EVALUATION OF MINJINGU PHOSPHATE ROCK PRODUCTS AS SOURCES OF PHOSPHORUS FOR MAIZE AND SORGHUM IN SOME MOROGORO AND HAI SOILS

BY

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ABSTRACT

Experiments were conducted to evaluate the effectiveness of partially acidulated phosphate rock (PAPR) and non acidulated Minjingu phosphate rock (PR) as sources of phosphorus for maize and sorghum. Two pot studies and two field experiments were conducted. Maize was the test crop in the initial pot study and in the field experiments while sorghum was used in the residual pot study. Five soils, namely Kwa Sadala, Mlama, Mafiga, Magadu and University Gate, varying widely in properties were used.

Results of these experiments showed that all the P carriers increased yields in Mlama, Magadu and University Gate soils, indicating that the three soils were P deficient and thus required supplemental P. The Kwa Sadala and Mafiga soils, with high available P and nearly neutral pH values, did not respond to either of the P sources.

The initial pot study results indicated that the PAPRs and the non acidulated PRs had fertilizer values nearing that of TSP in Mlama soil. In the Magadu and University Gate soils the PAPRs and PRs were generally inferior to TSP.

Results of the residual pot study showed that the PAPRs and PRs had superior residual effectiveness compared to TSP in Magadu, Mlama and University Gate soils, indicating that over time the P carriers substantially dissolved in the three soils.

The field study results revealed trends similar to those of the initial pot experiment in the Magadu and University Gate Soils. The PAPRs and PRs were inferior to TSP.

Results of these experiments suggest that the Minjingu PR products may be effective sources of P for the Mlama, Magadu and University Gate soils and in other soils with similar properties. The results should be confirmed under different field conditions, especially for the PAPRs since it is the first time they have been tested in Tanzania.

DECLARATION

I GERALD GERVAS KIMBI, do declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and has not been submitted in any other University for a degree award.

...14-3-1991.....
Date

....
Signature

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DEDICATION

This dissertation is dedicated to my beloved uncles and sisters who took the trouble of educating me.

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1.0 INTRODUCTION

The use of conventional P fertilizers in developing countries has drastically decreased due to increases in prices of the same in the world market (Rajan and Gillingham 1986). As a result, efforts have been directed to the use of low cost indigenous materials such as local deposits of phosphate rock (PR) (Hammond et al. 1986).

In general, experimental results have shown that PR is most effective when used on acid soils that are deficient in P (Khasawneh and Doll 1978). Anderson (1965, 1970); Mnkeni et al. (1986); Semoka and Mnkeni (1986); Ngatunga et al. (1989), among others, have reported work done with PR from a local deposit, the Minjingu PR, in Tanzania. Results from these experiments have shown that in most cases Minjingu PR was as effective a source of P as triple superphosphate (TSP) when used on acid soils and P deficient soils. Most of these studies were carried out using beneficiated Minjingu PR, the product obtained through sieving, drying and concentration of the rock material. The beneficiated product is the one used for the production of TSP and NPK fertilizers at the Tanga fertilizer factory.

The cost of P in beneficiated Minjingu PR is about 40% of the cost of P in TSP (Floor and Kimambo 1989). Although this would appear to be a fair alternative, it is nevertheless worthwhile evaluating the agronomic effectiveness of the unbeneficiated Minjingu PR with the aim of eliminating the costs involved in beneficiating the rock for direct application purposes. This could benefit farmers in P deficient areas close to the mine. Research along this line has been given very little attention in Tanzania.

Partial acidulation of phosphate rock has been employed in many parts of the world as an alternative way in increasing the solubility of PRs that may be too low in reactivity. Interest in partially acidulated phosphate rock (PAPR) has been due mainly to its favourable economics of production compared to superphosphate production, as the former uses less acid (Friesen et al. 1987). Compared to PR, PAPR is expensive due to the process of partial acidulation but much more beneficial due to enhanced solubility and hence more possibilities of its use in neutral and alkaline soils. In Tanzania no work has been done to evaluate agronomic effectiveness of PAPR. It could, however, be an attractive alternative especially in areas with soils which are not very acidic.

Studies conducted by Singh and Uriyo (1978) indicated the occurrence of acid soils in every district in Tanzania. For example, soils of Hai district were reported to have pH values ranging from 4.5 to 5.6, with exchangeable calcium ranging from 0.3 to 4.7 Cmol (P+)Kg^{-1} soil. Extractable P levels were also suspected to be considerably low. Direct application of Minjingu PR and/or PAPR could reduce the problem of P deficiency in these areas.

The research reported here was conducted with the following objectives:

a) to evaluate the effectiveness of non acidulated and partially acidulated products of Minjingu PR as sources of P for maize in some soils of Hai and Morogoro districts.

b) to determine the residual effectiveness of the materials using sorghum as a test crop.

Hai district was chosen because of its relatively close proximity to the Minjingu PR mine, and Morogoro district because some information already exists on crop responses to PR application on some of its soils.

2.0 LITERATURE REVIEW

Phosphorus may be supplied to the soil by various P sources. Among them are conventional P fertilizers, phosphate rock (PR) and partially acidulated phosphate rock (PAPR). This review will mainly focus on PR and PAPR, the materials which were used in the present study.

Direct application of ground PR has received varied attention over the years. In view of mounting economic problems in developing countries, low cost and low energy consuming methods are receiving increased attention (Luken and Blumel 1984). Hammond et al. (1986) noted that the mounting interest in PR is due to low input of capital and energy required to prepare the product, making it one of the cheapest P fertilizers possible.

Various studies have been conducted to assess the usefulness of PRs for direct application in agricultural production, and several reviews have been published on the subject (Khasawneh and Doll 1978; Jaggi 1986; Hammond et al. 1986; Semoka and Mnkeni 1986). In general, experimental results have shown that PR is most effective when used on acid soils that are P deficient.

2.1 Some important considerations on the effectiveness of PR

For direct application purposes, effectiveness of PR has been shown to depend on a number of factors, which include:

2.1.1 Type and reactivity of PR

Of the three rock types in which phosphates are found (i.e. igneous, metamorphic and sedimentary), only sedimentary phosphates have, in most cases, proved beneficial for direct application. Khasawneh and Doll (1978) reported that igneous and metamorphic rocks are coarsely crystalline and do not possess internal surfaces. These properties render them inactive and nearly inert for direct application purposes. Sedimentary PRs, on the other hand, consist of fairly open, loosely consolidated aggregates and microcrystals with relatively large specific areas, thus making them more reactive (Hammond et al. 1986).

Previous work has however, shown that even with sedimentary PRs wide differences in reactivity occur. Experimental results have shown that a greater extent of substitution of CO_3^{2-} for PO_4^{3-} in the apatite structure results in higher reactivity (Khasawneh and Doll 1970; Marwaha and Kanwar 1981; Lehr and McClean 1972). Carbonate substitution for phosphate increases the reactivity of PR because it decreases the crystal size and thus increasing the specific surface area of the apatite aggregates (Lehr and McClean 1972). The Minjingu PR deposit in Tanzania is of the sedimentary type (Harris 1981).

Reactivity of a PR also depends on the particle size used, which influences the surface area of the dissolving particles. In various reviews (Rogers et al. 1953; Khasawneh and Doll 1978; Hammond et al. 1986), it has been concluded that P availability increases with fineness, but the degree of improvement rarely justifies grinding to sizes less than 100 mesh (150 µm). Economically feasible grinding has been reported to be that from which at least 80% of the material passes the 100 mesh screen (Hammond et al. 1986).

2.1.2 Soil related factors

Using fluorapatite as an example, Hammond et al. (1986) demonstrated the important soil factors in the dissolution of PR by considering the equation which follows:

$$Ca_{10}(PO_4)_6F + 12H^+ \longrightarrow 10Ca^{2+} + 6H_2PO_4^- + 2F^-$$

From the above equation, and according to the mass action law, they were able to show that dissolution of PR in soil solution would be favoured under conditions that soil pH, soil exchangeable Ca and soil solution P concentration, are low. These three factors are individually reviewed below.

2.1.2.1 Soil pH

More PR fertilizer dissolves in acidic soil than in alkaline or neutral soils (Barnes and Kamprath 1975; Khasawneh and Doll 1978). Laboratory experiments with single soil modifier to various pH levels have shown that PR dissolution increases linearly with decreasing pH

(Kanabo and Gilkes 1987). Likewise, agronomic effectiveness of PR has been found to be higher in acid soils than in neutral or alkaline soils (Peaslee *et al.* 1962; Hammond *et al.* 1986). Jonnes (1948) has shown the importance of pH in PR dissolution. He found that at pH 5.0, 235% more P was taken up from PR by a crop of rye (*Secale cereale*) than when the soil was limed to pH 6.5.

On the other hand, Bennet *et al.* (1957), working with maize as the test crop, obtained a grain yield response to PR on liming from pH 5.0 to 5.8. Cooke and Widdowson (1958) obtained equal or better responses with PR than single superphosphate even on soils having pH values as high as 6.5. However, such responses could be due to factors other than pH, for example, adequate moisture and low soil Ca status.

Generally, PRs have been found to be effective at pH < 6.0 (Marwaha and Kanwar 1981; Khasawneh and Doll 1978).

2.1.2.2 Exchangeable Ca and P status in the soil

Khasawneh and Doll (1978) noted that poor PR dissolution could be caused by presence of more Ca or more free $CaCO_3$ in the soil. This has been explained as being due to the calcium "common ion" effect, whereby high Ca levels in soil solution depress Ca dissolution from PR (Welte 1978).

As for soil P status, the dissolution of PR is enhanced where there is a low concentration of $H_2PO_4^-$ ions in the soil solution (Khasawneh and Doll 1978). Thus, Amberger (1978) was able to show that PR application is beneficial in agricultural production if applied to soils that are severely to moderate deficient in P. It has little or no effect in soils of medium to high P status.

Organic matter is another factor known to enhance dissolution of PR. According to Hammond et al. (1986), organic matter upon hydrolysis may supply some organic functional groups or anions such as citrate or oxalate that can effectively chelate Ca^{2+} ions, thus lowering the Ca^{2+} activity in the soil. This in turn provides a driving force for further dissolution of PR.

2.1.3 Plant related factors

Khasawneh and Doll (1978) have reviewed various studies where results indicated that crops vary greatly in their ability to utilize P from PR. The differences among crops were related to their demand patterns for both Ca and P and how these demand patterns alter composition of the soil solution at the root-soil interface. Roggers et al. (1953) grouped crops into two categories based on their efficiency on PR utilization. Efficient users of PR included cloves, mustard, rape and cabbage while inefficient PR users were cotton, cowpeas and most cereals. Asher and Ozanne (1961) reported a high correlation between cation exchange capacity (CEC) of plant roots and the uptake of Ca and P from PR. They found that plants with the high CEC rooting systems were more effective in obtaining Ca and P from PR than were plants of low CEC root systems. Similarly, Ray and Van Diest (1979) observed that P from PR was more available to legumes than grasses such as buckwheat (*Fagopyrum esculentum*).

Most recently, Flash *et al*. (1987) tested the PR mobilizing capacity of three cereals in a pot experiment. This capacity was found to increase in the order of maize < pearl millet < finger millet. The increasing order was reflected in the quantities of calcium absorbed by the three plant species, which followed the same trend.

2.1.4 Fertilizer placement

Placement methods have been reported to substantially affect PR utilization by crops. Khasawneh and Doll (1978) noted that PR placement should ensure thorough mixing in the rooting zone. Broadcasting of the finely ground material followed by incorporation into the soil has been found to be the appropriate placement methods as it affords the widest distribution of PR in the upper rooting zone. It also permits the largest extent of contact between plant roots and PR particles (Hammond *et al*. 1986).

2.1.5 Rainfall

Rainfall is often cited as one of the factors that influence the agronomic effectiveness of PRs (Hammond *et al*. 1986). Bambey (1957) quoted by Hammond *et al*. (1986), reported results of work done in Senegal showing that the fertilizer efficiency of PR increased with rainfall. However, it was not established whether this was a direct or an indirect effect. The indirect effect is associated with the fact that soils in higher rainfall areas have low pH, low amount of available Ca and a higher amount of organic matter. All these factors are known to enhance the agronomic effectiveness of PRs.

2.2 Crop responses to PR application

A number of workers have demonstrated the potential for direct application of PR as a source of P for crops. Leon et al. (1978) quoted by Hammond et al. (1986), reported results of experiments conducted during the period of 1969 - 1971 using Oxisols from the Colombian Llanos. They compared Turmeque PR with TSP using corn as the test crop. It was observed that the Colombian PR was relatively ineffective during the first year at one site but as effective as TSP during the next two years. At the second site, the PR was as effective as TSP in all years.

Rice grown in acid soils has also shown good response to PR application. In India, Jaggi (1986) reported results of experiments conducted on three acid soils from different locations in which PR was found to be as effective as, or better than, superphosphate in increasing paddy yields.

PR has also been reported to increase both P and Ca uptake by plants in P deficient soils (Hammond et al. 1986; Mnkeni et al. 1986). Increased P and Ca uptake following PR application has been thought to be a result of enhanced supply of Ca and P in the soil solution.

Semoka and Mnkeni (1986) have reviewed work done with Minjingu PR in Tanzania using maize, cotton, groundnuts, pasture and sorghum as test crops. It was found that in most cases, Minjingu PR gave a positive response which, when assessed for periods of 3 to 6 years (residual effects included), was found to be equal to, or greater than that from superphosphate.

Anderson (1965) compared Minjingu PR and double superphosphate (DSP) using some pastures as test crops. He found Minjingu PR to be significantly inferior to DSP in the first year, but no significant differences between the two P sources were noted in the subsequent years, indicating substantial residual value of the PR. When groundnut was used as the indicator crop, Anderson (1970) observed slightly higher yields due to PR application compared to DSP. However, the differences were not statistically significant.

Scaife (1968) obtained a good response with Minjingu PR using cotton. Results of the six year experiment indicated that Minjingu PR outyielded DSP in all seasons, suggesting that it could be a good substitute for the water soluble P source. This also showed that the rock had adequate residual effect compared to DSP.

Ikerra (1985) working with an Ultisol and maize as indicator crop found Minjingu PR to be inferior to TSP at equal rates of P application, but had comparable effect values when applied at three times the rate of TSP.

In another study with Minjingu PR using four soils, Mnkeni et al. (1986) observed that TSP and the PR were equally effective as sources of P for maize on two of the soils which were acidic and low in extractable P. Significant residual effectiveness due to PR application was also observed in the soils which responded to Minjingu PR and TSP application.

In a long term field experiment conducted on acid sandy loam soils of Naliendele in South Western Tanzania, Ngatunga et al. (1989) found Minjingu PR to be as effective as TSP as a source of P for sorghum.

2.3 Partially acidulated phosphate rock (PAPR)

Partial acidulation of PR is among the methods for enhancing reactivity of indigenous PR. PAPR is an underacidulated product that has been treated with only a portion of the acid (usually sulphuric or phosphoric) required to convert the calcium phosphate in the rock into monocalcium phosphate monohydrate, a water soluble salt (Roy 1985). The proportion of the acid added is expressed as a percentage of the stoichiometric quantity of acid required for fully acidulating that particular PR.

Interest in the use of PAPR is partly due to the reduced cost of production realized due to use of less than the required amount of the acid for superphosphate manufacture (Friesen et al. 1987). It is also related to the fact that P from PR is less susceptible to fixation in highly weathered acid soils (ibid.).

2.3.1 Chemistry of partial acidulation and PAPR reaction in soil

Roy (1985) summarized the chemistry of acidulation using sulphuric acid (equation 1) and phosphoric acid (equation 2), as shown below:

$$\underset{\text{(fluorapatite)}}{Ca_{10}(PO_4)_6F_2} + \underset{\text{(sulphuric acid)}}{7yH_2SO_4} + \underset{\text{(water)}}{3yH_2O} \longrightarrow \underset{\text{(monocalcium phosphate)}}{3yCa(H_2PO_4)_2.H_2O}$$

$$+ \underset{\text{(calcium sulphate)}}{7yCaSO_4} + \underset{\text{(hydrofluoric acid)}}{2yHF} + (1-y)\ \underset{\text{(fluorapatite)}}{Ca_{10}(PO_4)_6F_2} \qquad [1]$$

$$\underset{\text{(fluorapatite)}}{Ca_{10}(PO_4)_6F_2} + \underset{\text{(phosphoric acid)}}{14yH_3PO_4} + \underset{\text{(water)}}{10yH_2O} \longrightarrow \underset{\text{(monocalcium phosphate)}}{10yCa(H_2PO_4)_2.H_2O}$$

$$+ \underset{\text{(hydrofluoric acid)}}{2yHF} + \underset{\text{(fluorapatite)}}{1yCa_{10}\ (PO_4)_6F_2} \qquad [2]$$

Where y represents the degree of acidulation for example, y = 1.0 corresponds to 100% acidulation; y = 0.5 to 50% acidulation, and so on.

As shown by the above two equations, the main products of the acidulation process are monocalcium phosphate (MCP) and fluorapatite.

The reaction of PAPR in soil can be figured by considering the fate of its constituent compounds namely MCP and apatite in the soil. Chien (1985) explained the fate of the compounds as follows:

When the PAPR comes into contact with soil MCP hydrolyses to dicalcium phosphate dihydrate (DCPD) and phosphoric acid as shown in the following equation:

$$\underset{\text{(MCP)}}{Ca(H_2PO_4)_2.H_2O} + H_2O \longrightarrow \underset{\text{(DCPD)}}{Ca_{10}HPO_4.2H_2O} + H_3PO_4$$

Part of the released H_3PO4 lowers soil pH to as low as 1.48 causing, dissolution of Fe and Al minerals which, in turn, react with water soluble P to form water insoluble Fe-Al phosphates. Part of the H_3PO_4 produced by MCP hydrolysis is neutralized by the unacidulated PR (apatite). This has the effect of protecting the water soluble P of PAPR from reacting with substantial quantities of Fe and Al. This protective effect accounts for the better effectiveness of PAPR, relative to superphosphate, often observed in high P fixing soils (Chien 1985).

2.3.2 Crop responses to PAPR application

Nordengren (1957) reported on one of the first PAPR products called Kotka phosphate, manufactured in Finland using ground PR reacted with a part of the stoichiometric amount of sulphuric acid which would completely acidulate the PR. This product was found to give 90% of the fertilizing effect of superphosphate on acid peat soils (pH < 5.2) and about 80% of the effect on less acid peat soils (pH > 5.2).

McLean and Wheeler (1964) and McLean et al. (1965) reported that the effectiveness of PAPR at 10-20% acidulation was equal to that of 100% acidulated PR for corn seedlings and alfalfa in growth chamber experiments. Gorbouchev (1981) confirmed that PAPRs of varying degrees of acidulation appeared to be as efficient as TSP.

A number of reports have, however, indicated that PAPRs are not as efficient as superphosphate. Lutz (1971) compared effectiveness of 20% PAPR to that of superphosphate for corn in a field experiment. He found that the soluble P fertilizer was superior to the PAPR. Hammond et al. (1980) in pot trials found that 20, 30 and 40% PAPR using H_2SO_4 made from a Togo PR were much less efficient than TSP in the first year. However, over three cropping periods the PAPRs were found to be 79-90% as effective as TSP. These results indicated that residual PAPR effectiveness increased with time.

The conflicting results in the observed agronomic efficiencies of PAPR compared to TSP or SSP could be attributed to a combination of fertilizer (i.e. PR), soil and plant factors. Friesen et al. (1987), however, reported that the observed differences in PAPR effectiveness have mainly been observed on experiments involving a single rate of P. Multiple rate P experiments have generally found PAPR effectiveness to increase with acidulation rate to 100% (as in TSP) (Hammond et al. 1980).

In Tanzania, no attempt has yet been made to evaluate the agronomic effectiveness of PAPR. The research reported here is the first such attempt.

3.0 MATERIALS AND METHODS

Two pot studies and two field experiments were conducted to evaluate the effectiveness of unbeneficiated Minjingu PR, beneficiated Minjingu PR and products of the latter acidulated at 25% level (25 PAPR), 50% level (50 PAPR) and 100% level (TSP) as sources of P for maize and sorghum.

3.1 Materials

3.1.1 Soils

Five experimental sites were selected. Two sites, namely Mlama and Kwa Sadala, were in Hai district, at $3^0$10'S $37^0$20'E. The other three sites were Magadu, University Gate and Mafiga. These were in Morogoro district and were situated at $6^0$51'S $37^0$39'E.

In each district, sites were chosen so as to include acidic and non acidic soils and/or high and low P soils. Soil samples from the top 20 cm were collected for laboratory analysis and for glasshouse studies. At each site, soil samples were randomly collected to cover, and to represent, the experimental areas. Samples for the pot studies were composited, air dried and ground to pass through an 8 mm sieve. A subsample was ground and passed through a 2 mm sieve for physical and chemical characterization of the soils.

Particle size distribution was determined by using the Bouyoucos Hydrometer method as described by Dewis and Freitas (1970) and moisture content at field capacity was estimated following the procedure described by Savage (1970).

Organic carbon was determined by the wet combustion method (Nelson and Sommers 1982). Total N was analysed by the Micro-Kjeldahl digestion method following the procedure of Bremner and Malvaney (1982). Available P was analysed by the Bray and Kurtz No. 1 method (Bray and Kurtz 1945) while pH was measured electrometrically both in water (1:1) and in 0.01M $CaCl_2$ solution (1:2) (McLean 1982). Exchangeable H and Al were determined by the KCl method (Barnhisel and Bertisch 1982).

Cation exchange capacity was determined by the ammonium acetate saturation method (Chapman 1965). Sodium and K were determined by flame photometry while Ca and Mg were measured by atomic absorption spectrophotometry.

The physico-chemical properties of these soils are summarized in Table 1. The Mlama and Magadu soils were strongly acidic, low in extractable P and exchangeable Ca, and with appreciable amounts of exchangeable Al. The University Gate soil was slightly acidic with low extractable P and low exchangeable Ca. Kwa Sadala and Mafiga soils had relatively high values of extractable P and exchangeable Ca. Medium pH values were also observed for the two soils. These categorizations are based on the reports of Singh et al. (1980) and Landon (1984). According to Landon (1984) exchangeable Ca values below $4Cmol(p+)Kg^{-1}$ soil are considered low while those above

Table 1: Some physico-chemical properties of soils used in the present studies

Experimental Soil	pH 1:1(H_2O)/ 1:2(0.01M $CaCl_2$)	OC	Total N	Extractable P	CEC	Ca	Exchangeable Cations Mg	Na	K	H	Al	Particle Size Distribution Sand	Silt	Clay	Textural Class	Moisture Content at field capacity	Soil classification
		--- % ---		mgPkg^{-1}	-----------	Cmol(P+)kg^{-1}soil	----------					----------	%	------------		---%---	
Mlama	4.9 4.7	4.80	0.50	3.85	3.60	1.35	0.30	0.17	0.58	0.2	1.0	44	38	18	L	37.9	NC
Magadu	5.2 4.9	1.25	0.18	5.96	5.61	2.50	1.50	0.21	0.69	0.2	0.6	54	13	33	SCL	15.4	Oxic Haplustult[1] Dystric Nitosol[2]
University Gate	6.1 5.8	1.19	0.19	5.83	6.91	3.85	2.10	0.22	0.64	0.10	NIL	48	12	40	SC	14.8	Tropeptic Eustrustox[1] Rhodic Ferralsol[2]
Kwa Sadala	6.4 6.2	2.6	0.38	57.81	15.05	10.20	3.18	0.24	1.28	0.14	NIL	24	18	58	CL	26.7	NC
Mafiga	6.7 6.5	1.30	0.24	12.51	8.45	6.00	1.50	0.19	0.83	0.13	NIL	60	10	30	SCL	16.8	Udic Haplustalf[1] Chromic Luvisol[2]

OC = Organic Carbon
L = loam
SCL = sandy clay loam
SC = sandy clay
CL = clay loam
NC = not classified
1 = USDA classification
2 = FAO classification

10Cmol(p+)Kg^{-1} soil are considered high. pH values (in water) less than 5.5 are low whereas between 5.5 and 7.0 are considered medium. With respect to P, Singh *et al.* (1980) categorized Bray 1 available P of up to 15 ppm as being low, 15 ppm to 30 ppm as being high and above 30 ppm as very high for maize in some soils of Morogoro.

The low pH, low extractable P and low exchangeable Ca levels in the Mlama and Magadu soils suggest that considerable dissolution of the PR materials could occur in these soils. On the other hand, the relatively high values of pH in the Kwa Sadala and Mafiga soils are not likely to encourage appreciable dissolution of the PR materials.

3.1.2 Phosphate fertilizers

All the P sources used originated from the Minjingu PR mine situated in Arusha region, Tanzania ($3^0$25'S $36^0$15'E). The PAPR materials were made from Minjingu PR acidulated with sulphuric acid by the International Fertilizer Development Centre in Muscle Shoals, Alabama, USA, while TSP was made from Minjingu PR acidulated with phosphoric acid at the Tanga Fertilizer Factory (in Tanzania).

The chemical composition of the phosphate materials used in the present studies is shown in Table 2. Except for TSP, all the Other materials were analysed by IFDC (IFDC communication, 1988).

Table 2: Percent concentration (by weight) of major elements in Minjingu PR products

Phosphate Material	WS	Total P	SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_4	F
	%							
TSP	18.3	20.8	NA	NA	19.3	NA	NA	2.7
Minjingu 50% PAPR	11.2	10.0	NA	NA	30.0	NA	25.3	2.0
Minjingu 25% PAPR	6.3	11.7	NA	NA	34.0	NA	18.0	2.6
Beneficiated Minjingu PR	0	13.5	11.2	1.3	50.6	1.1	NA	3.2
Unbeneficiated Minjingu PR	0	11.5	13.9	2.9	36.0	0.5	NA	2.6

NA = Not analyzed

WS = Water solubility

Sources: IFDC (1988)
Floor and Kimambo (1989)

TSP had the highest P concentration followed by beneficiated PR, 25 PAPR, unbeneficiated PR and 50 PAPR, respectively. With regard to Ca concentration, beneficiated PR had the highest value while TSP had the lowest. Other P sources had intermediate values. The concentrations of P and Ca in the Minjingu PR (11.5% P and 36.0% CaO) compares well with those of the North Carolina PR (13.3% P and 48.1% CaO) which is the most reactive PR in the world (Day 1978).

Among the P carriers, TSP had the highest water solubility followed by 50% PAPR and 25% PAPR. Beneficiated and unbeneficiated PR were not water soluble.

3.2 Pot Experiments

3.2.1 Initial pot experiment

As already mentioned, 0-20 cm soil samples for glasshouse studies were taken from many spots representative of the experimental sites. Four kg samples were weighed into plastic pots and the following treatments were applied:

a) Control
b) TSP (reference fertilizer)
c) Minjingu 50 PAPR
d) Minjingu 25 PAPR
e) Beneficiated Minjingu PR
f) Unbeneficiated Minjingu PR

Each of the P sources was applied at the rate of 0.16 g P/pot (= 80 kg P/ha) by mixing thoroughly with the soil samples.

A two factor factorial arrangement was used with soil as one factor, the other being P sources. The treatments were arranged in a randomized complete block design with three replicates.

The treated soils were watered to approximately field capacity (1/3 bar) and incubated for seven days in a glass house. Five maize (Zea mays L. var. Staha) seeds were then planted in each pot. Thinning was done to two plants per pot one week after emergence. Further watering was done as necessary to maintain the soils at approximately field capacity. Aldrin 40% dust was applied in the planting holes at sowing at the rate of 0.04 mg/pot to control cut worms (Agrostitis spp). Two weeks after emergence sulphate of ammonia was applied at the rate of 0.16 g N/pot (= 80 kg N/ha). In addition, each pot received the equivalent of 12 mg/pot (= 6 kg/ha) each of Zn and Cu, 0.1 mg Mo/pot (= 0.5 kg/ha) and 2.4 mg B/pot (= 1.2 kg/ha). The nutrient carriers were $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$, $(NH_4)_4Mo_7O_{24}.4H_2O$ and $Na_2B_4O_7.10H_2O$, respectively.

Harvesting was done after six weeks of growth. The plants were cut 1 cm above the soil level and rinsed of any adhering particles using distilled water. The plants were then dried at 65^0C to constant weight after which dry matter yield was determined. The samples were ground and screened to pass through a 1 mm sieve for tissue analysis.

Tissue P was extracted by the dry ashing method (Juo 1979). Determination of P in the extract was by the vanado-molybdate method (Jackson 1958). Calcium in the extract was determined by atomic absorption spectrophotometry.

3.2.2 Evaluation of residual effectiveness of the phosphate sources

After harvesting, the soils of each pot were dried, ground and mixed. Maize roots from the previous experiment were removed and the soils were screened to pass through an 8 mm sieve and filled back into respective pots. Subsamples were composited separately for each treatment. Analysis for pH, extractable P and Ca were carried out on each composited sample as per section 3.1.1. Sorghum (Sorghum bicolor L. var Serena) seeds were sown into the potted soils. This crop was used to evaluate the residual effectiveness of P from the previous experiment (section 3.2.1) and was harvested after six weeks of growth.

3.3 Field Experiments

Field experiments were conducted in two locations namely Magadu and University Gate at the Sokoine University of Agriculture farm, Morogoro district. The sites were selected on the basis of the pronounced positive response to applied P materials as observed in the pot experiments involving soils from the two sites.

Land preparation involved ploughing followed by harrowing. The experimental design was similar to that of the pot studies except that the treatments were replicated four times. The experiment was laid down on plots with dimensions of 3m x 5m. The P materials were applied at rates equivalent to those in pot studies by broadcasting followed by incorporation into the soil before sowing. The rate of sowing was three seeds per hill at a spacing of 75 cm (between rows) x 30 cm (within rows). Thinning was done to one plant per hill two weeks after emergence.

Sulphate of ammonia was applied at the rate of 80 kg N/ha at "knee height" stage of growth. The plots were maintained weed free throughout the growing season. Harvesting was carried out at maturity. The entire plots were harvested. Grain yield was expressed at 13% moisture content. Grain samples were ground to pass through a 1 mm sieve and analysed for P and Ca as per section 3.2.1.

3.4 Statistical analysis

Statistical analysis of data was done according to the model described by Snedecor and Cochran (1980). The New Duncan's Multiple Range Test (NDMRT) was used to compare differences between treatment means. The relative agronomic effectiveness (RAE) values were computed using dry matter yield for the pot experiments and grain yield for the field experiments. Relative efficiency values of P and Ca uptake in the pot studies and field experiments were also computed. The formula used for both RAE and relative efficiency values was the one described by

Engelstad _et al_. (1974), that is:

$$RAE = \frac{Y_F - Y_C}{Y_R - Y_C} \times 100$$

Where:

Y_F = Yield due to one of the tested fertilizers

Y_R = Yield due to reference fertilizer (in this case TSP)

Y_C = Yield in the control treatment

4.0 RESULTS AND DISCUSSION

4.1 Initial pot study

The effects of P carriers on the dry matter yields of maize are shown in Tables 3a and 3b. The five soils studied varied widely in productivity as reflected by their control yield data (Table 3a). Control yield was highest in Kwa Sadala soil followed by Mafiga, University Gate, Magadu and Mlama soils. The main effect means show that the soils' differences in productivity were generally maintained even after P ammendment. Phosphorus sources significantly increased yields in Mlama, Magadu and University Gate soils but no effect was observed in the Kwa Sadala and Mafiga soils (Table 3a). Table 3b shows the levels of significance of the P source effects associated with the yield responses to the different P materials. A significant P source x soil interaction was observed (Table 3b) indicating that the response due to the P sources varied with soils.

The observed yield differences in the control treatments/soil (Table 3a) may be related to the soil test results (Table 1). For example, exchangeable Ca, extractable P and CEC of these soils followed a decreasing pattern similar to that of yields, indicating a corresponding trend of decreasing fertility status.

These differences in response to P sources may be related to the extractable P levels observed on these soils (Table 1). The Mlama soil had extractable P of 3.85 mg P Kg^{-1} soil while Magadu and University Gate soils had

Table 3a: Effect of phosphate sources on initial dry matter yield (maize), residual dry matter yield (sorghum) and total dry matter yield in the pot studies

Soil	Control	Phosphate source					Means
		TSP	Minjingu 50% PAPR	Minjingu 25% PAPR	Beneficiated Minjingu PR	Unbeneficiated Minjingu PR	
			A: INITIAL DRY MATTER YIELD (IDM) (g/pot)				
Mlama	5.71	11.8k	11.2k	11.7k	11.0k	13.11jk	10.7d
Magadu	14.3ghijk	21.4c	19.2cde	16.4efghi	20.0cd	16.2efghi	17.9b
University Gate	12.4jk	17.9def	16.0efghi	16.1efghi	15.1efghij	14.0hijk	15.3c
Kwa Sadala	24.5b	25.3b	29.4a	26.4ab	26.3ab	26.6ab	26.4a
Mafiga	16.8defgh	17.1defgh	18.5efg	17.5defg	18.6cdef	17.0defgh	17.9b
Mean	14.7b	18.7a	18.8a	17.6a	18.2a		
			B: RESIDUAL DRY MATTER YIELD (RDM) (g/pot)				
Mlama	0.4j	1.0j	1.2j	1.1j	1.1j	1.2j	1.0e
Magadu	2.3i	6.3h	7.2defgh	7.0defgh	7.3defgh	7.7def	6.3c
University Gate	2.2i	6.6fgh	6.7efgh	6.4gh	6.8efgh	6.5gh	5.9d
Kwa Sadala	10.5c	11.7ab	12.7a	11.8ab	11.5b	11.1bc	11.6a
Mafiga	6.9defgh	7.5defg	8.1d	7.8de	7.3defgh	7.7def	7.6b
Mean	4.5c	6.6b	7.2a	6.8ab	6.9ab		
			C: TOTAL (A + B) DRY MATTER YIELD (TDM) (g/pot)				
Mlama	6.1k	12.7j	12.3j	12.8j	12.1j	14.2ij	11.7d
Magadu	16.5i	27.7c	26.5cde	27.5efgh	27.3cd	23.9cdefgh	24.1c
University Gate	14.7ij	24.7cdefg	22.6fgh	22.5fgh	21.9gh	20.6h	21.1c
Kwa Sadala	35.0b	37.0b	42.0a	38.2b	37.9b	37.7b	38.0a
Mafiga	25.8cde	24.6defgh	26.6cdefg	25.0cdefg	26.0cdef	24.7cdefg	25.2b
Mean	19.2c	25.3ab	26.0a	24.5b	25.0ab	24.2b	

Simple effect and main effect means followed by the same letter are not significantly ($P < 0.05$) different using the New Duncan's Multiple Range Test.

Table 3b: Results of the ANOVA on initial dry matter yield (IDM = maize), residual dry matter yield (RDM = sorghum) and total dry matter (TDM = maize + sorghum) in the pot studies

Source of variations	IDM	RDM	TDM
Soil	**	**	**
P sources	**	**	**
Reps	NS	NS	NS
P source x soil	**	**	**
CV (%)	10.27	9.38	8.10

** = Significant at $P < 0.01$

NS = Not significant

CV = Coefficient of variation

values of 5.96 and 5.83 mg kg-1 soil,respectively.These values are all below the critical level of 15 mg P Kg^{-1} soil established for maize in some soils of Morogoro district by Singh et al. (1980), reflecting a P deficiency condition. This would explain the response of yields and P uptake to added P as observed on these soils (Tables 3a, 4a and 4b). The lack of response in the Kwa Sadala soil may be due to the high extractable P content observed in this soil (Table 1), which was greater than the critical level, indicating that P was not limiting. The medium P level in the Mafiga soil may account for the marginal response observed on this soil.

TSP increased DM yields on the Mlama, Magadu and University Gate soils (Table 3a). This response was associated with a significant increase in P uptake (Table 4a), suggesting that the observed response was largely due to enhanced P uptake. Results of the soil analysis after harvest (Tables 5a and 5b) support the observed increases in DM yield and P uptake in the three soils. For example, increases in extractable P relative to the control due to TSP application were 119%, 53% and 84% for the Mlama, Magadu and University Gate soils, respectively. This implies that the observed responses were contributed largely by increased soil P levels due to P application in the three soils. These results are in agreement with those of Muller et al. (1985) and Easterwood et al. (1986) who concluded that water soluble phosphate provides adequate

Table 4a: Effect of phosphate sources on initial P uptake (maize), residual P uptake (sorghum) and total P uptake in the pot studies

Soil	Control	TSP	Minjingu 50% PAPR	Minjingu 25% PAPR	Beneficiated Minjingu PR	Unbeneficiated Minjingu PR	Mean
		Phosphate source					
			A: <u>INITIAL P UPTAKE (IPU) (mg/pot)</u>				
Mlama	5.27	13.95	15.13	15.25	14.73	16.34	13.44d
Magadu	17.35	29.23	28.44	21.81	25.97	23.22	24.34c
University Gate	17.17	31.41	27.09	25.97	22.94	22.58	24.53c
Kwa Sadala	27.68	72.50	79.56	73.91	75.91	71.63	73.49a
Mafiga	39.81	41.69	40.71	41.55	41.74	38.46	40.66b
Mean	29.46c	37.75ab	38.19a	35.70ab	36.18ab	34.48b	
			B: <u>RESIDUAL P UPTAKE (RPU) (mg/pot)</u>				
Mlama	0.31	0.96	1.13	1.11	1.09	1.27	1.10d
Magadu	2.45	7.57	8.99	8.48	8.26	9.01	7.46c
University Gate	2.27	7.65	8.06	7.03	7.71	7.29	6.67c
Kwa Sadala	28.95	31.80	34.79	30.68	32.11	30.12	31.41a
Mafiga	16.24	17.14	18.52	17.44	17.19	18.02	17.42b
Mean	10.04b	13.02a	14.34a	12.95a	13.27a	13.14a	
			C: <u>TOTAL (A + B) P UPTAKE (TPU) (mg/pot)</u>				
Mlama	5.58	14.91	16.46	16.36	15.82	17.61	14.46d
Magadu	19.80	36.80	37.43	30.20	34.23	32.22	31.80c
University Gate	19.44	39.05	35.15	33.00	30.65	29.87	31.19c
Kwa Sadala	96.63	104.30	114.35	104.59	107.60	101.93	104.90a
Mafiga	56.04	58.83	59.23	58.99	58.93	56.48	58.08b
Mean	39.50c	50.78ab	52.52a	48.65b	49.45ab	47.62b	

Simple effect and main effect means followed by the same letter or none at all are not significantly ($P < 0.05$) different using the New Duncan's Multiple Range Test.

Table 4b: Results of the ANOVA on initial P uptake (IPU) by maize, residual P uptake (RPU) by sorghum and total P uptake (TPU) in the pot studies

Source of variations	IPU	RPU	TPU
Soil	**	**	**
P sources	**	**	**
Reps	*	NS	NS
P source x soil	NS	NS	NS
CV (%)	11.97	13.92	9.77

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively

CV = Coefficient of variation

Table 5a: Effect of acidulated and non acidulated products of Minjingu PR on some soil properities after harvest in the initial pot study

	Mlama Soil				Magadu Soil			
	PH 1:1 (H_2O)/ 1:2(0.01M $Cacl_2$)	Extractable P	Exchangeable Ca	Exchangeable Al	PH 1:1 (H_2O)/ 1:2(0.01M $Cacl_2$)	Extractable P	Exchangeable Ca	Exchangeable Al
		mg P kg^{-1}soil	---Cmol(p+)	kg^{-1} ----		mg P kg^{-1}	---Cmol(p+)	kg^{-1} ----
Control	5.0/4.6	3.12	1.48	1.12	5.1/4.8	6.68	2.66	0.61
TSP	5.0/4.6	6.82	3.62	0.88	5.3/4.9	10.25	4.35	0.54
Minjingu 50 PAPR	4.9/4.7	6.27	3.69	0.90	5.2/4.8	9.72	4.20	0.52
Minjingu 25 PAPR	5.0/4.7	5.95	3.55	0.84	5.5/4.8	10.13	4.30	0.50
Beneficiated Minjingu PR	5.0/4.6	6.01	4.15	0.80	5.3/4.8	10.30	4.92	0.52
Unbeneficiated Minjingu PR	4.9/4.7	6.08	4.25	0.84	5.3/4.9	9.20	4.10	0.54

Table 5b: Effect of acidulated and non acidulated products of Minjingu PR on some soil properties after harvest in the initial pot study

	University Gate Soil			Kwa Sadala Soil		
	PH 1:1(H_2O)/ 1:2(0.01MCacl_2)	Extractable P	Exchangeable Ca	PH 1:1(H_2O)/ 1:2(0.01MCacl_2)	Extractable P	Exchangeable Ca
		mg P kg^{-1} soil	Cmol(P+)kg^{-1}		mg P kg^{-1}soil	Cmol(p+)kg^{-1}
Control	5.9/5.7	5.42	3.51	6.3/6.1	53.01	11.20
TSP	6.0/5.0	5.95	5.89	6.4/6.2	59.74	10.20
Minjingu 50 PAPR	6.1/5.8	8.98	6.10	6.5/6.2	60.07	12.31
Minjingu 25 PAPR	6.2/5.0	9.07	6.48	6.4/6.3	58.72	12.07
Beneficiated Minjingu PR	6.1/5.9	10.10	5.96	6.4/6.2	60.07	22.75
Unbeneficiated Minjingu PR	6.0/5.9	9.65	6.50	6.5/6.3	59.30	11.21

Table 5c: Effect of acidulated and non acidulated products of Minjingu PR on some soil properties after harvest in the initial pot study

	Mafiga soil		
	pH 1:1(H_2O)/ 1:2(0.01M$CaCl_2$)	Extractable P	Exchangeable Ca
		mg P kg^{-1} soil	Cmol(p+)kg^{-1}
Control	6.6/6.4	13.00	5.50
TSP	6.6/6.5	14.85	7.10
Minjingu 50 PAPR	6.7/6.4	14.07	7.65
Minjingu 25 PAPR	6.6/6.4	13.15	6.95
Beneficiated Minjingu PR	6.8/6.5	14.01	7.85
Unbeneficiated Minjingu PR	6.7/6.4	13.75	6.95

P nutrition for plants in P deficient soils.

Both 50 PAPR and 25 PAPR increased DM yield and P and Ca uptake in the same soils which responded to TSP application (Tables 3a and 4a).The associated increase in the P uptake indicated that the PAPRs influenced the available P status of the soils. This is supported by the extent to which these materials increased extractable P levels as shown by the soil analysis data after harvest (Tables 5a and 5b). Increases in extractable P levels relative to the control ranged from 31% to 101% for 50 PAPR and 52% to 91% for 25 PAPR in the same soils which responded to TSP ammendment. This suggests that the PAPRs underwent considerable dissolution, resulting in more soluble P in soil solution and hence increased P uptake and DM yields. The highest increases in extractable P levels due to PAPRs application were observed in the Mlama soil. This may be due to the fact that the soil had the lowest initial P content (Table 1). This low P content may have resulted in the highest magnitude of response observed in the Mlama soil compared to the other two soils. Comparison of responses to 50 PAPR and 25 PAPR shows that there was no significant difference between the two P sources in each of the Mlama, Magadu and University Gate soils, indicating that the materials were equally effective within those soils.

Both 50 PAPR and 25 PAPR influenced yields to the same extent as TSP (the reference fertilizer), in the Mlama and University Gate soils (Table 3a). In the Magadu soil, 50 PAPR gave yields comparable to those from TSP whereas 25 PAPR was inferior. These results somewhat agree with observations by Chien (1978) which indicated that in acid soils some PAPRs could perform better than or the same as TSP. He suggested that equal or inferior performance by TSP could be due to reduced efficiency of P in TSP, caused by its tendency to revert to less soluble forms in the soil through fixation reactions. In contrast, fixation reactions are less pronounced for the PAPRs compared to TSP (Friesen et al. 1987).

Application of both beneficiated and unbeneficiated PR increased DM yields on the soils (Mlama, Magadu and University Gate) which responded to TSP application (Table 3a). A similar pattern of response was noted for the P and Ca uptake data (Tables 4a, 6a and 6b) suggesting that the increased yield was a result of increased P and Ca uptake. This is supported by the soil analysis results after harvest (Tables 5a and 5b) which indicate that the P materials increased residual P and Ca levels in the Mlama, Magadu and University Gate soils, indicating that there was substantial dissolution of the P carriers in these soils. Beneficiated PR increased yield more than unbeneficiated PR on the Magadu soil, suggesting that the beneficiated rock was more effective than the unbeneficiated PR on this soil. On the other hand, no differences in yield were observed between the two sources in the Mlama and University Gate soils, indicating that the two P materials had equal effectiveness in these soils.

Table 6a: Effect of phosphate sources on initial Ca uptake by maize, residual Ca uptake by sorghum and total Ca uptake in the pot studies

	Phosphate source						
Soil	Control	TSP	Minjingu 50% PAPR	Minjingu 25% PAPR	Beneficiated Minjingu PR	Unbeneficiated Minjingu PR	Mean
			A: INITIAL Ca UPTAKE (ICaU) (mg/pot)				
Mlama	8.85	26.17	26.09	26.07	24.47	29.29	23.49e
Magadu	35.39	59.48	52.70	44.85	52.65	43.22	48.05c
University Gate	28.23	49.00	42.60	42.87	38.40	35.14	39.37d
Kwa Sadala	151.71	152.68	174.37	161.15	153.77	157.86	158.59a
Mafiga	95.73	97.68	100.77	100.09	101.36	80.29	95.99b
Mean	63.98c	77.00ab	79.31a	75.01ab	74.13ab	69.16bc	
			B: RESIDUAL Ca UPTAKE (RCaU) (mg/pot)				
Mlama	0.67g	1.96g	2.44g	2.24g	2.24g	2.57g	2.02d
Magadu	4.51g	13.35f	15.68f	14.48f	16.35f	16.52f	13.48c
University Gate	4.34g	14.24f	14.64f	13.99f	24.46f	13.89f	12.60c
Kwa Sadala	51.68c	57.51abc	62.82a	58.72ab	56.01bc	54.61bc	56.89a
Mafiga	28.18de	30.27d	23.47e	31.04d	28.76d	28.76d	28.91b
Mean	17.88b	23.47a	23.81a	24.09a	23.56a	23.87a	
			C: TOTAL (A+B) Ca UPTAKE (TCaU) (mg/pot)				
Mlama	9.53j	28.13i	28.53i	28.31i	26.71i	31.86i	25.51e
Magadu	39.90hi	72.83e	68.39ef	59.33efg	69.00ef	59.75efg	61.53c
University Gate	32.57i	63.24efg	57.25efg	56.86efg	52.87efgh	49.03gh	51.97d
Kwa Sadala	203.39b	210.20b	237.19a	219.86b	209.78b	212.76b	215.48a
Mafiga	123.91cd	127.96cd	124.24cd	131.13c	130.12c	112.04d	124.90b
Mean	81.86c	100.47ab	103.12a	99.10ab	97.69ab	93.03b	

Simple effect and main effect means followed by the same letter or none at all are not significantly different ($P < 0.05$) using New Duncan's Multiple Range Test.

Table 6b: Results of the ANOVA on initial Ca uptake (ICaU) by maize, residual Ca uptake (RCaU) by sorghum and total Ca uptake (TCaU) in the pot studies

Source of variations	ICaU	RCaU	TCaU
Soil	**	**	**
P sources	**	**	**
Reps	NS	NS	NS
P source x soil	NS	*	*
CV (%)	13.96	15.26	9.81

*, ** = Significant at $P < 0.05$ and $P < 0.01$, respectively

NS = Not significant

CV = Coefficient of variation

The two PR materials gave yields comparable to those under TSP in the Mlama soil. However, in the Magadu and University Gate soils only beneficiated PR was comparable to the reference fertilizer. Unbeneficiated PR was inferior to TSP on these soils.

It is interesting to note (Table 3a) that it was only on the strongly acidic Mlama soil where both beneficiated and unbeneficiated PR were comparable to TSP. It would seem that the low pH in Mlama soil had a profound effect on the dissolution of both the levels of extractable P and exchangeable Ca detected after harvest (Table 5a). Both beneficiated and unbeneficiated PR doubled extractable P levels in the Mlama soil compared to the control, whereas increases in exchangeable Ca levels relative to the control were almost three times. This indicates that the Minjingu rocks had substantially dissolved in this soil, and this may be associated with the low pH prevailing in this soil. Kanabo and Gilkes (1987) also found PR solubility to increase with increasing acidity.

Both beneficiated and unbeneficiated PR gave yields similar to those under 50 PAPR and 25 PAPR in the Mlama and the University Gate soils. In the Magadu soil the effects of the unbeneficiated PR were comparable to those of 25 PAPR.

It is of practical interest to note (Table 3a) that the PR materials had more or less similar effectiveness with the PAPRs even in the slightly acidic University Gate soil (pH 6.1). This would appear to contradict the generally accepted view that availability of P in PRs is highest in strongly acid soils (Peareles et al. 1962; Hammond et al. 1986). These results therefore suggest that factors other than acidity influenced the effectiveness of PRs in the University Gate soil. These factors could be adequate moisture which prevailed throughout the growing period and the low initial P content observed for this soil. Sufficient moisture and low soil P content are known to enhance PR solubility (Hammond et al. 1986). The results of the present studies are somewhat similar to those obtained by Cooke and Widdowson (1959), who observed equal or better response of PR compared to TSP in soils of pH values higher than 6.5.

4.1.1 Relative effectiveness of the P sources

The RAE values were generally highest in the Mlama soil followed by the University Gate and Magadu soils (Table 7). This trend was associated with differences in the extractable P content of the soils (Table 1). For example, the Mlama soil, with the highest RAE values, had the lowest extractable P level. The other two soils, which had lower RAE values, had relatively higher extractable P levels.

The relative agronomic effectiveness values varied within the individual soils. In the Mlama soil 50 PAPR, 25 PAPR and beneficiated PR had nearly comparable values, implying that they had comparable fertilizer (TSP) substitution values. Unbeneficiated PR had higher RAE than that of TSP, suggesting that it had higher effectiveness than the reference fertilizer. In the Magadu soil, beneficiated PR gave the highest RAE value followed by 50 PAPR, 25 PAPR and unbeneficiated PR which had effectiveness comparable to that of 25 PAPR. For the University Gate soil the PAPRs gave the highest, and similar, RAE values whereas the non acidulated P sources had the lowest effectiveness values.

The RAE values in Table 7 generally suggest that the non acidulated P carriers had effectiveness comparable to the partially acidulated sources. This was, however, more pronounced in the Mlama soil. These results are of practical interest since beneficiated and unbeneficiated PRs could be attractive P sources in this soil as they are cheaper relative to the PAPRs and TSP. This is also true for the Magadu and University Gate soils. For example, beneficiated PR had the highest RAE value in the Magadu soil (81%) and had nearly 50% substitution value of the reference fertilizer in the University Gate soil. Beneficiated PR could also be the best P material in the Magadu and University Gate soils. The RAE values in Table 7 also show that the RAE values decreased as soil pH increased. The Mlama soil, with pH of 4.9, had the highest RAE values whereas the University Gate soil (pH 6.1) had the lowest RAE values. Mnkeni et al. (1986) also found RAE values to decrease with increasing pH.

Table 7: The relative agronomic effectiveness of the Minjingu PR products and their relative efficiencies in affecting P and Ca uptake by maize and sorghum in the initial and residual glasshouse studies

Treatments	Mlama soil			Magadu soil			University Gate soil		
	I	R	C	I	R	C	I	R	C
				Relative agronomic effectiveness (%)					
TSP	100	100	100	100	100	100	100	100	100
50% PAPR	90	137	94	69	124	89	65	102	79
25% PAPR	98	117	102	31	118	63	67	98	78
Beneficiated MPR	87	115	91	81	124	96	49	102	72
Unbeneficiated MPR	121	137	123	28	137	66	29	99	59
				Relative efficiency in P uptake (%)					
TSP	100	100	100	100	100	100	100	100	100
50% PAPR	114	143	117	93	128	104	70	107	80
25% PAPR	115	114	116	38	118	63	62	87	69
Beneficiated MPR	109	114	110	73	114	85	41	100	37
Unbeneficiated MPR	128	137	129	49	108	73	38	93	53
				Relative efficiency in Ca uptake (%)					
TSP	100	100	100	100	100	100	100	100	100
50% PAPR	100	131	102	72	126	87	69	104	75
25% PAPR	99	115	101	37	112	50	70	98	79
Beneficiated MPR	90	115	92	72	134	88	50	103	66
Unbeneficiated MPR	90	115	92	32	135	60	33	97	54

I: Initial experiment data
R: Residual experiment data
C: Combined data (initial and residual data)

Comparison of the P carriers in relation to P and Ca uptake (Table 7) indicated a pattern corresponding to that of the RAE values. For example, the relative efficiency values due to P and Ca uptake were generally highest in the Mlama soil followed by the Magadu and University Gate soils. Relative effectiveness of the non acidulated P sources was also reflected by the relative efficiency values. The relative efficiency in P and Ca uptake data, therefore, confirm that both P and Ca uptake contributed to the observed crop responses in the Mlama, Magadu and University Gate soils.

4.2 Residual pot experiment

Soil analysis results after harvest in the initial pot study revealed that P sources substantially increased both extractable P and exchangeable Ca (Tables 5a and 5b). Increases in extractable P relative to the control ranged from 54.3% in the Mlama soil to 11.8% in the Kwa Sadala soil. This indicated that all the fertilizers tested had potential residual effects. A residual experiment was, therefore, carried out to ascertain this potential. Sorghum (Sorghum bicolor var. Serena) was used as the test crop as P deficiency is one of the problems limiting its increased production (Mnkeni 1989). Treatment effects were evaluated using dry matter yield, P and Ca uptake and their respective RAE values.

Dry matter yield results for the residual study (Table 3a) shows that yields in the Mlama, Magadu and

University Gate soils were increased by each of the residual P treatments. No increases in yield were noted in the Mafiga and Kwa Sadala soils. The trends of these results were similar to those observed in the initial pot experiment, reflecting the high original P status of the soils (Table 1). The yield increases due to P sources were significant (Table 3b) showing that the P materials profoundly influenced yields in the Mlama, Magadu and University Gate soils in the residual experiment. A significant P source x soil interaction (Table 3b) was also observed indicating that the performance of the P carriers varied with soil as was the case in the initial study.

Dry matter yield data in Table 3a indicate that the Minjingu PR materials applied in the initial experiment gave yields similar to those from TSP in the Mlama, Magadu and University Gate soils. The exception was the unbeneficiated PR which resulted in higher yields only in the Magadu soil. This suggests that the non acidulated and partially acidulated Minjingu PR products had residual value equal to that of the reference fertilizer. It also indicates that the Minjingu PR products had comparable residual effects in the three soils. Further, the results showed that unbeneficiated PR had higher residual fertilizer value than TSP in the Magadu soil.

Relative agronomic effectiveness values (Table 7) generally indicate that the non acidulated and partially acidulated P carriers had residual effectiveness higher than that of the reference fertilizer in the Mlama, Magadu and University Gate soils. This implies that with time the P carriers substantially dissolved in the three soils. This was also reflected by the pronounced increases in extractable P and exchangeable Ca revealed in the soil analysis data after harvest in the initial pot study (Tables 5a and 5b), indicating that the P sources underwent considerable dissolution in the three soils. This was not observed, however, in the Kwa Sadala and Mafiga soils (Tables 5b and 5c). These findings are of significant interest since these inexpensive P alternatives like beneficiated and unbeneficiated PRs could be considered when choosing P fertilizers for these soils. RAE values also reflect that the partially acidulated and non acidulated P carriers had comparable effectiveness in these soils. Again, this is of paramount importance in fertilizer decisions regarding what would be the cheapest P source for these soils. Relative efficiency due to P and Ca uptake (Table 7) followed a pattern corresponding to that of RAE values, suggesting that both P and Ca uptake contributed to the observed responses.

The effect of the residual P sources on calcium uptake differed on the five soils as revealed by a significant P source x soil interaction (Table 6b). This interaction was, however, not observed in the original pot study. Reason for this observation could not be established.

4.3 Initial and residual combined data

The combined data of the two pot studies reflect the trends observed in the initial and residual studies. Mean total dry matter values (Table 3a) support the conclusion that the Mlama, Magadu and University Gate soils would benefit from P application because response to added P was evident. The lack of response observed in the Kwa Sadala and Mafiga soils in the two studies is also reflected by the combined data, confirming that additional P will not be beneficial in these soils. The data also reflects the P source x soil interaction observed in the two studies, confirming that the performance of the P carriers varied with soils (Table 3b).

With regard to specific P materials, the combined data indicate that all the P sources performed uniformly in the Mlama soil, a trend which was also reflected by the two pot studies. The data also indicate that there was no pronounced difference between the P carriers in the University Gate and Magadu soils. However, superiority of TSP in the two soils was again reflected as was the case in the original pot study.

Combined RAE values (Table 7) indicate that RAE for the fertilizer materials decreased with increasing pH. RAE values were highest in the strongly acid Mlama soil but lowest in the slightly acid University Gate soil. This is consistent with the RAE values observed in the two pot studies. Uniformity in performance of the P sources in the Mlama soil is also reflected by the combined RAE values.

As was observed in the original study, RAE values from the partially acidulated and non acidulated Minjingu PR products were lower than that of TSP, supporting the previous conclusion that the reference fertilizer was superior in the Magadu and University Gate soils. The combined data also indicate that next to TSP, the PAPRs had the highest RAE values followed by the other PRs in the University Gate and Magadu soils.

Combined P and Ca uptake data (Table 4a and 5a) also suggest that the observed responses in the three soils were a result of improved P and Ca uptake. A significant P source x soil interaction on calcium uptake (Table 6b) confirms the observation in the residual experiment that differences regarding Ca uptake existed. The combined data suggests that the interaction was brought about by the relatively higher performance of 50 PAPR in the Kwa Sadala soil.

4.4 Field Experiments

The study was conducted to confirm under field conditions the effects of the partially acidulated and non acidulated Minjingu PR products as observed in the pot study. This experiment was carried out on two of the soils tested in the pot studies, namely the Magadu and the University Gate soils. These soils were among the soils which responded to added P in the pot study.

Maize (Zea mays L. var Staha) was again used as the test crop and treatments were similar to those in the pot experiment.

4.4.1 Response to the P sources

A significant P source effect on grain yield was observed on both experimental sites (Table 8a). Unlike in the pot studies, no significant P source x soil interaction on grain yield was observed (Table 8b).

Triple superphosphate, the reference fertilizer, significantly increased yields in the Magadu and the University Gate sites (Table 8a). Both 50 PAPR and 25 PAPR increased grain yield in the two locations (Table 8a). This increase was associated with corresponding increases in P and Ca uptake (Table 8a). Mean yield values for the two sites (Table 8a) indicate that 50 PAPR had similar treatment effect on grain yield as compared to 25 PAPR.

Beneficiated and unbeneficiated PR significantly increased yields in the Magadu and University Gate sites (Table 8a). This corresponded to increases in both grain Ca and grain P uptake (Table 8a).

A significant P source effect and the absence of a P source x soil interaction on grain yield observed for the Magadu and University Gate sites indicate that there was response to the added P carriers and that the P sources performed uniformly in the two sites. It would seem that the pronounced interactions observed in the pot studies were contributed to by the other soils not included in the

Table 8a: Effect of phosphate sources on maize grain yield, grain P uptake and grain Ca uptake in the field experiments

	Phosphorus source						
	Control	TSP	Minjingu 50% PAPR	Minjingu 25% PAPR	Beneficiated Minjingu PR	Unbeneficiated Minjingu PR	Mean
			A: <u>GRAIN YIELD (GY) (kg/ha)</u>				
Magadu	2033	3607	3400	3275	3082	3127	3087
University Gate	2133	3483	3383	3333	3167	3117	3103
Mean	2083d	3545a	3392a	3304ab	3124c	3122c	
			B: <u>GRAIN P UPTAKE (GPU) (kg P/ha)</u>				
Magadu	3.41	6.58	7.02	6.55	5.71	5.79	5.80
University Gate	3.25	7.16	6.94	6.50	5.64	5.36	5.81
Mean	3.20c	6.87a	8.00a	6.52a	5.67b	5.57b	
			C: <u>GRAIN Ca UPTAKE (GCaU) kg Ca/ha</u>				
Magadu	0.24	0.59	0.52	0.47	0.43	0.43	0.45
University Gate	0.24	0.50	0.47	0.47	0.39	0.38	0.41
Mean	0.24d	0.54a	0.49b	0.47b	0.41c	0.40c	

Treatment means of given site and main effect means followed by the same letter or none at all are not significantly ($P < 0.05$) different using the New Duncan's Multiple Range Test.

Table 8b: Results of the ANOVA on maize grain yield (GY) grain P uptake (GPU) and grain Ca uptake (GCaU) is the field experiments

Source of variations	GY	GPU	GCaU
Site	NS	NS	**
P sources	**	**	**
Reps	NS	NS	NS
P source x site	NS	NS	NS
CV (%)	6.99	12.64	9.35

** = Significant at $P < 0.01$

NS = Not significant

CV = Coefficient of variation

field experiments.

Response to added P in the form of TSP confirmed the need for supplemental P on the Magadu and University Gate soils, as first observed in the pot studies. The observed grain yield increases following application of both 50 PAPR and 25 PAPR in the two locations, and the corresponding increases in grain P and Ca uptake, suggest that the responses could partly be due to enhanced P and Ca uptake. This is supported by the after-harvest soil test results (Tables 9a and 9b) which indicate that there were increases in soil extractable P and exchangeable Ca levels relative to the controls in both soils. Both 50 PAPR and 25 PAPR nearly doubled extractable P and exchangeable Ca levels in the Magadu and University Gate sites. This signifies that the PAPRs underwent considerable dissolution in two experimental locations, hence the observed increases in grain yield and P and Ca uptake. Hammond et al. (1980) also found PAPRs to increase extractable P levels in P deficient soils. The observed similarity in treatment effect on grain yield between 50 PAPR and 25 PAPR on the two locations shows that the two PAPRs were equally effective on either of the sites. These results were consistent with those obtained in the initial pot study where 50 PAPR was as effective as 25 PAPR in both the University Gate and Magadu soils. Comparison of the PAPRs with the reference fertilizer (TSP) indicates that 50 PAPR had similar effect on grain yield to TSP, implying that it was as effective as TSP on the two sites.

Table 9a: Effect of phosphate sources on some soil properties after harvest in the field experiments

Site	Phosphate source						Mean
	Control	TSP	Minjingu 50% PAPR	Minjingu 25% PAPR	Beneficiated Minjingu PR	Unbeneficiated Minjingu PR	
			A: SOIL pH				
Magadu	5.3	5.4	5.3	5.3	5.2	5.3	5.3
University Gate	6.1	6.2	6.1	6.1	6.1	6.1	6.1
Mean	5.7	5.8	5.7	5.7	5.7	5.7	
			B: EXTRACTABLE P (EP) (Cmol(P+) kg^{-1})				
Magadu	4.93	8.31	7.75	8.07	7.67	6.54	7.21
University Gate	5.16	9.33	8.24	7.78	8.14	7.79	7.74
Mean	5.05c	5.82a	8.00ab	7.93ab	7.90ab	7.16b	
			C: EXCHANGEABLE Ca (ECa) (Cmol(p+) kg^{-1})				
Magadu	2.47	4.73	4.28	4.31	4.15	4.07	4.00
University Gate	3.47	6.94	6.80	6.19	6.19	5.96	5.93
Mean	2.97c	5.83a	5.54ab	5.25ab	5.17ab	5.02b	
			D: EXCHANGEABLE Al (EAl)(Cmol(p+) kg^{-1})				
Magadu	0.73a	0.58bc	0.65ab	0.50c	0.50c	0.55bc	0.59

Simple effect and main effect means followed by the same letter are not significantly ($P<0.05$) different using the New Duncan's Multiple Range Test.

Table 9b: Results of the ANOVA on some soil properties after harvest in the field experiments

Source of variations	pH	EP	ECa	EA
Site	**	NS	**	-
P source	NS	**	**	*
Reps	NS	NS	NS	*
P source x site	NS	NS	NS	-

*, ** = Significant at P < 0.05 and P < 0.01, respectively

NS = Not significant

CV = Coefficient of variation

On the other hand, 25 PAPR gave lower yields relative to the reference fertilizer showing that it was inferior to TSP.

The increases in grain yield obtained as a result of application of both beneficiated and unbeneficiated PR, and the corresponding increases in both grain P and Ca in the two experimental sites, suggest that the materials underwent considerable dissolution in the Magadu and university Gate locations. It also implies that the observed increases in grain yield could partly be due to improved P and Ca nutrition. This trend of results compares well with that observed by Mnkeni et al. (1986) who also found Minjingu PR to substantially increase P and Ca uptake by maize.

Beneficiated PR gave yields comparable to those from unbeneficiated PR in the two sites (Table 8a) indicating that the P sources were equally effective in the two locations.

On comparing the PRs to the reference fertilizer, both beneficiated and unbeneficiated PR gave yields lower than those from TSP (Table 8a), indicating that they were inferior to the reference fertilizer in the two sites. Compared to the PAPRs, both beneficiated and unbeneficiated PRs had yields comparable to those from 25 PAPR, showing that they were equally effective. The 50 PAPR increased yields more than any of the PRs, reflecting its superior effectiveness relative to the PRs in the Magadu and University Gate sites.

It is, however, interesting to note from these results that despite the differences, the non acidulated P sources were able to increase grain yield substantially in the two sites. This could be due to enhanced solubility caused probably by adequate moisture during the growing season. The 1989 cropping season was characterized by relatively high and well distributed rainfall throughout the growing season as compared to the two previous seasons (Table 10). Hammond *et al*. (1986) also noted that adequate moisture could substantially increase PR solubility. This can be substantiated by increases in soil extractable P and exchangeable Ca levels in the soil analysis data after harvest (Table 9a) following application of the PRs. Both beneficiated and unbeneficiated PR increased extractable P levels by about 60% whereas exchangeable Ca was increased by nearly 70% relative to the controls. This indicates that the two P sources underwent considerable dissolution in these soils.

Table 10: Rainfall data for 1987, 1988 and 1989 cropping seasons*

	Total Rainfall							
Year	March 1-14	March 15-31	April 1-14	April 15-30	May 1-14	May 15-31	June 1-14	June 15-30
	mm							
1987	3.30	43.90	33.50	53.50	4.30	7.90	22.70	0.00
1988	77.80	43.90	76.30	28.40	104.30	28.40	0.00	3.30
1989	77.70	68.70	169.90	81.50	33.20	79.50	8.50	2.40

* Source: Sokoine University of Agriculture meteorological station
P.O. Box 3000
Morogoro
Tanzania

4.2.2 Relative agronomic effectiveness of the P carriers

Data in Table 11 show RAE values of the P sources and their relative effects on grain P and grain Ca in the Magadu and University Gate sites. All RAE values for the PAPRs and PRs were below 100% suggesting that they had lower fertilizer values than the reference fertilizer.

Differences among individual P sources existed as was the case for the observed responses. In the Magadu site, the PAPRs had higher effectiveness than the non acidulated PRs. Generally, 50 PAPR and 25 PAPR had more or less the same effectiveness. Likewise, beneficiated and unbeneficiated PRs had nearly the same effectiveness. A similar trend was observed in the University Gate site. As it was for RAE values, relative efficiency due to P and Ca uptake values were lower than 100% and the PAPRs had relatively higher values compared to the other PRs. Relative efficiency values were similar between the two PAPRs. Likewise, similarity between the other PRs was also shown. It is concluded that the observed responses in yields relative to the controls were contributed to by improvement of both P and Ca nutrition.

Results of the field experiment therefore confirm those of the initial pot study where RAE values for TSP were highest in the Magadu and Gate sites, followed by the PAPRs and the PRs. Thus, the observed RAE values confirm that the PAPRs had higher fertilizer substitution values compared to the other PRs in the two sites.

Table 11: The relative agronomic effectiveness of the Minjingu PR products and their relative efficiencies in affecting grain P and grain Ca uptake by maize under field conditions

Treatments	Experimental Site	
	Magadu	University gate
	Relative Agronomic Effectiveness (%)	
TSP	100	100
50% PAPR	87	93
25% PAPR	79	89
Beneficiated Minjingu PR	67	77
Unbeneficiated Minjingu PR	69	73
	Relative Efficiency in P uptake (%)	
TSP	100	100
50% PAPR	84	95
25% PAPR	73	83
Beneficiated Minjingu PR	55	61
Unbeneficiated Minjingu PR	57	54
	Relative Efficiency in Ca uptake (%)	
TSP	100	100
50% PAPR	80	88
25% PAPR	66	88
Beneficiated Minjingu PR	54	58
Unbeneficiated Minjingu PR	54	54

These results may also suggest that beneficiated and unbeneficiated PRs could be acceptable P alternatives in these soils since RAE values (Table 11) indicate that the two P carriers were about 70% effective relative to the reference fertilizer. This is an important aspect since the processes involved in their preparation are fairly less energy consuming compared to those in the case of the PAPRs and TSP and should be relatively more affordable by farmers.

5.0 SUMMARY AND CONCLUSIONS

The various Minjingu products studied increased yields in the Mlama, Magadu and University Gate soils mainly because the soils were acidic and deficient in P. No response was observed in the Kwa Sadala and Mafiga soils because they had relatively high extractable P contents.

The non acidulated and partially acidulated Minjingu PR products were as effective as or in some cases better than TSP, the reference fertilizer, in the strongly acidic Mlama soil. These materials could thus be good TSP substitutes in this soil. In view of their relatively low cost, the direct application of non acidulated Minjingu PR products is recommended for this and other soils with similar properties.

In the Magadu and University Gate soils the agronomic effectiveness followed the order TSP > PAPRs > non acidulated PRs in the initial pot study and field experiments. The lower effectiveness of the PAPRs and non acidulated PRs compared to TSP was attributed to the relatively high pH of these soils compared to that of the Mlama soil. Nevertheless, the appreciable effectiveness of the PAPRs and PRs observed on these soils indicates their potential as TSP alternatives in these soils if found to be economically viable.

Results of the residual pot experiment indicated that in most cases the PAPRs and the PRs had superior residual value compared to the reference fertilizer (TSP). Cheaper P sources like the non acidulated PRs could be the best P materials in the Mlama, Magadu and University Gate soils as they had residual effectiveness higher than that of TSP in these soils. Further testing of this aspect is, however, needed to confirm this trend.

Further research is recommended for the PAPRs to evaluate their effectiveness under different field conditions since it is the first time these P materials have been tested in Tanzania.

6.0 REFERENCES

Amberger, A. 1978. Experiences with soft rock phosphates for direct fertilizer application. Seminar on phosphate rock for direct application. IFDC, Muscle Shoals, Alabama. 349-356.

Anderson, G.D. 1965. Estimation of the potential productivity of some pasture in the Mbulu Highlands of Tanganyika by application of fertilizers. East African Agricultural and Forestry Journal 30(3): 206.

Anderson, G.D. 1970. Fertility studies on a sandy loam in semi arid Tanzania II. Effect of phosphorus and potassium and lime on yields of groundnuts. Experimental Agriculture 6: 213-222.

Asher, G.J.; Ozanne, P.G. 1961. The cation exchange capacity of plant roots and its relationship to uptake of insoluble nutrients. Australian Journal of Agricultural Research 12: 755-766.

Barnhisel, R.; Bertisch, B.M. 1982. Aluminium. In Methods of Soil Analysis part 2 (Edited by Page A.L.) Agronomy 9. American Society of Agronomy, Inc. Madison Wisc. 275-296.

Barnes, J.S.; Kamprath, E.J. 1975. Availability of North Carolina phosphate rock applied to soils. North Carolina Agricultural Experimental Station Technical Bulletin No. 229, Raleigh, North Carolina, 129 pp.

Bennett, O.L.; Ensiminger, L.E.; Pearson, R.W. 1957. The availability of phosphorus in various sources of phosphate as shown by green house studies. Soil Science Society of America Proceedings 21: 531-524.

Bray, R.H.; Kurtz, L.T. 1945. Determination of total organic and available forms of phosphorus in soils. Soil Science 59: 39-45.

Bremner, J.M.; Malvaney, C.S. 1982. Total Nitrogen. In Methods of Soil Analysis Part 2 (Edited by Black, C.A.). Agronomy 9. American Society of Agronomy, Inc. Madison, Wisc. 1149-1179.

Chapman, H.D. 1965. Cation exchange capacity. In Methods of Soil Analysis Part 2 (Edited by Black, C.A.). Agronomy 9. American Society of Agronomy, Inc. Madison Wisc. 891-901.

Chien, S.H. 1978. Reactions of Phosphate rocks, Rhenania phosphate and superphosphate with an acid soil. Soil Science Society of America Journal 42: 705-708.

Chien, S.H. 1985. Reactions of phosphate fertilizers in soils. Paper prepared for the development of indigenous phosphate deposits training programme. IFDC, Muscle Shoals, Alabama, 22 pp.

Cooke, G.W.; Widdowson, F.V. 1958. Field experiments on phosphate fertilizers. A joint investigation. Journal of Agricultural Science 53: 46-63.

Day, D.P. 1978. Aspects of North Carolina Phosphate rock. Seminar on phosphate rock for direct application. IFDC, Muscle Shoals Alabama, pp 43-73.

Dewis, F.; Freitas, J. 1970. Physical and chemical Methods of soil and water analysis FAO Soil Bulletin 10: 51.

Engelstad, O.P.; Jugsujinda, A.; De Datta, S. 1974. Response by flooded rice to phosphate rocks varying in Citrate solubility. Soil Science Society of America Proceedings 38: 524-529.

Easterwood, G.W.; Street, J.J.; Sartain, J.B. 1987. Influence of phosphate rock on dry matter yield and P uptake of *Zea mays* L. Soil and Crop Science Society of Florida Proceedings 45: 72-75.

FAO - UNESCO. 1974. Soil map of the world. Vol. 1 Legend. Unesco, Paris, 59 pp.

Fenster, W.E.; Leon, L.A. 1978. Utilization of phosphate rock in tropical soils of Latin America (a research proposal) seminar on phosphate rock for direct application. International Fertilizer Development Centre. Muscle Shoals Alabama, 174-210.

Flach, E.N.; Quaks, W.; Diest, A.V. 1987. A comparison of the rock phosphate mobilizing capacity of various crop species. Tropical Agriculture (Trinidad) 64: 347-352.

Floor, J.; Kimambo, E.I. 1989. Considerations on and experience with the use of Minjingu rock phosphate as a direct source of P fertilizer. In Proceedings of the Phosphate Research Meeting (Edited by Kaihura, F.B.S.; Floor, J.; Ikerra, S.T.) Mkonge Hotel, Tanga, pp. 22-24.

Friesen, D.K.; Sale, P.W.G.; Blair, G.J. 1987. Long term greenhouse evaluation of partially acidulated phosphate rock fertilizers I. Effect of acidulation on availability of phosphorus from rocks. Fertilizer Research 23: 31-44.

Garbouchev, I.P. 1981. The manufacture and agronomic efficiency of a partially acidulated phosphate rock fertilizer. Soil Science Society of America Journal 45: 970-974.

Hammond, L.L.; Chien, S.H.; Polo, J.R. 1980. Phosphorus availability from partial acidulation of two phosphate rocks. Fertilizer Research I: 37-49.

Hammond, L.L.; Chien, S.H.; Mokwunye, A.U. 1986. Agronomic value of unacidulated phosphate rocks indigenous to the tropics. Advances in Agronomy Journal 40: 89-140.

Hangi, A.Y. 1986. Beneficiation of phosphate rock. Minjingu mine experience. In Agrogeology in Africa (Edited by Wachira, W.K. and Notholt, A.J.G.) 120-127.

Harris, J.F. 1981. Summary of the Geology of Tanganyika, Part IV, Economic Geology. p. 114.

Ikerra, T.W.D. 1986. Evaluation of Minjingu phosphate rock as a source of phosphorus for maize when applied in combination with compost or farm yard manure. M.Sc. dissertation. Dept. Soil Sci., Sokoine University of Agriculture, Morogoro, Tanzania;

Jackson, M.L. 1958. Soil Chemical analysis, Prentice Hall, Inc.; Englewood Cliff, New Jersey, CPSA 75-96.

Jaggi, T.N. 1986. Direct application of low grade phosphate rock in acidic soils - Its impact on economics. IMPROS Seminar.

Jones, U.S. 1948. Availability of phosphorus in rock phosphate as influenced by potassium and nitrogen salts, lime and organic matter. Agronomy Journal 40: 765-770.

Juo, A.S.R. 1979. Dry ashing for Ca, Mg, K and P determination in plant tissues. Selected methods of soil and plant analysis. Manual series No. 1. Publication by IITA, Ibadan, Nigeria, pp. 52-53.

Kanabo, I.A.K.; Gilkes, R.J. 1987. The role of soil pH in the dissolution of phosphate rock fertilizers. Fertilizer research 12: 165-174.

Khasawneh, F.E.; Doll, E.C. 1978. The use phosphate rock for direct application to soils. Advances in Agronomy Journal 30: 159-206.

Landon, J.R. 1984. Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, New York, 112-123.

Lehr, J.R.; McClean, G.H. 1972. A revised laboratory reactivity scale for evaluating phosphate rocks for direct application. Bulletin Y - 43, TVA, Muscle Shoals, Alabama.

Luken, H.; Blumel, G. 1984. Phosphate rock as a direct application fertilizer. Can it help to relieve food shortage in some low income developing countries? Geologisches Jahrbuch 17: 3-27.

Lutz, J.A. Comparison of partially acidulated rock phosphate and concentrated superphosphate as sources of phosphorus for corn. Agronomy Journal 63: 919-922.

Marwaha, B.C.; Kanwar, B.S. 1981. Utilization of ground phosphate as a direct phosphatic fertilizer. Fertilizer News 26: 10-20.

McLean, E.O. 1982. Soil pH and lime requirements. In Methods of Soil Analysis part 2 (Edited by Page A.L.) Agronomy 9. American Society of Agronomy, Inc.; Madison Wisc. 199-223.

McLean, E.O.; Wheeler, R.M. 1964. Partially acidulated rock phosphate as sources of phosphorus to plants I. Growth chamber studies. Soil Science Society of America Proceedings 28: 545-550.

McLean, E.O.; Wheeler, R.W.; Watson, J.D. 1965. Partially acidulated rock phosphate as a source of phosphorus to plants II. Growth chamber and field corn studies. Soil Science Society of America Journal 29: 625-628.

Mnkeni, P.; Semoka, J.; Buganga, J. 1986. Evaluation of agronomic effectiveness of Minjingu phosphate rock as a source of phosphorus for maize in four soils of Morogoro district, Tanzania. In proceedings of the 8th Annual General Meeting of the Soil Science Society of East Africa, (Edited by Magunda, M.K.; Fenster, W.E.), Kampala, Uganda pp. 180-195.

Mnkeni, P.N.S. 1989. A review of soil fertility and fertilizer use research and recommendations in Tanzania. In Proceedings of the East and Southeast African Fertilizer Management and Evaluation Network Workshop, 1989, Nairobi, Kenya (edited by Ssali, H. and Williams, L.B.) pp. 161-195.

Muller, S.; Bagemann, O.; Ansorge, H. 1986. The effect of various phosphorus fertilizers on yields, phosphorus uptake by plants and conversion of phosphorus fertilizers in long term experiments in different soils. Fertilizer research 10: 231-236.

Nelson, D.W.; Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In Methods of Soil Analysis Part 2 (edited by Page, A.L.) Agronomy 9. American Society of Agronomy. Inc., Madison, Wisconsin pp. 539-577.

Ngatunga, E.N.L.; Haule, K.L.; Deckers, J. 1989. A comparison of the effects of application of Minjingu phosphate rock and triple superphosphate on the yield of sorghum on acid sandy loam soils of Naliendele in South Eastern Tanzania. In Proceedings of the Phosphate Research Meeting (Edited by Kaihura, F.B.S.; Floor, J.; Ikerra, S.T.). Mkonge Hotel, Tanga, pp. 31-35.

Nordengren, S.V. 1957. New theories of phosphate reactions in soil and their possible impact on methods of fertilizer manufacture. Fertilizer and Feeding Stuffs Journal 47: 345.

Rajan, S.S.S.; Gillingham, M. 1986. Phosphate rocks and phosphate rock/sulfur granules as fertilizers for hill country pasture; New Zealand Journal of Experimental Agriculture 14(3): 313-318.

Ray, B.; Van Diest, A. 1979. Utilization of phosphate from different sources by six plant species. Plant and Soil 51: 577-589.

Rogers, H.T.; Pearson. R.W.; Ensiminger, L.E. 1953. In Soil and Fertilizer Phosphorus in Crop Nutrition (edited by Piere, W.H. and Norman, A.G.) Academic Press, New York Vol. 14. pp. 189-249.

Roy, H.A. 1985. The manufacture of partially acidulated phosphate rock. Prepared for the development of indigenous phosphate deposits training programme. IFDC, Muscle Shoals Alabama. 27 pp.

Peaslee, D.E.; Anderson, E.A.; Burns, G.R.; Black, C.A. 1962. Estimation of relative value of phosphate rock and superphosphate to plants on different soils. *Soil Science Society of America Proceedings* 26: 566-570.

Savage, S. 1970. Introductory laboratory soil science manual, Department of Renewable Resources, McGill University, Canada. pp. 56-57.

Semoka, J.M.R.; Mnkeni, P.N.S. 1986. Agricultural application of phosphates and other agrominerals: Possibilities and limitations. *In Agrogeology in Africa* (edited by Wachira, W.K. and Notholt, A.J.G.) pp. 149-160.

Scaife, A. 1968. The effect of cassava fallow and various manurial treatments on cotton at Ukiriguru, Tanzania. *East African Agricultural and Forestry Journal* 33: 231.

Singh, B.R.; Uriyo, A.P.; Kilonde, M.; Msaky, J.J. 1980. Evaluation of soil testing methods for available potassium in some soils of Morogoro. *In proceedings of the second symposium on intercropping in semi arid areas*, 1980, Morogoro, Tanzania (edited by Keswani, C.L. and Ndunguru, B.J.) p. 27.

Singh, B.R.; Uriyo, A.P. 1978. Some acid soils in Tanzania, their occurrence and chemical properties. *University Science Journal (University of Dar es Salaam)* 4(2): 3-9.

Snedecor, G.W.; Cochran, W.G. 1980. Statistical methods, Iowa State University Press, Iowa, USA, 298-330.

Soil Survey Staff. 1975. Soil taxonomy. United States Department of Agriculture, Handbook No. 436 Washington DC, 754 pp.

Welte, E. 1978. Viewpoint on utilization of phosphate rock for direct application. Seminar on phosphate rock for direct application. IFDC, Muscle Shoals Alabama, 325-337.