essential for crop production. The shoots concentration of P in the residual P of MPR and TSP treatments were statistically comparable and were above control treatments but less than those to fresh application due indicating that the residual P found into the soil was enough for maize production at least for a single cropping season.

Recommended P applications from fresh TSP and MPR resulted in higher P concentration in plants than the other treatments indicating that higher performance of production could be attained when residual P is supplemented with fresh application although it might lead to luxurious consumption of P. The residual P levels in the MPR and TSP treatments were above the level of 25 mg P/kg (Singh *et al.*, 1997) reported to be adequate under field conditions. In this experiment it has been found that all fresh application treatments had increased DMY, P concentration and P uptakes significantly over the residual P treatments thus it was concluded that the suggested optimal P levels in soil under field conditions is not enough under pot experiment to supply plant available P at optimal levels and might need to be reviewed.

Uptake of P followed a similar trend to that of P concentration in plants. The P uptake values in control treatments were comparable but were significantly lower than uptake values in the other treatments. This was attributed to higher P supply in the soil for these treatments resulting into higher P concentration and DMY which in turn gave higher P uptake values. It can be generalized that the soils treated with P from both P sources (MPR and TSP) supplied enough P and had higher uptakes while the control treatments had inadequate P supply and had low levels for optimal plant growth. A similar trend was reported by Mbanzibwa (2004) in Nkundi and Mlingano soils treated with the same P sources.

4.3.4. Calcium concentrations and uptake in maize plants.

Concentrations and uptake of Ca in maize plants are presented in Table 8. All the Ca concentrations values in maize leaves ranged from 0.15 to 0.32 %. Tisdale *et al.* (1993) and Steinhilber and Salak (2009) reported sufficiency levels of calcium to be 0.3 to 0.6 %. Bergman (1992) proposed a higher Ca sufficiency range of 0.5% to 1 %. The concentration levels were high in control treatments. This may be due to low DMY the nutrients are concentrated as can be easily extracted. The rest of the treatments were statistically comparable in the levels of Ca concentration in plant shoots, but at the same rate of P application MPR treatments had relatively higher values of Ca concentration than TSP, indicating that MPR was slightly better in Ca supply to plants than TSP. Mtengeti (2008) reported similar findings that at the third season of her experiment, Ca concentration was higher in MPR treated soil than TSP treatments.

Calcium uptake followed a different trend to Ca concentrations. The control treatments had significantly lower Ca uptake values than those in which either MPR or TSP was applied. This is because the DMY in control treatment plants were very small compared to those plants in treatments that received P and other nutrients. The residual P treatments of MPR and TSP gave statistically comparable Ca uptake although at the same rate of P application in MPR treatments the values of Ca uptake were higher than TSP treatments because MPR resulted in higher Ca concentration.

4.3.5 Nitrogen uptake and concentrations in maize plants.

Concentrations and uptake of nitrogen (N) in maize plants after the pot experiment are presented in Table 8. The absolute control treatment had 0.9 % N indicating that the soil was severely deficient in N. The deficiency level of N is suggested to be 2.45 % at earleaf stage of maize plants (Reuter and Robinson, 1986). This indicates that N was limiting plant growth in this treatment. The N concentration in other treatments ranged from 2.7 to 2.8 % and was statistically higher than that in the absolute control treatment showing a clear response to N application. However, this range was below the sufficiency range of levels 3.5 to 5.0 % suggested by (Tisdale *et al.*, 1993) and Steinhilber and Salak (2009) therefore plant shoots had low N. The residual P of MPR and TSP treatments were statistically comparable in N concentrations, meaning that the influence of P residuals on concentration of N in plants was similar. Fresh application of MPR and TSP at the P recommended rate was statistically comparable in plants N concentration meaning application of fresh P did not influence N uptake.

The N uptake was statistically lower in absolute control treatments due to small plants with lower DMY and low levels of concentration. Although the P control treatment had comparable N concentration value to other treatments its uptake was statistically lower because of small plants which resulted in lower DMY than the other treatments. The residual P treatments had statistically comparable N uptake values but were significantly than the control treatments. The treatments which received P at 66.4 mg P/ kg from MPR increased N uptake as compared to the plants in residual P treatments. This implies that applying MPR similar to that found in the soil increases the amount of N taken up.

Table 8: Effects of residual P from two different sources and their combination with different P rates of MPR and TSP on plant Ca and N uptakes and concentrations

Treatments	Ca conc. (%)	Ca uptake (mg/kg)	N conc. (%)	N uptake (mg/kg)
Absolute Control	0.26 ab	10.2 c	0.9 c	36.5 h
P treatment control	0.32 a	20.6 c	2.7 b	183.6 g
P _{26.1} (Residual MPR)	0.21b	78.9 ab	2.7 b	1005 f
P _{33.2} (Residual TSP)	0.19b	61.8 b	2.7 b	978 f
P _{66.4} (Residual + fresh TSP)	0.15b	71.40 ab	2.8 a	1251 ab
P _{66.4} (Residual + fresh MPR)	0.21b	89.1 ab	2.8 a	1142 e
P ₁₆₀ - (Residual + fresh MPR)	0.23ab	102.2 a	2.8 a	1233 bc
P ₁₆₀ (Residual + fresh TSP)	0.18 b	83.0 ab	2.7 b	1216 cd
P ₁₆₀ (Fresh MPR)	0.18 b	77.9 ab	2.8 a	1196d
P ₁₆₀ (Fresh TSP)	0.16 b	78.1 ab	2.8 a	1274 a
CV (%)	25.1	12	3.8	16.7

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

4.3.6 Potassium, Magnesium and Zinc concentrations and uptakes in maize plants

Concentrations and uptake of K, Mg and Zn in maize plants are presented in Table 9. The levels of K ranged from 2.9 to 4.5 (%). These levels of K are within the sufficiency range (2.5 to 5.0 %) suggested by (Tisdale *et al.*, 1993; Steinhilber and

Salak, 2009) which indicates that the growth of plants was not limited by K availability in the different treatments. The absolute control treatment had a higher K concentration value than other treatments; despite that no KCl was applied to this treatment as was done in other treatments. This indicates that the soil had enough K for maize growth. In P treatment control K was applied as KCl and the concentration indicating K was not limiting nutrient in this treatment. The residual TSP treatment had higher concentration of K than the residual MPR treatment probably due to higher levels of Ca in residual MPR treatment. In all TSP treatments K concentration values were higher than those in MPR treatments. This might indicate an antagonistic effect between K and Ca (Table 9). So that in soils with low K levels application of MPR might need an application of K to avoid imbalances. Pathak and Kalra (2007) reported that corn grown on lime treated soils had higher Ca and Mg content and lower K content indicating that K was hindered by the presence of high Ca levels from lime. Regardless that K concentration was high in control treatments their uptake was the lowest probably due to small plants which accumulated small amount of P. The highest K uptake was found in treatment where 160 mg P /kg was from TSP as a fresh application.

Magnesium concentration in maize plants ranged from 0.33 to 0.48 %. These values fall in the sufficiency range reported by Tisdale *et al.* (1993) and Steinhilber and Salak (2009) to be 0.15 to 0.6 % for maize plants. The highest value was observed in the P treatment control which was significantly different from other treatments. There was no Mg applied in the treatments as the soil had adequate levels of Mg (Table 2) for plant growth. The absolute control and all other treatments were fairly

comparable in Mg concentrations showing that this element was not limiting plant growth in the potted soils. At equal rate of P application either from TSP or MPR the Mg concentration in plants was not significantly different which indicate that both the two sources had no influence on Mg concentration of plants.

The uptake of Mg was lower in control treatment than other treatments despite that had higher concentration because of lower DMY which accumulated lower amount of Mg in plant shoots. In all treatments where recommended P rate was applied the Mg uptake levels were comparable regardless of P source. Both residual P treatments from either MPR or TSP at the same P application rate were fairly comparable in influencing Mg uptake. In general P sources and rates did not influence Mg concentration in maize plants.

The concentration of Zn in plants in the absolute control was deficient probably due to the levels found in the absolute control soil i.e. 1 mg Zn/kg soil (Table 2) was not enough for optimal Zn concentration in plant tissues. It might be suggested that provided Zn was applied in soils of pot experiment at (10 mg Zn/kg), the rate used was not appreciable to supply the nutrient above the critical levels.

Table 9: Effects of residual P from two different sources and their combination with different P rates of MPR and TSP on plant K, Mg, and Zn uptake and concentrations

Treatments	K conc. (%).	K uptake (mg/kg)	Mg conc. (%)	Mg uptake (mg/kg)	Zn conc. (ppm)	Zn uptake (mg/kg)
Absolute Control	4.1 ab	173.1 d	0.43 ab	18.5 c	5.1 c	0.2 d
P treatment control	4.0 ab	264.7 d	0.48 a	32.2 c	26.3 a	1.8 cd
P _{26.1} (Residual MPR)	3.3 bc	1210 c	0.43 ab	158.2 b	20.2 ab	7.4 ab
P _{33.2} (Residual TSP)	4.5 a	1525 b	0.43 ab	149.6 b	18.7ab	6.5 ab
P _{66.4} (Residual + fresh TSP)	3.4 bc	1531 b	0.43 ab	197.4 a	12.7 bc	5.8 ab
P _{66.4} (Residual + fresh MPR)	3.2 bc	1303 bc	0.33 b	134.3 b	16.9 ab	6.9 ab
P ₁₆₀ (Residual + fresh MPR)	2.9c	1256 c	0.37 b	162.8 ab	20.8 ab	9.2 a
P ₁₆₀ (Residual + fresh TSP)	3.4 bc	1518 b	0.37 b	166.1 ab	14.8 bc	6.6 ab
P ₁₆₀ (Fresh MPR)	3.6 bc	1510 b	0.40 ab	165.2 ab	12.2 bc	5.0 bc
P ₁₆₀ (Fresh TSP)	4.0 ab	1804 a	0.40 ab	181.1 a	10.9 bc	4.9 bc
CV (%)	12.3	10.1	25.9	21.2	14.2	16.2

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

Zinc concentration was statistically comparable for all the recommended P treatments but their concentrations were slightly lower to those of residual P in the MPR and TSP treatments probably due to lower levels of P in their respective soils. (Tisdale *et al.*, 1993) reported the similar findings that Zinc availability to plants decreased with application of higher phosphate fertilizers. Also Sabry (1980) studying the Egyptian alluvial soils reported the concentration of Zn in shoots was

reduced at higher P application. The effects of residual P from both TSP and MPR sources was statistically comparable in concentration of Zn in the plants indicating uptakes of Zn from the applied ZnSO_4 in potted soils was not influenced by residual P of these soils

4.4 Correlation Relationships Between Various P Fractions with Different Plant Parameters from the Pot Experiment

The correlation relationships and coefficient of determination between various fractions with different plant parameters are presented in Table 10. The contribution of each P fraction in plant performances in terms of DMY, P concentration and P uptake of maize plants are discussed below.

4.4.1 Correlation relationships between labile P fraction with DMY, P concentration and P uptake

Results of correlation between labile P fractions on DMY, P concentration and P uptake are presented in Table 10. Iron oxide -Pi was highly significantly ($P=0.05$) correlated with DMY, P concentration and P uptake. The r values were 0.71, 0.72, and 0.76 for DMY, P concentration and P uptake, respectively. The coefficient of determination (R^2) for P uptake was 0.58 showing that this fraction accounted for 58 % P uptake. This is attributed to the fact that the fraction contributes much more to the readily available P for plants.

For NaHCO_3 -Pi the correlation coefficient values were 0.79, 0.62 and 0.76 for DMY, P concentration and P uptake, respectively. The coefficient of determination (R^2) for P uptake was 0.58 showing that NaHCO_3 -Pi accounted for 58 % P uptake. These two

fractions constitute the inorganic labile P fraction which is highly correlated with plant P uptake. Baljit *et al.* (1995) reported similar results that Olsen P was highly significantly correlated with wheat DMY and P uptake. Also Mtengeti (2008) reported that the inorganic labile P fraction was correlated with maize DMY, shoot uptake and P concentrations during the third cropping cycle on a Ferrasol and an Acrisol.

The total labile fraction was significantly correlated with DMY, plant P concentrations and uptake. The correlation indicates that this fraction accounted for 56 % of the P uptake by maize plants. The $\text{NaHCO}_3\text{-Po}$ fraction was not correlated with any of the parameters tested suggesting that it had no or little effects on the performance of these plant growth parameters.

These results are in agreement with Ikerra *et al.* (2006) and Mtengeti (2008) as they reported no correlation of this fraction with DMY, P concentration and P uptake in acidic soils with low organic matter. The reason for this trend was probably due to low organic matter content of the test soil which in had low organic P such that the crop depended mainly on inorganic fertilizers for its P supply.

4.4.2. Correlation relationship between moderately labile P fraction with DMY, P concentration and P uptake

Results on correlation relationships between moderately labile P fractions, DMY, plant P concentration and uptake are presented in Table 10.

Table 10: Linear correlation coefficients (r) and coefficient of determination (R^2) between pot soils P fractions and maize DMY, P concentration and p uptakes)

P fractions	Correlation coefficient (r)			Coefficient of determination (R^2)
	DMY	P concentration	P uptake	
FeO-Pi	0.71*	0.72*	0.76*	0.58
NaHCO ₃ -Pi	0.79 *	0.62 *	0.76*	0.58
NaHCO ₃ -Po	0.15 ns	-0.15 ns	0.01 ns	0.00
NaHCO ₃ - Total	0.67 *	0.528*	0.67 *	0.45
Total labile P	0.74 *	0.61*	0.75*	0.56
NaOH - Pi	0.73 *	0.44*	0.67 *	0.45
NaOH -Po	0.27 ns	0.49*	0.40 ns	0.16
Moderately labile P	0.80 *	0.67*	0.79 *	0.64
1M HCl- Pi	0.70 *	0.20 ns	0.70 *	0.49
H ₂ SO ₄ - P	0.38 ns	0.39 ns	0.32 ns	0.10
Recalcitrant	0.43 ns	0.252 ns	0.37 ns	0.14

Key: Number followed by *=significantly correlated at <5%, ns not significantly correlated

The r values for NaOH Pi were 0.73, 0.44 and 0.67 for DMY, P concentration and P uptake respectively which indicate significant correlations. The coefficient of determination (R^2) for P uptake was 0.45 showing that this fraction accounted for 45 % P uptake. This might suggest that the P fractions do not exist as discrete components but constitute a continuum and change from one pool to another. The fraction could contribute P for plants when the labile fraction is deficient. The correlation coefficients are comparable to those reported by Mtengeti (2008) for an Acrisol of 0.56, 0.36, and 0.67 for the same plant parameters.

The coefficient of determination (R^2) for P uptake and NaOH- Po was 0.16 showing that this fraction accounted for 16 % P uptake obtained from stable organic compounds such as humic- and fluvic- acids or inositol phosphates sorbed to Al and Fe hydroxide (Anderson, 1980). Satell and Morris (1992) reported the similar findings that in a green house experiment 45% of total soil P was in the NaOH fraction but out of this 72 % was NaOH- Po, therefore plant P was related to the organic fraction of this soil. The reason that only 16 % contributed to plant growth in this experiment is supported by the organic carbon figures of the test soil which was low and therefore may had low organic P reserves to contribute for P uptake.

4.4.3 Correlation relationship between recalcitrant P fraction with DMY, P

Concentration and P uptake

4.4.3.1 HCl-P fraction

Results on correlation coefficients between HCl-P fraction with DMY, P concentration and P uptake having r values 0.70, 0.20, and 0.70 ($P=0.05$), respectively are presented in Table 10. The HCl fraction was significantly correlated with DM yields, but was not significantly correlated with P concentration indicating that with the levels of P applied the concentration was not influenced by this fraction. The coefficient of determination (R^2) for P uptake was 0.49 showing that this fraction accounted for 49 % P uptake. May be this fraction slightly contributes to the labile fraction. The observed correlation coefficients are comparable to those reported by Abekoe and Sahrawat (2003) for an Ultisol under subsequent five seasons of rice cultivation after application of TSP that HCl-P was declining. The fraction declined considerably from 2.3 mg P /kg in the uncultivated soil to 0.18 mg

P /kg traces in all the cultivated indicating that it declined because in that study it was the only potential source of available P to crops under field conditions in the highly weathered Ultisol in that study.

However, these results are contrary to those of Mtengeti (2008) who found that the HCl-P fraction in a Ferralsol was not significantly correlated with plant parameters at the third cropping cycle suggesting that when levels of the more labile fraction i.e. FeO-Pi, NaHCO₃-Pi and NaO-Pi are high in the soil solution PR dissolution is hindered thus minimizing its contribution to P concentration in plants. Ikerra *et al.* (2006) also found no correlation between the HCl –P fraction with maize yields and P concentration.

4.4.3 .2 H₂SO₄ - P fraction

Results on correlation coefficients between H₂SO₄ fraction with DMY, plant P concentration and P uptake having r values 0.38, 0.39, 0.32 respectively are presented in Table 10. The H₂SO₄ fraction was not significantly correlated with all the three plant parameters. The coefficient of determination (R²) for P uptake was 0.10 showing that this fraction accounted for 10 % P uptake.

Also the total recalcitrant followed the same trend as there was no correlation with DMY, plant P concentration and P uptake having r values of 0.43, 0.25, and 0.37 respectively. The coefficient of determination (R²) for P uptake was 0.14 showing that this fraction accounted for 14 % P uptake. May be the fraction contributed less to P uptake because it constitutes apatite in which is easily dissolved by soil weak acids of soils. The soils used had an average of 0.0001M about (4.4 pH) which is a

weak acid to dissolve an apatite compared with the strong extracting solution H_2SO_4 with 18 M of hydrogen ions. It may be suggested that in the short time of fertilizer P application, the fraction does not contribute to the available P for plants. Abekoe and Sahrawat (2003) reported that about 54 % of the total TSP applied in the soil was left in the residual form. The residual P of the uncultivated soil and that of the P control plots remained the same, despite long-term cultivation (five cropping seasons) indicating that this P fraction was not easily available to plants.

Therefore from this study it can be generalized that P availability to plants was not only depending on a single fraction, but also depended on continual change of inorganic P pools of labile and non labile P fractions. The labile P contributed 58 % to P uptake in plants of which 56 % was inorganic P. Moderately labile P fraction contributed 64 % of which 45 % was inorganic P and 49 % was contributed by 1 M HCl P.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results of the study the following conclusions were drawn:

- 1) Experimental plots treated with a total of 480 kg P/ ha from either TSP or MPR in an Ultisol at Magadu SUA farm had substantial residual available P seven years after fertilizer application was stopped. The absolute control plots had very low P level (3.4 mg P/kg) while the P treated plots had Bray I-P levels of 26.1 mg P/kg and 33.2 mg P/kg for MPR and TSP treatments, respectively. Both P sources had comparable residual available P levels for maize growth.

- 2) Both sources (TSP and MPR) had similar effects on the total labile and therefore had comparable potential in availing P for plant growth. The moderately labile P was slightly higher than in MPR treated soils indicating that the treatments had different characteristics of P being held strongly by chemisorptions to Fe and Al components of soil surfaces. The residual total recalcitrant P fractions were relatively higher in the MPR treated soil compared with the TSP treatment. It is concluded that the large portion of Ca bound P or undissolved apatite was still in MPR treated soil.

- 3) The residual P from the two (MPR and TSP) had similar effects on maize DMY, P concentration and P uptake. The residual P increased these

parameters significantly above control treatment but was significantly lower than fresh P applications from both sources. Fresh application of both MPR and TSP increased maize DMY, P concentration and uptake over the residual P treatments suggesting that residual levels were inadequate for meeting plant requirements under pot conditions.

Both MPR and TSP fertilizers application had effects on other soil parameters such as pH and Ca. Both sources were comparable in maize Ca concentrations and uptake. Fresh applications of both sources had similar effects on maize Ca concentration and uptake. MPR treatments had higher pH levels than TSP with a difference of about 0.4 pH units for treatments which received fresh TSP and MPR.

The total labile and moderately labile P fractions were positively correlated with DMY, P concentrations and P uptake. The contribution of the three fractions namely total labile, moderately labile, and HCl –P to P uptake were 58 %, 64 %, and 49 %, respectively indicating that these fractions had a direct relationship with the P uptake. Generally, it was concluded that application of relatively large rates of P either as MPR or TSP resulted in relatively high levels of residual available P seven years after P application was stopped but the levels achieved were below optimum under pot conditions.

5.2 Recommendations

- 1) Furthermore studies should be carried out to establish for how long the observed residual P will be useful for maize production. There is a need to

determine a critical level under pot conditions since it is apparent from this study that it is different from that established under field conditions.

- 2) The results from this pot experiment should be extended to field level for verification under natural circumstances before the findings are recommended to farmers. Also the findings should be verified in other soil types with high P fixing capacities such as Andosols and Ferrasols.
- 3) Because MPR could be more economical than TSP and other water soluble P sources, it can replace TSP in this soil and other similar types with comparable properties.
- 4) The findings in this study may not hold for crops other than maize. It is therefore recommended that MPR be evaluated with those crops before their adoption by farmers.

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APPENDICES

Appendix 1: Details of treatments tested in the pot experiment

Treat	Rates in mg /kg soil	Description of the treatments
1	$P_0N_0K_0Zn_0S_0B_0Mo_0$	(Absolute control). No nutrients were applied. The treatment was intended to evaluate maize P uptake under natural fertility status.
2	$P_0N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	(P treatment control). Received adequate levels of N, K, S, Zn, B and Mo but not P (P treatment control) The treatment was for evaluating the P uptake under optimum levels of N, K, S, Zn, Bo, and Mo but without P from external sources.
3	$P_{26.1}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	Received adequate levels of N, K, S, Zn, B and Mo plus residual P from MPR at a total application of 480 kg/ha applied previously. The treatment was intended to evaluate the residual P effectiveness of MPR found in the applied previously
4	$P_{33.2}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	Received adequate levels of N, K, S, Zn, B and Mo plus residual P from TSP at a total application of 480 kg/ha applied previously. The treatment was intended to evaluate the residual P effectiveness of TSP found in the soil.
5	$P_{66.4}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	Received adequate levels of N, K, S, Zn, B and Mo, plus a fresh TSP application at a rate equal to the residual P found into the soil treated with TSP 480 kg/ha .The treatment was intended to compare the effectiveness of residual P that were found into the soil to an equal amount of freshly applied TSP.
6	$P_{66.4}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	Received adequate levels of N, K, S, Zn, B and Mo plus a fresh MPR application at the rate equal to the residual P that was found into the soil treated plot with MPR 480 kg/ha. For comparison the amount applied made equal to the P applied in treatment 5. Therefore 38.1 Pmg /kg soil were contributed by fresh MPR. The treatment intended to compare the effectiveness of residual P that was found into the soil to equal amount of fresh application of MPR.
7	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P source was a residual P from the MPR 480 kg treated plot plus topping up with fresh MPR to reach the recommended P rate of 160 mg P/kg. The treatment intended to evaluate the effectiveness of residual P plus topping up of MPR to a recommended P rate.
8	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	P source was residual P from TSP 480 kg P/ha treatment plus topping up with fresh TSP to reach P rate of 160 mg P/kg. The treatment was intended to evaluate the effectiveness of residual P plus topping up of TSP to a recommended P rate.
9	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	Received recommended P, N, K, S, Zn, B and Mo. Only fresh MPR was a P source. The soil used was from an absolute control plot. The treatment was intended to evaluate the effectiveness of recommended fresh MPR.
10	$P_{160}N_{400}K_{50}S_{20}Zn_{10}B_2Mo_1$	Received recommended P, N, K, S, Zn, B and Mo. Only fresh MPR was a P source. The soil used was from an absolute control plot. The treatment was intended to evaluate the effectiveness of recommended fresh MPR.

Appendix 2: Salvage method used in soil moisture determination

- An empty measuring cylinder was weighed to get its weight. Then soil was poured in it to mark 100 cm^3 . Then a measuring cylinder with soil was weighed to get its weight. Fifteen ml of water was measured and poured in the cylinder above. The water was left to drain down the cylinder and the wetting front was recorded after 24 hours i.e. 65 cm^3 . The cylinders were replicated to have three replicates and an average of wetting front was found
- **Calculations**
- Suppose 15 cm^3 of water wetted 65.7 cm^3 of soil means 22.8% occupy water at field capacity in 24 hrs.
- Then $4000\text{ cm}^3 \times 22.8 / 100 = 912\text{ cm}^3$
- Taking 90% of field capacity (i.e. $912\text{ cm}^3 \times 0.9 = 820.8\text{ cm}^3$) as the amount of water needed to be applied to maintain the field capacity of the soil.

Appendix 3: Iron Oxide impregnated filter paper (FeO-pi) procedure

1. Paper Strips preparation

The filter paper (Whatman No. 50) was immersed in acidified FeCl_3 , using tweezers, for at least 5 minutes. The paper was allowed to dry at room temperature. The paper was pulled rapidly and uninterrupted through a bath containing 2.7 M NH_4OH to neutralize the FeCl_3 and produce amorphous iron (hydr) oxide (ferrihydrite, denoted as FeO). Then the paper is rinsed with distilled water to remove adhering particles of FeO and dried. After air drying, the paper was cut into strips with a (reactive) surface of 40 cm^2 (generally 2 by 10 cm).

2. Shaking of soil suspension with FeO-pi strips

One of the prepared strips above was mixed with 40 ml 0.01 M CaCl_2 and 1 g of soil in a 100 ml bottle at room temperature. The mixture was mixed on a reciprocating shaker at a speed of 130 excursions/ min, or at 4 rpm end over- end, for 16 h. The strip is taken out, thoroughly rinsed with distilled water to remove adhering soil particles.

3. Determination of P extracted by FeO-pi paper

The paper strips taken from the solution above was mixed for 1 h with 40 ml 0.1 M H_2SO_4 before P is determined by colorimetry procedure or by inductively coupled plasma spectrophotometry.

4. Calculations of extracted P in mg P/kg soil,

$$P = (C_p \times V) / W$$

Where: P concentration in H_2SO_4 , mg/l

V = volume of H_2SO_4 , l

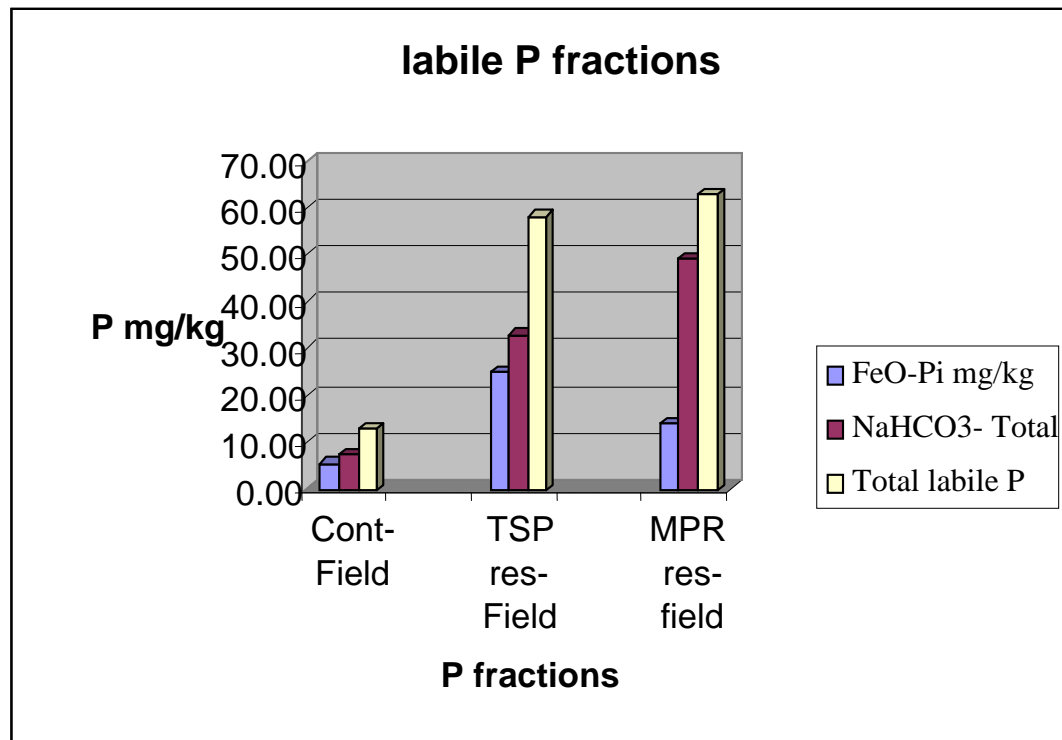
W = mass of soil used, kg

Appendix 4: Effects of residual P from two different sources and their combination with different P rates of MPR and TSP on soil micronutrients

Treatments	Soil micronutrients			
	Zn	Mn	Fe	Cu
Absolute Control	1.1 e	50.7c	36.85b	0.673ab
P treatment control	6.3d	76.63a	47.35ab	0.660abc
Residual MPR	9.8 ab	62.84bc	39.79ab	0.620abcd
Residual TSP	8.9 c	53.89c	46.30ab	0.540de
P _{66.4} from fresh and residual TSP	9.1 c	59.26c	53.38a	0.690a
P _{66.4} from fresh and residual MPR	9.9 a	58.75c	39.62ab	0.593bcde
P ₁₆₀ Recom.P from fresh and residual MPR	9.2 bc	52.36c	37.17b	0.553de
P ₁₆₀ Recom.P from fresh and residual TSP	9.2 bc	62.58bc	53.28a	0.547de
P ₁₆₀ Recom P from MPR	6.2 d	60.41c	34.91b	0.587cde
P ₁₆₀ Recom.P from TSP	6.2 d	73.94ab	40.89ab	0.527e
CV (%)	4.7	11.0	17.3	6.5

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

Appendix 5: The labile fraction in the Magadu soils collected after seven years since fertilizer application ceased.



Appendix 6: The labile moderately fraction in the Magadu soils collected after seven years since fertilizer application ceased

