Effects of Combining Minjingu Phosphate Rock and Triple Superphosphate with Selected Plant Biomass on Phosphorus Availability in Two Soils with Contrasting Properties

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Abstract

An incubation experiment was conducted to assess the influence of combining Minjingu phosphate rock (MPR) with Gliricidia (GLC) sepium leaves and maize stover (MS) on MPR dissolution and availability of the dissolved P in Magadu and Kilosa soils. The two soils have been classified as Oxic Haplustult and Ultic Haplustalf, respectively. Treatments tested were: an absolute control (ABS), and addition of either MPR, MPR+GLC, MPR+GLC+MS, TSP, TSP+GLC, GLC, GLC+ MS. The rate of application of MPR and TSP was 40 mg Pkg[-1] while the rate of biomass application was 1 gkg[-1]. All samples were incubated for 42 days but sub-samples were withdrawn from each treatment periodically for determination of NaOH- and Bray 1-P. In addition, a P adsorption study was conducted to determine the P adsorption parameters of the two soils. The results indicated that at 42 days of incubation 75% of the applied MPR had dissolved in Magadu soil while 50% of the MPR had dissolved in Kilosa soil. Addition of plant biomass did not improve the dissolution of MPR in both soils. The amount of MPR dissolved in Magadu soil was comparable to that released by TSP. However in Kilosa soil, on average the amount of P dissolved from MPR was much less by 54% than that from TSP. On the other hand, Bray 1- P from the MPR treatments was comparable in Magadu and Kilosa soils despite the large difference in the extent of MPR dissolution in the two soils. Addition of organic materials caused slight increases in Bray 1-P in both TSP and MPR treatments in the two soils. The level of Bray 1-P from the TSP treatments was on average 50% higher in Kilosa soil than in Magadu soil. This was attributed to higher P fixation in Magadu soil than in Kilosa soil. It was concluded that soil factors especially pH and P adsorption capacity had big influences on MPR dissolution and availability of the released P. However co-application of MPR and organic materials did not enhance dissolution of MPR but tended to increase available P.

Key words: Gliricidia sepium, maize stover, NaOH-P, Bray-1-P, PR dissolution, P fixation

Introduction

Phosphorus is one of the constraints to food production and prevails in highly weathered tropical African soils due to low native phosphorus and high fixation by iron and aluminium (Warren, 1992). The deficiency is aggravated by nutrient mining through continuous cropping without proper P fertilisation in such soils.

Phosphate rock (PR) has received attention as a low-cost P fertiliser for acid soils (Chien and Menon, 1995; Khasawneh and Doll, 1978). Phosphate rocks release P upon dissolution. Several factors are known to influence PR dissolution and availability of the released P. The main factors are soil pH, exchangeable acidity, exchangeable Ca, soluble P level, P fixing capacity and organic matter content. In agroforestry systems, the enhancement in biomass production could increase soil organic matter content and production of organic acids which may enhance

PR dissolution in soils. Currently, there is limited information on the influence of biomass from agroforestry plants on the dissolution of PR. Incorporation of plant biomass in combination with PR might be appropriate in areas where FYM, labour and skills of composting are limited or not available.

In this study, biomass from *Gliricidia sepium* leaves, maize stover or both were combined with Minjingu phosphate rock (MPR) to determine their effects on MPR dissolution and availability of the released P. *Gliricidia*, maize stover and MPR are all locally available in Tanzania. While MPR is mined from a deposit located near Arusha, *Gliricidia sepium* is a multipurpose leguminous tree commonly used in tropical farming systems (Garrity and Mercado, 1994).

The general objective of this study was to determine the influence of combining MPR with plant biomass on MPR dissolution and availability of phosphate from the phosphate rock. Specific objectives were: to assess the extent of dissolution of MPR in two soils with contrasting properties; to determine the influence of combining MPR with *Gliricidia* leaves or maize stover on MPR dissolution and availability of phosphate from the PR; to determine the influence of a mixture of maize stover and *Gliricidia* leaves on MPR dissolution and availability of phosphate from PR; to assess whether mixing plant biomass with MPR could enhance the solubility of the latter in a soil of relatively high pH and to compare the effects of the treatments on P availability in the two test soils.

Materials and Methods
Soils, plant materials and fertilizers
Magadu soil classified as an Oxic Haplustult (Kaaya *et al.*, 1994) while Kilosa soil sampled from Ilonga Agricultural Research Institute Farm in Kilosa District and classified as Ultic Haplustalf (Szilas, 2002) were selected for the study. The two soils had been under natural fallow for the past ten years or more and differed widely in soil pH. The pH values of Magadu and Kilosa soils were 4.9 and 6.2, respectively. A composite top soil sample was collected from each site, air-dried, ground and sieved through a 2 mm sieve. The samples were used for an incubation experiment and for routine analysis.

Two sources of organic materials, namely *Gliricidia sepium* leaves and maize stover were evaluated in the study. Mature *Gliricidia* leaves were collected, dried on plastic mesh and stored in clean nylon bags while maize stover was collected from harvested fields, chopped into small pieces of about 2 cm and stored to await incorporation.

Minjingu phosphate rock (12.9% P) ground to <0.15 mm and TSP (20.2% P) were used as sources of P while the source of N was sulphate of ammonia (SA) containing 21% N.

Routine soil analysis
Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH was determined in 1:2.5 soil: water suspensions using a pH meter (MacLean, 1982a). Organic carbon was determined by the Walkley and Black method (Nelson and Sommer, 1982). Total N was determined by macro-Kjedahl digestion-distillation method (Bremner and Mulvaney, 1982). Cation exchange capacity was determined according to Rhodes (1982) method. Exchangeable Ca, Mg and K and Na in the ammonium acetate leachates were analysed by atomic absorption and flame photometry, respectively. Citrate-dithionite extractable Fe and Al oxides were determined according to the method described by Holmgren (1967). Exchangeable Al was extracted by 1M KCl and determined by titration with NaOH (MacLean, 1982b). Bray 1 (Bray and Kurtz, 1945) and NaOH (Syers and Mackay, 1986) extractants were used to extract P from the samples. The NaOH extractant was used to estimate the amount of P that has dissolved from the P sources at any sampling period. Extracted P by both methods was determined colorimetrically using the ascorbic acid-molybdate blue method (Murphy and Riley, 1962).

Analysis of plant materials
Leaf samples were digested using the method of Okalebo *et al.* (1993) and total N, P and K in the digests were determined using respective procedures for each element as described above for soil analysis. Organic carbon in plant materials was determined by the Walkley and Black method (Nelson and Sommer, 1982).

P adsorption study

Phosphorus adsorption study was conducted following the procedure outlined by Fox and Kamprath (1970) and Fox *et al.* (1971). Data from this study were fitted to the Langmuir equation (Barrow, 1978) and the adsorption maxima (m) and bonding energies (k) of the two soils were calculated using the linear form of the equation.

Incubation study

In this study 500 g of soil sieved through a 2 mm sieve was weighed into each 500 ml plastic container and different materials were mixed with the potted soils to constitute the treatments listed below. The materials used were triple superphosphate (TSP), Minjingu phosphate rock (MPR), Gliricidia leaves (GLC) and maize stover (MS). Maize stovers were ground to pass through 2mm sieve while GLC leaves were crushed by hand to about the same size as that of MS. The treatments used in the incubation experiment following complete randomized block design were as follows: absolute control; TSP (40 mg P/kg soil); MPR (40 mg P/kg soil); GLC (1 g/ kg soil); MS (1 g/kg soil) and GLC + TSP (40 mg P from TSP /kg soil, 1 g GLC /kg soil). Other treatments were GLC + MPR (40 mg P from MPR /kg soil,

GLC = 1 g/kg soil); GLC + MS (GLC + MS = 1 g/kg soil) and MPR + GLC + MS (40 mg P from MPR /kg soil, GLC + MS = 1 g/kg soil). The GLC and MS were mixed in the ratio of 1:1 in treatments 8 and 9.

A low rate of biomass addition was chosen based on the findings of ICRAF (1996) that a combination of this rate of *Tithonia diversifolia* biomass with MPR gave high maize yields in Western Kenya. In addition such quantities of biomass can easily be obtained in most farms and are less laborious in handling. The potted and treated soils were incubated at about 25^0C and maintained at approximately field capacity for 42 days. Samples of the incubated soils were withdrawn at 0, 3, 7, 14, 28 and 42 days of incubation for determination of Bray1- and NaOH-P.

Results and Discussion

Properties of experimental soils, organic materials and Minjingu PR

Selected physical and chemical characteristics of Magadu and Kilosa soils are shown in Table 1. Different properties of the two soils were ranked according to criteria reported by Landon (1990).

Table 1: Selected physical and chemical characteristics of Magadu and Kilosa soils

	Soil	
Parameter	Magadu	Kilosa
pH in water (1:2.5)	4.90	6.2
pH in KCl (1:2.5)	4.50	5.9
Organic carbon (%)	1.20	1.9
Total N (%)	0.07	0.1
Exch. acidity (cmol (+) kg^{-1})	0.85	0.05
Exch. Al^{3+} (cmol (+) kg^{-1})	0.50	0.00
Exch. H^{+}(cmol (+) kg^{-1})	0.35	0.05
CEC (cmol (+) kg^{-1})	8.40	13.2
Base saturation (%)	44.76	97.2
Exch. bases (cmol (+) kg^{-1})		
Ca^{+}	1.77	9.52
Mg^{2+}	1.43	2.89
K^{+}	0.51	0.28
Na^{+}	0.05	0.14
Bray 1 P (mg P kg^{-1})	6.50	7.50
DTPA zinc (mg Zn kg^{-1})	1.04	1.35
Free Fe$_2$O$_3$ (%)	7.70	4.20
Al$_2$O$_3$ (%)	0.13	0.05
Particle sizes:-		
Sand (%)	35.00	44.0
Silt (%)	8.20	17.2
Clay (%)	56.80	38.8
Textural classes	Clay	Sandy clay

Organic materials

Selected chemical properties of the two sources of biomass tested in the study are presented in Table 2. *Gliricidia* had a narrower C/N ratio (12.4:1) than maize stover (114:1) implying that GLC would decompose faster than MS (Handayanto *et al.*, 1994).

Table 2: Selected chemical properties of plant materials used in the study

Units		%			Ratios	
Parameter	OC	N	P	K	C/N	C/P
GLC	45	3.63	0.11	1.6	12.4	409:1
MS	48	0.42	0.15	1.0	114.3	306:1

GLC = Gliricidia leaves, MS= Maiza stover

Phosphate rock

Minjingu PR contained 2.4% P while the calcium oxide content was 46.4% (Table 3). These values compare well with those of the most reactive North Carolina PR (Kumar *et al.*, 1993) suggesting that MPR may behave similarly.

Table 3: Chemical composition of Minjingu phosphate rock (MPR)

			P								
Parameter	Total	NAC[1] Soluble	CaO	MgO	Na$_2$O	K$_2$O	MnO	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	LOI
Content (%)	12.9	**2.4**	46.4	3.4	0.84	1.4	0.04	10.4	2.3	1.0	8.70

[1] Neutral ammonium citrate, LOI= loss on ignition (Source: Harris, 1981)

Table 4: Adsorption parameters for Magadu and Kilosa soils as estimated from linear form of the Langmuir equation

Soil type	Regression equation	Adsorption maxima (m) (mgPg-1)	Bonding energy (k) (L. mg-1)	Correlation coefficient(r)
Magadu	Y= 0.0009+0.0019X	500	2.1	0.99
Kilosa	Y= 0.0018+0.0032X	300	1.8	0.90

P adsorption study

The results of the adsorption studies for the two soils are presented in Table 4 and Fig. 1. The results show that the P adsorption maximum for Magadu soil was about twice that for Kilosa soil. The high P adsorption capacity of Magadu soil was attributed to its higher contents of oxides of Fe and Al than in Kilosa soil (see Table 1). Kaaya (1989) had also reported high quantities of kaolinite, oxides and hydroxides of Fe and Al in Magadu soil. The P adsorption maximum obtained for Magadu soil in the present study is comparable to that reported by Mackenzie *et al.* (1997).
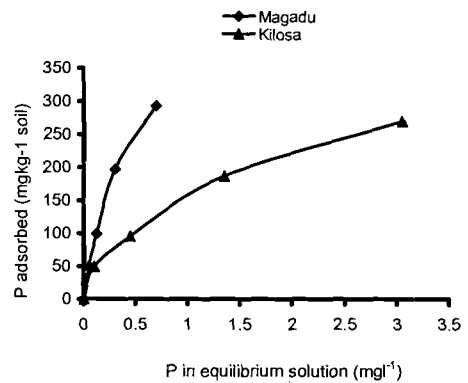

Figure 1: Phosphorus adsorption isotherms for Magadu and Kilosa Soils

Changes in NaOH-P as affected by organic materials

Figure 2 shows that the NaOH-P values associated with application of GLC, MS and GLC+MS in Magadu soil were generally similar and low. This observation was probably due to similarity in P content of GLC and MS. Figure 3

shows changes in NaOH-P as affected by organic materials in Kilosa soil. All the NaOH-P values were below 20 mgkg^{-1}. As explained above, the three materials had similar effects with regard to P improvement.
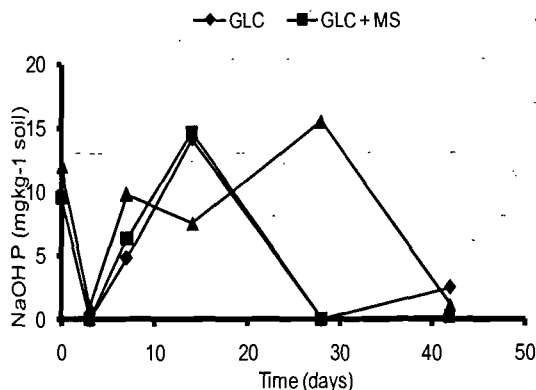

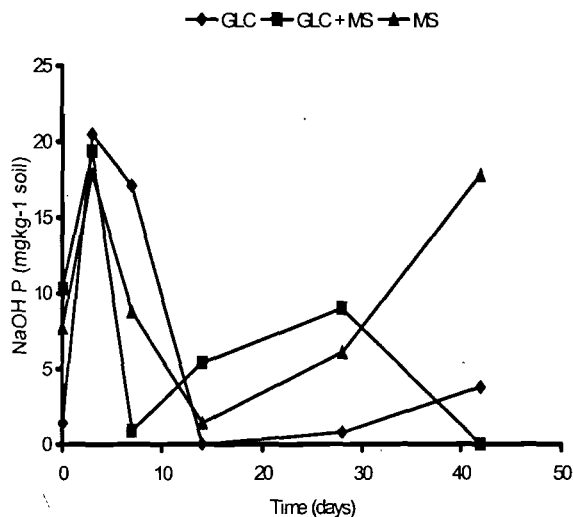Figure 2: Effect of incorporation GLC, MS or GLC + MS in Magadu soil on NaOHP

Figure 3: Effect of adding GLC, MS or GLC + MS into Kilosa soil on NaOH P

Changes in NaOH-P as affected by different treatments

Figures 4 and 5 show the effects of MPR or TSP alone and in combination with organic materials on ΔNaOH-P in Magadu and Kilosa soils,

respectively. The data in Figure 4 indicate that ΔNaOH-P in MPR and TSP treatments were comparable averaging 30 mg P kg^{-1}. This indicated that up to 75% of applied MPR was dissolved in Magadu soil which had low pH. Similar findings were reported by Mwakisimba (1999) who observed ΔNaOH-P levels in Magadu soil ranging from 77.6% to 82.5% between 28 and 70 days of incubation. These results are encouraging since they indicate a high potential of MPR to supply P in Magadu soil and in other soils with similar properties. The ΔNaOH-P data in Kilosa soil were generally higher in TSP treatments than in MPR treatments. This indicated that solubility of MPR was less than that of TSP in Kilosa soil that was relatively less acidic than Magadu soil. Co-application of organic materials with either TSP or MPR did not increase NaOH-P in Magadu soil but decreased MPR dissolution in Kilosa soil. This was attributed to increase in Ca supply in the soil system obtained from the decomposition of added biomass which in turn depressed MPR dissolution.
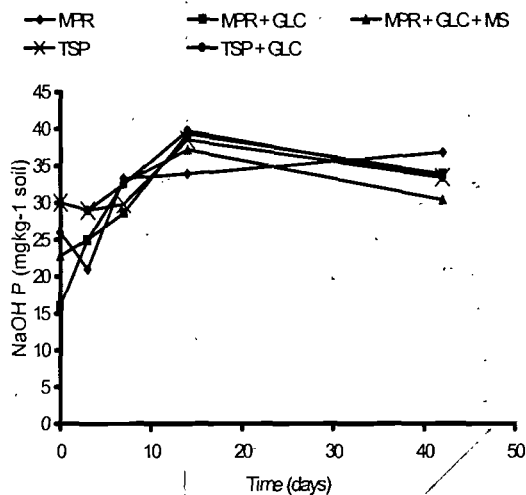

Figure 4: Effect of incorporating MPR, and TSP separately or in combination with GLC, MS or GLC + MS into Magadu soil on NaOH-P
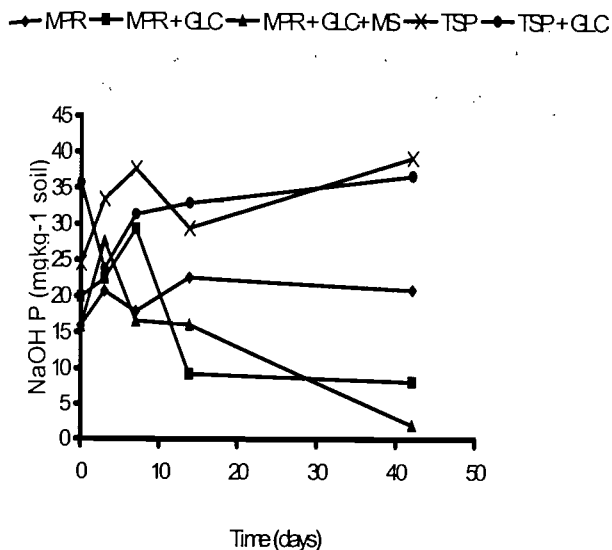
Figure 5: Effects of incorporating MPR, and TSP separately or in combination with GLC, MS or GLC + MS into Kilosa soil on change in NaOH-P

Comparison of MPR dissolution in Magadu and Kilosa soils (Figure 6) shows that ΔNaOH- P was greater in Magadu soil than Kilosa soil. On average between 75 – 90% of the applied P was recovered as NaOH-P in Magadu soil while in Kilosa soil the recovery was about .50% of the applied P. This means that dissolution of MPR was higher in the strongly acid Magadu soil than in the slightly acid Kilosa soil.

Hammond *et al.* (1986) and Khasawneh and Doll (1978) reported similar results.
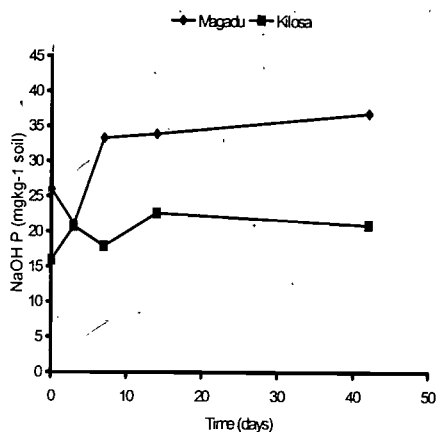

Figure 6: Comparison of effects of incorporating MPR at a rate of 40 mg P/kg to Magadu and Kilosa soils on NaOH-P

Changes in Bray 1-P as affected by application of organic materials

Changes in Bray 1- P as affected by incorporation of organic materials alone are shown in Figures 7 and 8. Figure 7 shows that Bray 1-P was higher in soil samples treated with GLC than in soil samples mixed with GLC+MS and MS. Incorporation of organic materials in Kilosa soil gave the same trend of Bray 1-P (Figure 8) except that Bray 1-P levels were higher in Kilosa soil than in Magadu soil. The higher Bray 1-P in the GLC treatment was probably due a greater extent of decomposition of the added *Gliricidia* leaves relative to maize stover. This might have resulted from two positive effects of Gliricidia biomass addition. Firstly it might have released some organic P into inorganic forms and secondly it might have generated organic anions which reduced P fixation in the soil. The higher Bray 1-P levels in Kilosa soil than in Magadu soil were probably due to the lower P fixation capacity of Kilosa soil relative to Magadu soil. Due to differences in P fixation capacities of the two soils, the organic anions released were more effective in reducing P fixation in the former soil than in the latter.
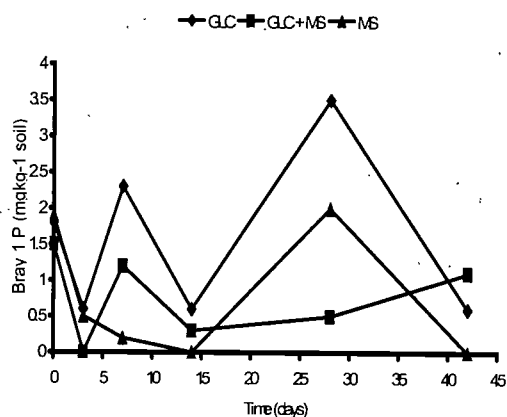

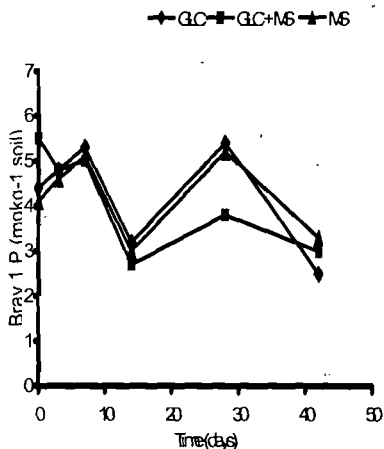Figure 7: Effects of incorporating GLC, MS or GLC + MS into Magadu soil on changes in Bray 1-P

Figure 8: Effects of incorporating GLC, MS
or GLC + MS into Kilosa soil on
changes in Bray 1-P

Figure 9: Effects of incorporating MPR and
TSP Separately or in combination
with GLC, MS or GLC + MS into
Magadu soil on changes in Bray 1-P

Changes in Bray 1- P as affected by different treatments

Figure 9 gives the changes in Bray 1-P over a period of 42 days as a result of MPR or TSP applied alone or in combination with organic materials in Magadu soil. Generally, Figure 9 indicates a decrease in Bray 1-P in TSP treatments from a maximum value of 28.3 mg P /kg at the beginning of the incubation to about 7mg P /kg at the 7th day of incubation. Thereafter Bray1-P remained more or less constant until the end of incubation at 42 days. This trend indicates a rather rapid fixation of soluble P released from TSP. In the MPR treatments, Bray 1-P increased from about 3 mg P /kg to about 7 mg P /kg during the first seven days of incubation and remained at this level for the rest of the incubation period.
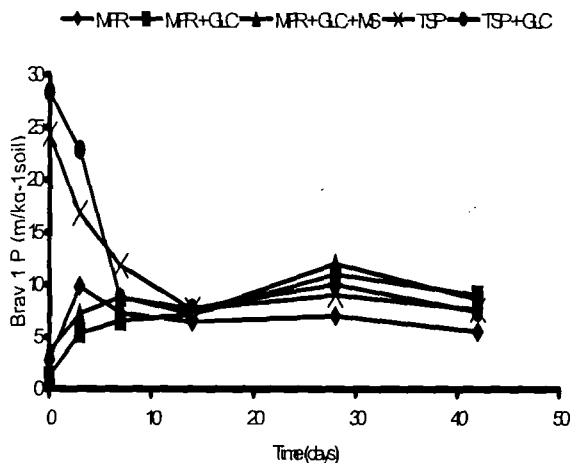
Combining MPR with organic materials slightly increased Bray 1-P in Magadu soil at 28 and 42-days of incubation. The improvement in Bray 1-P was probably due to a decrease in P sorption of the soil as reported by Nziguheba et al. (1998). However, there was no corresponding positive effects on Bray 1-P in TSP treatments leading to the possibility that by the time organic anions from organic material were released most of the fixation of P from TSP had already taken place as indicated by a sharp decrease in labile P during the first week of incubation. Between the 7th - and 42nd - day of incubation Bray 1-P values in TSP and MPR treatments were comparable indicating that the availability of P from both TSP and MPR in Magadu soil was comparable. The data further indicate that a high proportion of soluble P was fixed during the incubation period irrespective of the P source.

Figure 10 shows the effect of incorporating MPR and TSP separately or in combinations with organic materials on ΔBray 1-P in Kilosa soil. The data indicate that ΔBray 1-P in MPR treatments increased slightly during the first 7 days of incubation but remained more or less constant at a value of about 7.5 mg P/kg thereafter. In the TSP treatments on the other hand, ΔBray 1-P decreased sharply during the first 7days of incubation, followed by a gradual

decrease to a value of about 19 mg P/kg. Combining either P source with organic materials did not change the Bray 1-P levels during the incubation period. The fact that MPR treatments had lower levels of Bray 1-P throughout the incubation period than TSP treatments was attributed to low dissolution of MPR in this soil, which had relatively high pH (pH$_{H2O}$=6.2). On the other hand, the ability to maintain relatively high Bray 1-P in the TSP treatments indicates that this soil has relatively low P fixation capacity as demonstrated by results of the P adsorption experiment.
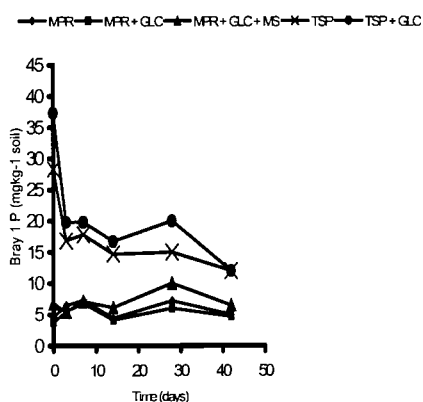

Figure 10: Effects of incorporating MPR and P separately or in combination with GLC, S r GLC + MS into Kilosa soil on changes in Bray 1-P

Figure 11 gives comparisons between Bray 1-P levels from MPR and TSP treatments in Magadu and Kilosa soils over the whole incubation period. The trends for the changes in Bray 1-P from the MPR treatments in the two soils were comparable with an equilibrium value of about 7.5 mg P/kg. Since there was higher MPR dissolution in Magadu soil than in Kilosa soil (Figure 6), the comparable ΔBray 1- P values indicate higher P fixation in Magadu soil than in Kilosa soil. The results indicate that the relative effectiveness of MPR in different soils will depend on a balance between the extent of dissolution and the extent of fixation of the dissolved P. These results suggest that in terms of MPR utilization comparable results may be obtained in the two soils despite

large differences in their characteristics. With TSP as the P source, a higher ΔBray 1-P was maintained in Kilosa soil than in Magadu soil again because of higher P fixation in the latter soil. This may result in better P efficiency in Kilosa soil and a higher residual effect than in Magadu soil.
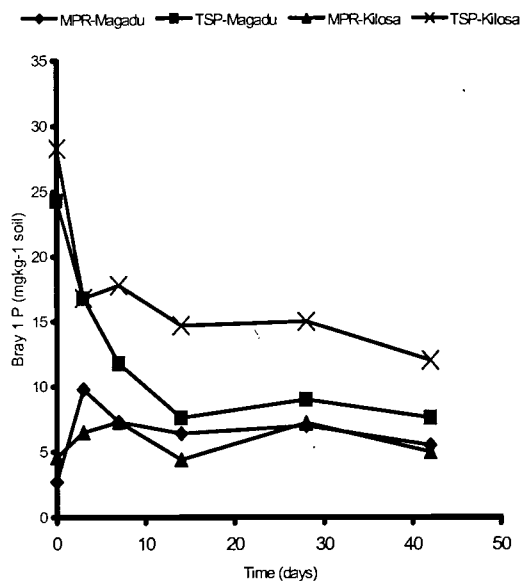

Figure 11: Effects of incorporating MPR or TSP at a rate of 40 mg P/kg into Magadu and Kilosa soils on changes in Bray 1-P

Conclusions and Recommendations

Reflecting on the findings of this study, it is concluded that, MPR dissolution in the strongly acid Magadu soil was comparable to TSP solubility but dissolution of MPR in the slightly acid Kilosa soil was much less than the solubility of TSP. However the levels of available P from MPR in the two soils were comparable because of higher P fixation in Magadu soil than in Kilosa soil. Application of a low rate of organic materials (equivalent to 1.8 tons/ha) in combination with either TSP or MPR had little effect on NaOH-P but slightly increased the level of available P from both sources.

Furthermore, two recommendations are put forward: First, MPR should be used in

strongly acid soils such as Magadu but application rates of the material should take into consideration the P fixation capacities of soils being used. Second, the role of organic materials in influencing P availability should be further evaluated in combination with moderate to high rates of organic materials.

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