Soil Productivity Research Programme
Misamfu Regional Research Centre

Overview of Phosphorus Research in Northern Zambia
1981-1993

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November, 1994

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Acknowledgement

INTRODUCTION

One of the major problems that has inhibited the development of economically successful agriculture in many areas of the tropics is poor soil fertility for crop production. Many tropical regions, are low in both total and available phosphorus. After water and nitrogen, the most commonly limiting nutrient elements in the these regions are probably phosphorus and sulphur (Sanchez, 1976).

Northern Zambia is characterised by high, reliable rainfall (above 1200 mm) with soils predominantly Oxisols and Ultisols that have been subjected to high leaching and intense weathering. These soils have good physical properties and generally are well suited for agriculture. They are however, constrained by having low inherent fertility, low pH (pH $CaCl_2$ = 4.2) and high levels of Fe and Al oxides. Many soil are low in P. A Survey of the soils in the region indicate widespread inherent P deficiency (generally in the range of 3-12 ppm P by Bray 1 method) (SPRP, 1989) and low to high P sorption capacities in the effective rooting zone (Guldberg, 1985). Field studies conducted by the Soil Productivity Research Programme (SPRP, 1986) revealed that crops seldom produce economical yield without application of P in most of these soils.

This report is a overview of phosphorus research in northern Zambia done mostly by SPRP between 1981 to 1993. This research include crop response to applied phosphorus, crop response to phosphorus fertilizer on soils with different adsorption capacities and evaluation of indigenous rock phosphates as a source of phosphorus.

LITERATURE REVIEW

PHOSPHORUS IN TROPICAL SOILS

Although phosphorus deficiency is a world-wide problem, it appears to be more acute in the humid tropics particularly in regions where there are acid, heavy-textured soils that are high in oxide and hydroxide minerals (Uehara and Gillmann, 1981). Total phosphorus in the tropical soils ranges from 50 to 2000 ppm and values less than 200 are common. (Dabin, 1980, Olson and Engelstad, 1972). According to Sanchez (1976) there are, in spite of the generally low content, some oxisols that are high in total phosphorus.

Phosphorus is a problem in these soils not because it is deficient, but because of the huge amounts of phosphate that need to be added to obtain optimal growth. In many cases the total amount of native phosphorus is quite high, but the element is present in forms that render it unavailable to plant. Phosphorus added as fertiliser, especially in soluble forms, is immediately sorbed onto oxide surfaces, and the strength of the chemical bonds formed makes it difficult for plants to compete with the surface for this nutrient (Uehara and gillman, 1981).

FORMS OF PHOSPHORUS IN THE SOIL

Phosphorus is present in soil soulution, inorganic and organic forms. The solid phase phosphorus is partly in organic form (30 to 50%) but, except on soils with a high proportion of organic matter, it is mostly in inorganic combination (50 to 70%) and is present in living (soil microflora and fauna) and dead organic matter. The latter results from plant animal residues.

Phosphorus in solution

Plant take-up their phosphorus mainly as orthophosphate, The ions are $H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}. In solution phosphorus is mostly present as primary or secondary orthophosphate ions ($H_2PO_4^-$ or HPO_4^{2-}) both of which are capable of direct adsorption by plant roots. The PO_4^{3-} ion is only significant in very alkaline solutions. The relative abundance of the two types of ions is largely depended on soil pH. Within the pH range 5 to 7.2, $H_2PO_4^-$ is the dominant ionic form, whereas between pH 7.2 and 9, $H_2PO_4^-$ ion dominants. Phosphorus deficiency in acid soils usually arises from too low concentration of orthophosphates in the soil solution, rather than from an inadequate total phosphorus content.

The inorganic phosphorus

The inorganic phosphorus is derived originally from the weathering of rock containing the mineral apatite, and is present in a variety of combination with iron, aluminium calcium and fluorine plus other elements. The solid inorganic forms of phosphorus are usually divided into three active fractions and two relative inactive fractions,

Active fractions

The active fractions can be grouped into;
1. Calcium-bonded phosphates (Ca-P),
2. aluminium-bonded phosphates (Al-P), and
3. iron-bonded phosphates (Fe-P).

Inactive fraction

1. Occluded
2. Reductant-soluble forms.

The form of inorganic phosphorus present in the soil depends on its chemical stage of weathering. In highly weathered soils most of the phosphorus is in the occluded or reductant-soluble forms because of the formation of iron and aluminium oxide coatings. In Ultisols both iron and aluminium phosphates predominate.

The organic Phosphorus

Quite a high proportion of the soil phosphorus is in organic form and the organic phosphorus is therefore an important property of the soil. Organic Phosphorus normally accounts for 20 to 50 percent of the total top soil phosphorus. The importance of maintaining organic matter is also a function of the maintenance of organic phosphorus, particularly in soils where most of the phosphorus is in this form. In unfertilised agriculture mineralization of organic material play an important role in making phosphorus available to plant and phosphorus management is largely a soil organic matter management (Van Wambeke, 1974; Sanchez, 1976). Its maintenance, therefore, is of great practical significance in traditional agricultural systems. This is mainly practised through fallow periods and some through manuring.

REACTION OF PHOSPHORUS WITH SOIL MINERALS

Phosphate availability in the soil is often a limiting factor for plant growth even though the total amount of soil-P may be high. Phosphorus concentration in the soil solution is influenced by various processes: by the uptake of plants, by the assimilation or release of inorganic phosphates from the pool of organic phosphorus, by equilibration with Ca-phosphate and with phosphate adsorption sites. Soluble phosphate added to the soil finally will go to the strongest sink (Mengel, 1985). In this respect it is important to fully understand the nature of the adsorption and precipitation reaction which occur when fertilizer phosphorus is added to soils of different mineralogical compositions.

Phosphorus Fixation

As soils weather their calcium content tends to decrease while reactive Al and Fe contents increase. With increasing weathering there is thus a shift in the control of phosphate solubility from Ca, which gives low phosphate ions concentration in the soil solution, to Al and Fe which form complex phosphorus compounds that are precipitated or strongly adsorbed on the clay lattice and amorphous sesquioxides. This is referred to as fixation. Fixation of P is initially rapid and then slows down; fixation capacity is greater at pH levels below 5.5 (Fox and Searle, 1978).

The process consists of transforming soluble monocalcium phosphate (superphosphates) into less soluble calcium, aluminium, or iron phosphates. When a superphosphate granule is placed in the soil, water initially moves into the granule and dissolves some of the monocalcium phosphate into dicalcium phosphate and free phosphoric acid. The solution coming out of the granule has a pH of 1 to 1.5. This acid solution dissolves aluminium, iron, potassium and magnesium compounds in soil particles. In acid soils aluminium and iron are most abundant and react with phosphorus to form relatively insoluble aluminium and iron phosphates (Sanchez, 1976). In calcareous soils the phosphates ions are precipitated by calcium and magnesium as relatively insoluble compounds. The mineralogy defines the product of phosphorus fixation. The higher the content of iron and aluminium oxide, the larger is the phosphorus-fixing capacity of the soil. Also, the higher the exchangeable aluminium content, the larger the phosphorus-fixing capacity will be. Therefore highly acid and weathered Oxisols and Ultisols generally have high phosphorus fixation capacities, whereas less acid soils with layer silicate mineralogy have much lower ones. However, Ultisols may have a lower sorption due to coarse texture in the topsoil. Fox et al., (1968) described the intensity of fixation according to mineralogy as follows:

Amorphous oxides > cryalline oxides> 1:1 clays 2:1 clays

(including allophane)   (Gibbsite, Goethite, etc.)

Phosphorus Desorption

A transformation of immobile form of P into mobile forms may occur when the concentration of P is lowered leading to desorption and dissolution processes. Other factors which may play a role in the release of phosphate are pH changes, reducing conditions and the presence of organic and inorganic species competing with P for the same binding sites. Decomposition and mineralization of organic forms may also lead to dissolved (ortho) phosphate (Birch, 1961).

Much of the fixed phosphorus remains slowly available for plant nutrition, and residual effects of fertilizer are common in the high fixing soils. If it where not for this long residual effect of phosphorus, there would be little hope of ever developing the high phosphorus-fixing soils of the tropics for intensive agricultural use (Uehara and Gillmann, 1981).

Phosphorus adsorption isotherms

Adsorption isotherms gives information about both buffering capacity and solution concentration aspects of P availability. The amount of fertilizer phosphorus that must be added to provide a concentration of 0.2 ppm P in the supernatant soil solution provides an indication of the magnitude of phosphorus fixation. This concentration value was chosen because many crops have an optimum growth at this concentration of phosphorus in the soil solution. If this concentration is continuously maintained in soil solution, it will provide adequate phosphorus for optimum plant growth for many crops. Clayey Oxisols, clayey Ultisols, and most Andepts have extremely high phosphorus fixation capacities, ranging from 300 to 1000 ppm P required to reach the desired concentration in the soil solution. Other tropical soils with predominantly layer silicate mineralogy, as well as coarse-textured Ultisols and Oxisols, have moderate to weak phosphorus fixation capacity.

For the purpose of comparing the standard P requirement of soil (P sorbed at 200 μg P/l solution) Juo and Fox, (1977) classified the soil according to P sorption as follows:

Standard P requirement (μg P/g Soil)	Scale	Usual mineralogy encountered
< 10	Very low	Quartz, organic materials
10-100	low	2:1 clay, quartz, 1:1 clays
100-500	Medium	1:1 clays with oxides
500-1000	high	oxides, moderately weathered ash
>1000	very high	desilicated amorphous material

SOIL FACTORS AFFECTING PHOSPHORUS AVAILABILITY

The physical and chemical characteristics of the soil largely control the availability of P to plants and influence the chemical nature of the end products formed when P fertilizers are applied to soil. These characteristics generally cannot be altered, but an understanding of their influence on P availability is helpful in using P fertilizer efficiently.

Mineralogy

The type of minerals in soils are of paramount importance to the phosphorus sorption. Fox et al., (1968) ranked the fixation capacity of most common types of clay as follows: amorphous oxides > crystaline oxides (goethite, gibbsite) > 1:1 clays > 1:2 clays.

In acid oxide-rich soils iron and aluminium-oxides are considered to be the most important adsorbants of phosphorus (Uehara and Gillmann, 1981) found that in some acid soils of Punjab, more than 90% of the adsorbed phosphorus was sorded to iron or aluminium.

Soil organic matter

The soil organic matter has several different effects on the solubility of the soil phosphorus. Scheffer et al., (1979) listed up these three effects:

Humic acids and fulvic acids will, due to their high calcium selectivity bind the calcium in the calcium phosphate and thus make the calcium phosphate more soluble.

Organic anions may be competing ions and make the phosphate ions desord, or they adsorb to the mineral particles and thus block the adsorbing sites for the phosphorus ions.

Many organic acids may form water soluble complexes with aluminium, iron or calcium and by that increase the solubility of phosphates that otherwise would have had low solubility.

All these properties of organic matter will increase the solubility of soil phosphate and lower adsorption should be expected in a soil containing organic matter than one without.

Soil pH

Soil pH influences the availability of P to plants in two ways. First, the pH of the soil solution largely determines the ion form that is present. Within the pH range 5 to 7.2, $H_2PO_4^-$ is the dominant ionic form, whereas between pH 7.2 and 9, $H_2PO_4^-$ ion dominants. Second, the pH of the soil also controls the type and solubility of the soil minerals. When a P fertiliser is added to an acid soil, it reacts with Fe and Al compounds to form complex products that can be quite insoluble and less available to the plant.

In alkaline or calcareous soils, soluble phosphate will also revert to relatively insoluble dicalcium and tricalcium phosphates or even apatite like compounds. Phosphorus ions may also be tied up in unavailable forms on the surface of $CaCO_3$ particles and on Ca-saturated clays. However, these precipitation compounds have large surface areas in contact with the soil solution, and much of the P may be slowly released for plant use.

Aeration and compaction

Soil aeration influences the oxidative state of inorganic compounds, the decomposition of organic matter and release of P, as well as the complex metabolic processes associated with plant growth. As a result, aeration as a definite influence on the availability and adsorption of P. An example is encountered in the production of paddy rice. Under anaerobic condition resulting from flooding, the ferric ion is reduced to the ferrous form. Ferrous phosphates are more soluble than the ferric phosphates; consequently, P availability is increased. Soil compaction and structure influence P relationships indirectly through effects on aeration. Increased compaction may impede root penetration resulting in P being positionally unavailable.

Moisture content

Moisture regimes also play a significant part in phosphorus transformations. Aluminium phosphates tend to accumulate in aquic soil moisture regimes, whereas iron phosphorus accumulate in ustic soil moisture regimes.

The major portion of the P moves to the root by diffusion through the water films around the soil particles. As soil moisture decreases, this diffusion path becomes more tortuous, and movement proceeds at a slower rate. Phosphorus uptake by plants has be shown to decrease as moisture tension increases. The relative uptake of P by maize seedling was 100, 94, 80,50 and 35 at 1/3, 1/2, 1, 3 and 5 bar of soil moisture, respectively (Olsen et al., 1961).

Movement and losses

Phosphorus is relatively immobile in most soils and does not move appreciably from the point of application. Soluble P rarely moves more than 2 to 3 cm from a fertilizer granule before reaction with soil components essentially stops further movement. Mechanically incorporation in the surface normally have little effect on the available P level of the underlying soil. This limited movement of P indicates the need for initially placing fertilizer P in the proper position for maximum effectiveness.

Because of its immobility in the soil, loss of P from the profile is small except for crop removal and soil erosion. The low concentration in the solution means that loss by leaching are small even if considerable drainage occurs. The only soils from which the losses of P by leaching is potentially significant on a short term basis are sands and some organic soils that have little tendency to react with P. However, since P tends to be concentrated in the surface soil, it is susceptible to loss by erosion. Phosphorus lost by this means is presently receiving considerable attention because of its influence on surface water quality.

Clay content

Soil constituents which determine P adsorption are often associated with the clay fraction. Soil texture therefore often influences the P sorption capacity of soils. In soils containing oxides or oxide coated layer silicates, P fixation is known to increase with clay content. This is often an indirect effect of iron an aluminium oxides found in the clay fraction. Sanchez (1976); fox and Searle (1978) report significant correlations of P adsorption with % clay and silt. Soil texture can often be used as a relative index of P adsorption capacity, particularly with soils that have similar mineralogy and chemical properties (Kamprath and Watson, 1980).

Time

The kinetics of phosphorus sorption changes with time. Soluble P added to soil is usually rapidly adsorbed at first, but the concentration of P in solution continues to decline slowly over a long time. The term adsorption can be restricted to the process that approach steady state within 1-7 days (Fox and Searle, 1978).

Temperature

Phosphate adsorption is influenced by temperature to an unexpected degree. An increase in temperature decreases the amount of P left in solution when the sorption process appears to be at equilibrium. Desorption is also increased by a higher temperature (Fox and Searle, 1978).

PHOSPHORUS MANAGEMENT IN NORTHERN ZAMBIA.

ECOSYSTEM DESCRIPTION

Location:

The Phosphorus research reported here have been carried out in northern Zambia, a region covering North-western, Copperbelt, Luapula and Northern provinces. This region is found between latitude 8° and 14° south of the equator. It covers a total area of 355,545 km², which represents almost 50% of the total land area of Zambia (Fig 1). This region is part of the central African plateau with elevations ranging from 900 m in the valleys to above 1800 m in the highest parts.

This region has a high annual rainfall of more than 1200 mm. Nearly all the rain falls in the rainy season from November to April. Due to high seasonal excess of precipitation over evapotranspiration the region is regarded as the high rainfall area of Zambia. This region is called region III in the agriculture research branch setting. The research activities have been carried out on research stations in the high rainfall area, viz. Misamfu, regional research centre in Kasama, Lucheche Research sub-station and Katito (Zam-Can) farm in Mbala, Malashi research Sub-station in Mpika, Luapula Research Station in Mansa, and Mutanda research Station in Solwezi. The work has been conducted on well established representative benchmark soils so as to extrapolate or transfer results obtained to similar soils in other parts of the high rainfall areas.
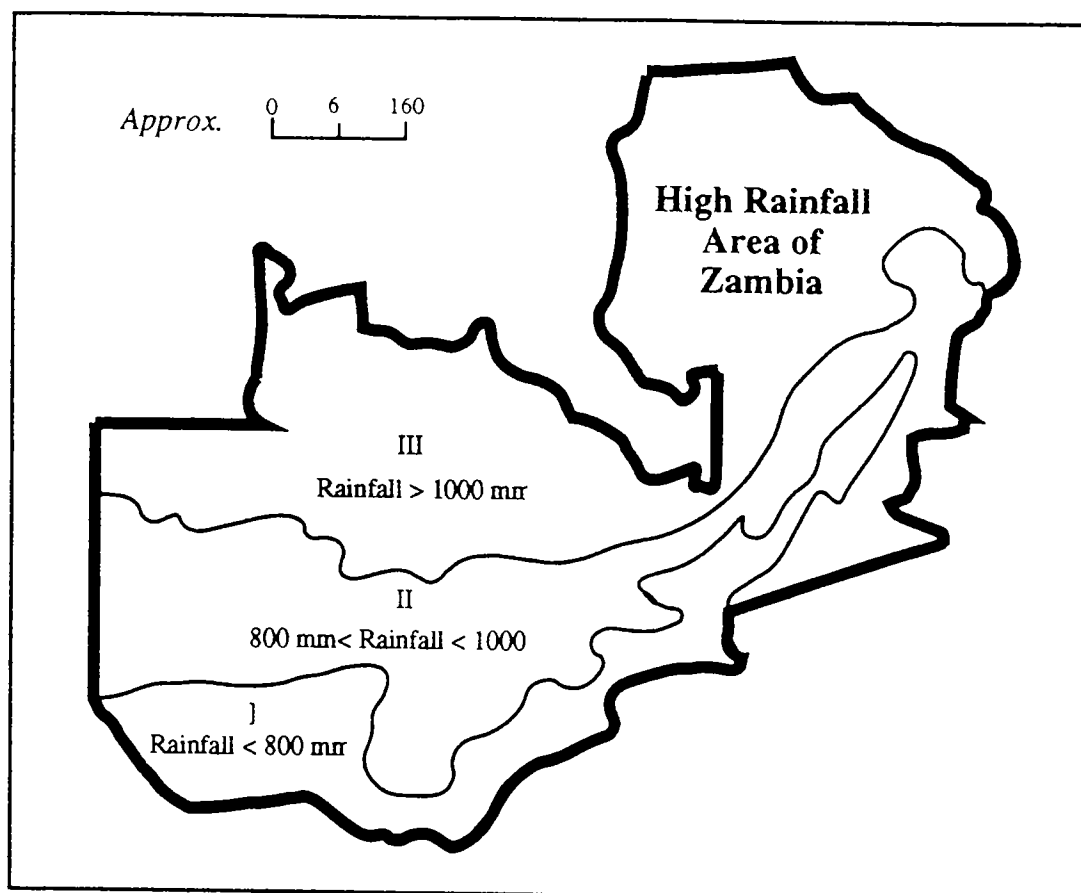
Fig. 1. Agro-Ecological Zones of Zambia

Climate

Northern Zambia has a sub-tropical climate due to its elevation although it lies on tropical latitudes. The region has a high reliable annual rainfall of between 1200 to 1400 mm, The variability of rainfall from year to year is low (Table 1). It has a relatively long growing period of 140-200 days between November and April. The dry season has a longer duration from May to October, and consists of a cool and hot season. The cool season is from May to mid August and the hot season from mid August to October. Pan evaporation is around 5 mm d^{-1} in the rainy and cool dry seasons, rising to 8 mm d^{-1} in the hot dry season. The area has a very good rainfall distribution in the cropping season. For at least in three months, the total rainfall exceeds evapotranspiration and this coinciding with active plant growth. During the rainy season the mean monthly maximum temperature is about 16° C and the relative humidity ranges between 63 and 82 percent.

Table 1. Monthly rainfall distribution for nine selected stations in northern Zambia (Manfield et al., 1976)

Station	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
					.... Rainfall (mm)								
					─────── Rainy season ───────								
Mbala	0	1	5	20	110	220	210	210	230	110	20	1	1125
Mporokoso	0	1	8	55	160	230	220	250	200	120	20	1	1275
Kafulwe	0	3	7	30	120	250	220	210	250	130	12	0	1250
Isoka	0	0	1	11	80	210	230	230	230	65	12	0	1075
Kasama	0	0	1	16	140	250	270	250	260	65	9	0	1275
Kawambwa	0	1	11	65	170	250	210	190	240	140	16	1	1300
Mpika	0	1	0	7	110	230	300	240	190	25	3	0	1100
Twingulu	0	0	1	12	150	270	320	300	290	50	4	0	1400
Mansa	0	0	1	25	140	240	240	220	220	60	6	0	1150

Vegetation

The main vegetation types found in the area are locally called *Miombo*, *Chipya* and *Mateshi*. The Miombo is the most extensive woodland and extends over the greater part of the area. It is often named *Brachystegia-Julbernardia*-woodland after the two dominating tree genera, which are both leguminous and fire-resistant. The Miombo woodland forms a single-storey, deciduous woodland with a light canopy cover at about 15-20m. The floor of the woodland is densely covered with high shrubs and grasses (15-30 % ground cover). Brachystegia spp. are usually found on deep, well-drained soils that retain moisture during the latter half of the dry season. The grassland of the Miombo areas are dominated by Hyparrhenia and Digitaria species.

Chipya and dry ever-green forest is common in lake basin and comprise an open woodland with perennial grasses subject intense dry-season fires. Species found under Chiya vegetation are fire-handy and intolerant to shade. Common species are *Pterocarpus angolensis*, *Erythrophleum africanum* and *Parinari Curatellifolia*.

Topography and drainage

The area is dominantly a uniform, very gently undulating plateau which is broken by major river systems and quartzitic hilly ridges which are resistant to weathering. This plateau is part of the Central African Plateau which extends from south Africa to the highlands of Ethiopia. The slopes are usually very gently and a large part of the area have slopes of about 1%. The plateau nature of the area is a result of weathering processes active for thousands of years, since the formation of the Gondwana land-Scape some 135-200 million years ago.

The area of Northern and Luapala provinces are drained by three major rive systems: the Chambeshi, the Luangwa and the Luapula. The Kafue, which is a sub drainage system of the Zambezi, is important in the North-Western and the Copperbelt provinces (Kalima, 1983).

SOILS AND SOIL REGIONS OF NORTHERN ZAMBIA.

The most important factor of soil formation in northern Zambia is the age of the land surface. The soil may be considered relict soils in that they are not a product of present, but previous erosion cycles, in which wetter and warmer climatic brought about the intense weathering and leaching of diverse parent materials to produce a relatively uniform soil over the gently undulating topography (Manfield et al., 1976).

The Kalima, (1983) described four major soil regions (Fig 2). The soil regions are characterised by geology and topography since climate and vegetation are almost uniform throughout the area.

Soil region 1

Strongly leached soils over non basic parent material. The strongly leached soils located on upland and derived from non basic rocks are the most dominant group consisting mainly Oxisols and Ultisols . These are the typical soils of the high rainfall area. There are very little or no reserves of primary minerals in the soil. The clay-fraction is dominated by Kaolinite and various amounts of iron and aluminium-oxides. The soils are generally characterised by low organic matter content, low CEC, low pH and low nutrient reserves, especially phosphorus. Ultisols are the most widespread soils of the region. They include Mufulira, Konkola, Katito and Maheba soil series (Oxic, Rhodic, Oxic and Rhodic/Acric Paleustult respectively) (USDA Soil Survey Staff, 1975). They are classified as Ferralsols in the FAO-UNESCO system (Veldkamp, 1983). The clay minerals are predominately kaolinitic and are less weathered than those found in Oxisols. Thus, shrinking and swelling clays may be present to give them poor physical properties, including instability and susceptibility to erosion. They are also sensitive to compaction by heavy machinery. Water infiltration through the argillic horizon may be slow and cause water logging and anaerobic conditions within the profile. Since the soil in this area are highly weathered and leached, most of them have high content of free aluminium and manganese ions that can limit plant growth (Msunza et al., 1983). However, the most limiting factor for agriculture production in these soils is chemical infertility rather than physical constraints.

The soils of this region are the most problematic soils to cultivate in this area, mainly due to the low pH which leads to aluminium toxicity, high phosphorus fixation and low fertility in

general. The soils are mostly classified as typic Haplustox and oxic paleustult in the Soil Taxonomy and Xantic, Orthic or Rhodic Ferralsols in the FAO/UNESCO classification system.

Soil region 2

Moderate leached soils over non basic parent material . These are moderate leached soils. pH ranges from 4.0 to 5.0 and BSP is more than 25% and can be as high as 60%. CEC is the same as in soil region 1. Aluminium saturation varies and can be as high as 60%. The texture is usually loamy and clayey. The structure is weak to moderate.

The major problem to agriculture utilization of the soils is poor soil structure, high susceptibility to erosion and aluminium toxicity. The soils are classified as typic Haplustox and Oxic paleustult in soil Taxonomy and Xantic, Orthic or Rhodic Ferralsols, ferric acrisols in FAO/UNESCO.

Fig. 2. Major soil regions of the high rainfall area of Zambia (Kalima, 1983).

Key

1 Strongly leached soils
2 Moderately leached soils
3 Soil derived from basic material
4 Flood plain soils
5 Kalahari sands
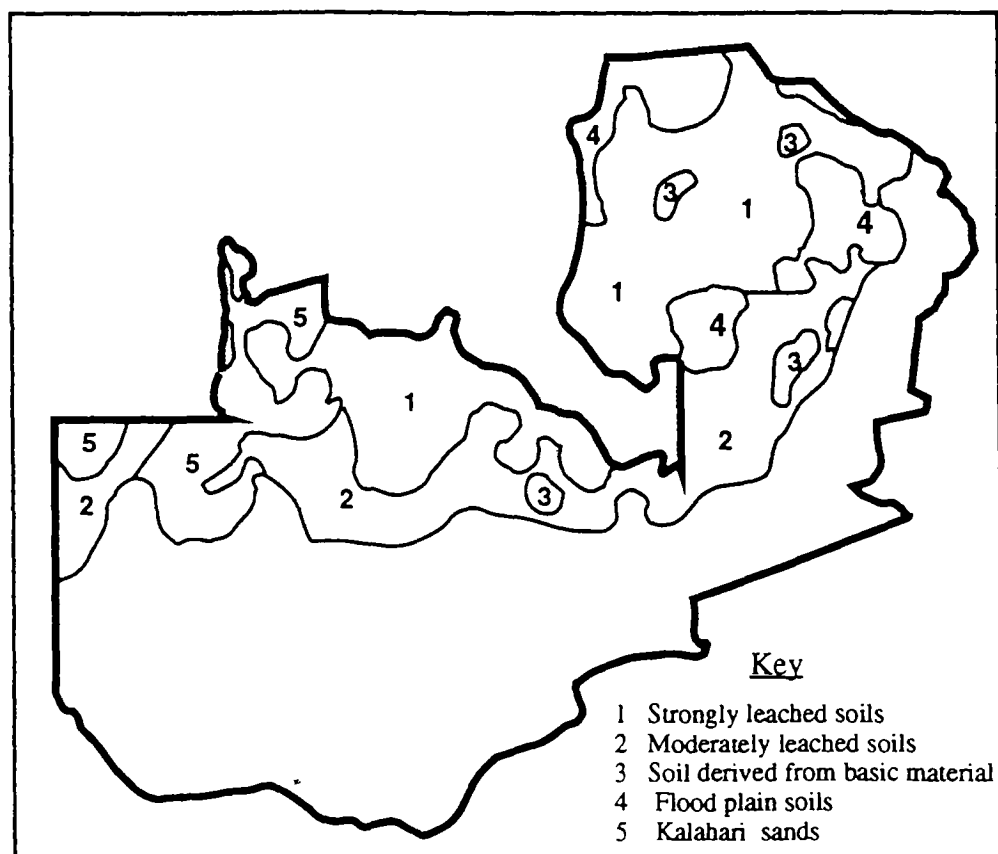
Soil region 3

Leached (Red) clayey soils derived from basic parent material. These soils have often been called "Red" soils. They are developed over basic parent material rich in ferromagnesium minerals or carbonatic parent material. CEC ranges from 12 to 20, BSP 25 to 50 and the average pH is 5.0. The aluminium saturation is variable, and content of free iron is high. soil texture is clay to clayey loam which are very friable. The dominant mineral is Kaolinite, although traces of 2:1 minerals have been observed.

These soils are used for small and large scale farming. They are highly prefferred for cultivation by farmers, due to the good structure, and chemical properties that are better than the other soils in the area. These soils are scattered all over the area, but limited in extent. They are mainly classified as quartzpsamment in soil Taxonomy and Ferralitic or cambic Arenosols.

Soil Region 4

Flood plain and lake basin soils. These are deep poorly drained soils of various textures occurring in river valleys, lake regions and shallow depression on the upland (dambos). The pH of the soils is usually low although clayey soils may have a high potential CEC. They are classified as Typic Haplauepts, loam or clayey, Kaolinitic, hyperthermic in Soil taxonomy and chromic pellic vertisols, (very rare), Dystric/eutric gleysols, Eutric gleysols or Haplic Phaeozems.

CROP RESPONSE TO APPLIED PHOSPHORUS

A lot of research in the tropics has shown large increases in yield of crop due to phosphate fertilizer application. In Zambia positive responses to fertilizer P has been shown with all crops though most of the work has been with maize. Although the P content of some of these soils may be adequate intially, deficiencies rapidly develop with few years of cultivation. All long-term trials with maize gave significantly higher yield when fertilizer P was applied together with other nutrients (Annual Reports 1969-78). At Misamfu both P and K became limiting after the third year of continuous cropping. Maize yield decline by 45% (Lungu, 1987).

At Mufulira the response of Soyabean to varying levels of N and P were tested. The yield more than doubles when 60 Kg P ha^{-1} was applied whereas there was no response to N in the absence of P (Fig.2) (Annual Report 1973/74).

Table 2. Effect of N and P on the yield of soyabean at Mufulira

Nitrogen	Phosphorus		
	0	30	60
Kg ha^{-1}	......Maize yield kg ha^{-1} ...		
0	596	1104	1543
60	537	1758	1035
120	449	1309	1758

Wheat was also shown to respond significantly to applied P at Zam-can Farm in Mbala. (Zambia-Canada, 1980). The highest yield were obtained at 60 kg ha^{-1} P_2O_5 with lime at 2000 to 8 000 kg ha^{-1}. The rate of 30 kg ha^{-1} P_2O_5 was significantly higher than where no P was applied. At all levels of lime there was a significant increase at 30 kg ha^{-1} P_2O_5 ha^{-1} over no P but no further improvement with 60 kg ha^{-1} P_2O_5 (Tabel 3).

Table 3. Effect of applied phosphorus and lime on wheat yield at Kalito Zam-Can Project farm Mbala.

Lime (kg ha⁻¹)	Phosphorus dose (kg ha⁻¹ P_2O_5)				
	0	30	60	60+boron	Mean
0	19	216	337	445	264
1000	278	713	995	863	714
1000 + 500	465	1052	1057	1194	942
2000	690	1166	1346	1398	1150
2000 + 500	665	1294	1444	1368	1193
4000	643	1071	1337	1188	1060
6000	832	1247	1336	1352	1191
8000	655	1105	1338	1317	1106
Mean	532	983	1154	1141	952

C.V = 15%
L.S.D =206.55

However, not all acid soils respond the same to applied phosphorus. Several trails have shown that acid soils such as the Misamfu and Malashi soil series respond very little to applied P (Table 4). Soil analysis show tha these soils have suficients amounts of P.

Table 4. Reponse of maize and soyabean to NPK over four cropping seasons Misamfu soil series.

Treatment	Maize		Soyabean	
	1986/87	1988/89	1987/88	1989/90
Nitrogen	----------------------kg/ha--------------------			
0	948	1343	719	412
70	3126	2508	724	399
140	4818	2626	820	350
Phosphorus				
0	2734	1620	700	355
20	2965	2253	740	389
40	3186	2604	828	418
Potassium				
0	3018	1703	696	359
40	3121	2524	752	429
80	2746	2250	816	374

PHOSPHORUS SORPTION OF SIX SOIL FROM NORTHERN PROVINCE

In order to understand why different soils respond differently to applied P a study was carried in northern province to investigate the behouvior of phosphorus in the soil.

Soil samples were taken at 0-20 cm and 20-40 cm soil depth from six different soils series in northern province. The soils were; Misamfu (yellow) sandy loam, Misamfu (red) sandy loam, Mufulira sandy loam, Kateshi sandy clay (Rodic Kandiustult), Katito, and Mbereshi soil series.

These samples where analysed for the following parameters; Mineralogy (by X-ray diffraction), Texture, Total carbon, pH, available phosphorus (by Al, Bray 1 and sodium bicarbonate methods), Acidity, Free Aluminum, Dithionite-citrate soluble Aluminum and Iron. Potassium, Mangesium, calcium.

To study the effect of lime on P sorption. Each soil was lime with calcium hydroxide at four levels of 0, 1, 2.5, and 4 time the amount needed to neutralize the amount of aluminium extracted with potassium chloride (Kamprath, 1970).

Phosphorus sorption was determined by adding a solution of a known concentration of phosphate to the soil, shaking it for 24 hours. The amount of phosphorus left in the sloution after this treatment was determined.

P sorbed= P added - P in eq. solution/100g
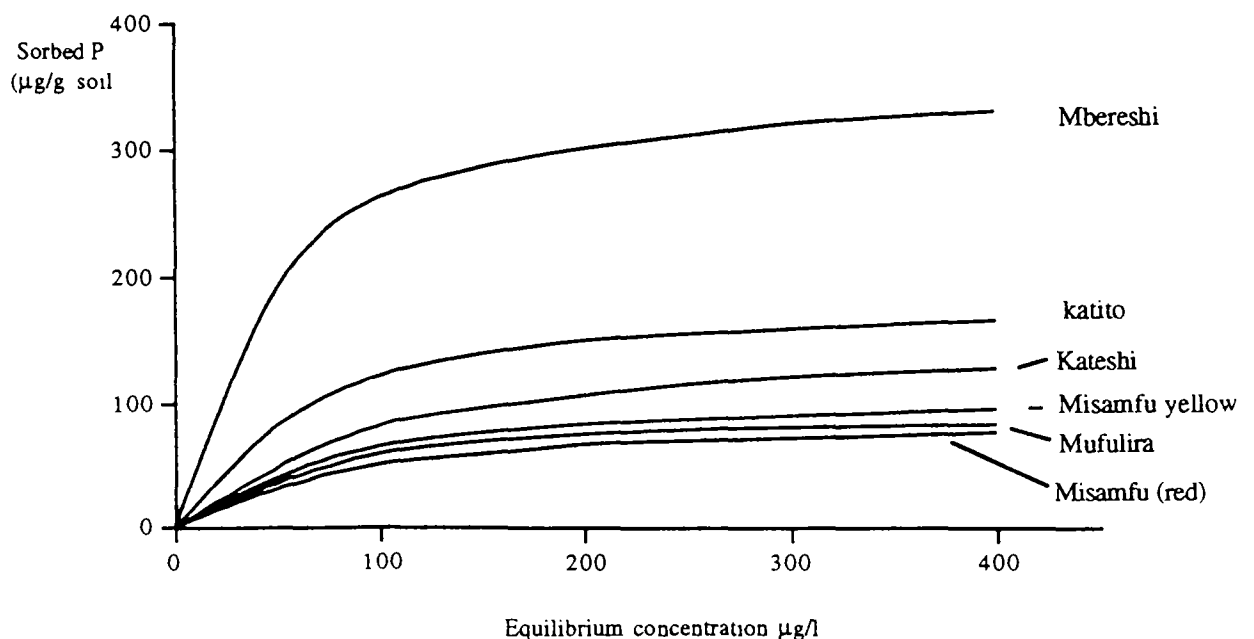
Fig. 3 Adsorption capacities of six soil from northern Zambia (source, Guldberg M, 1985)

From the adsorption isotherms (Fig. 3) the soils are found to sorb from 80 to 301 μ P/g soil at the standard equilibrium concentration. Based on the classification sytem for phosphorus adsorption (Juo and Fox, 1977) these soils can be classified as low to medium adsorbing soils.

The two soils from Mbala region (Katito and Mbereshi) and the soils from Kateshi coffee Estate are classified as medium adsorbing soils while the three soils from Misamfu (Misamfu yellow, Misamfu red and Mufulira) have values in the upper part of the low adsorbing soils. The three soils from Misamfu do not differ much in their capacity to sorb phosphorus, while the three other differ widely in thier capacities especially Mbereshi which was the highest sorbing soil.

Effect of liming on P sorption:

Soils reacted differently upon liming and had different sorption response. Misamfu yellow, Mufulira and Katito soil series had marked decreases in phosphorus sorption at the two lowest amounts of added lime. Misamfu red shows only a small decrease in phosphorus sorption when lime was added. Mbereshi soil series showed a continously marked reduction in phosphorus sorption as lime was added in increasing amounts. In this soil the optmum liming, considering phosphorus sorption, is probably more than 4 time the aluminum equivalent. Kateshi responded to liming by increasing phosphorus sorption when the smalles amount of lime was added and deceased when more lime was added.

According to the investigation the soils don't show any particular pH level at which phosphorus sorption was at a minmium (Guldberg,1985).

RELATIONSHIP BETWEEN SOIL PROPERTIES AND P SORPTION.

Mineralogy

In Juo and Foxs classification system for phosphorus sorption in soils (1977), The low adsorbing soils are generally considered to have 2:1 clays, quartz and 1:1 clays. The three soils (Misamfu yellow, Misamfu red and Mufulira soil series) that are classified in that group are dominated by Kaoilinite in the clay fraction, but they also contain some goethite and illite. The silt fraction is dominated by quartz, but also contains some illite.

The Medium adsorbing soils according to this system are likely to have 1:1 clays with oxides. The three soils (Kateshi, katito and Mbereshi soil series) which belong in this group have oxides and are dominated by Kaolinite with only traces of illite in the clay fraction. The relative higher content of Kaolinite compared to quartz and illite, due to the texture, in these soils can explain some of the sorbing properties (Guldberg, 1985).

Aluminium and Iron oxides.

Phosphorus sorption shows a clear tendecy to increase as the amount of amorphous and crstalline aluminuim-oxides extracted with dithionite citrate is increased (Fig.4). The corelation is 0.98. Like wise there is a correlation between sorded phosphorus and dithionite citrate-soluble iron-oxides. The correlation of the regression line is 0.93. Increased dithionite-critrate-soluble iron and aluminium does not seem to have a clear cut tendency for increased P sorption.
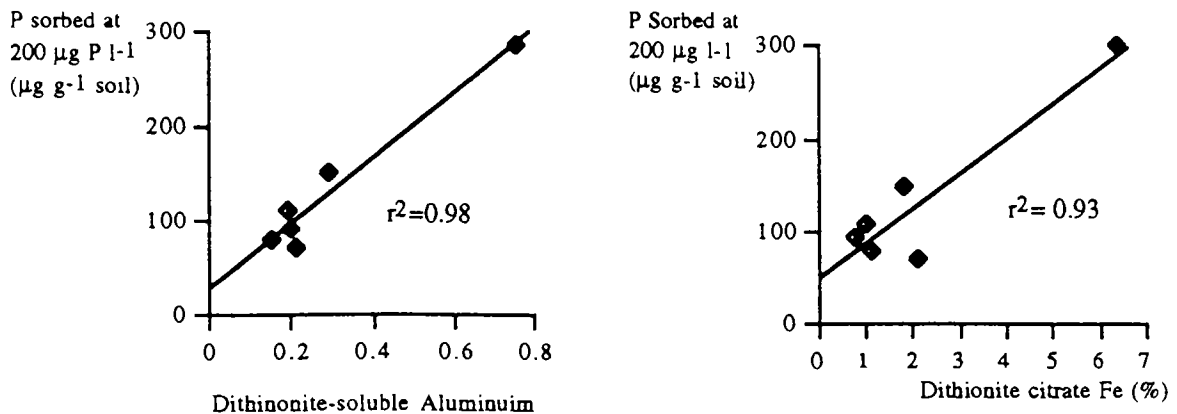
Figure 4. The relationship between P sorded at 200 µg P l^{-1} and Dithionite citrate soluble Aluminuim and iron.

Soil Texture

In this study there was a good correlation between clay content and phosphorus adsorption. The specific surface of the soil increase exponentially with an increase of the clay content. The correlation factor for the regression line on a semi log curve (Fig. 5) is 0.96 and the points are spread out on both axis indicating a fairly good correction between these two properties. This is strong evidence that phosphorus sorption is correlated to the specific suface of the soil. The three low sorbing soils in this experiment have a markedly large amount of sand than the other three. (table) since the minerals in the sand fraction are low sorbing minerals and have a small surface area they dilute the other high reacting minrals present and the soil as a whole gets a lower sorption.
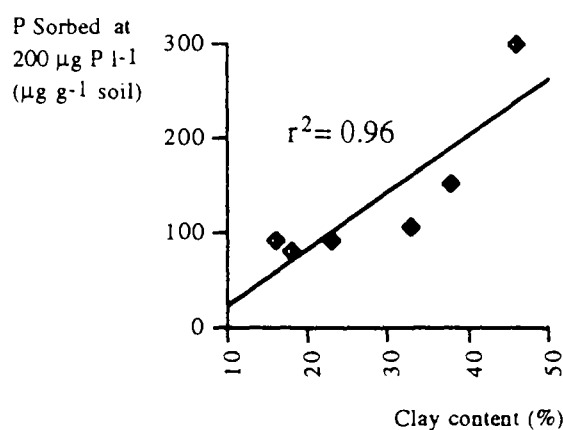
Fig. The correlation between clay content and the logarithm of phosphorus sorption at 200 µg p/l

Conclusion

From the work on the six soils from northern province one can make some conclusions.The soils contain very little available phosphorus and are in need for additional sources for optimal plant growth. They sorb a large proportion of added phophorus, but the sorption capacities vary from soil to soil. At the standard supernatant solution of 200 µg p/l the sorption vary from 80-300 µg p/g soil.

Liming the soils resulted in a decrease, but not an elemination in phosphorus sorption in the soils.

There were correlations between phosphorus sorption and content of dithionite-soluble iron. No correlation was found betwwen phosphorus sorption and pH, acidity, content of potassium chloride-soluble aluminium, total carbon or content of cation. There was a tendency for the soils to have an increased phosphorus sorption as one moved from Kasama towards Mbala. However, this needs more verification with investigation on more soils (Guldberg, 1985).

PHOSPHORUS STUDY ON 17 SOILS FROM THE HIGH RIANFALL ZONE (HRZ)

A pot study was carried out using 17 soils from different areas in northern Zambia These soils where analysed for the following parameters; mineralogy (by X-ray diffraction), texture, total carbon, pH, available phosphorus (by Al, Bray 1 and sodium bicarbonate methods), acidity, Free Aluminum, Dithionite-citrate soluble aluminum and iron. Potassium, mangesium, calcium. aluminium and iron oxideswere also extracted with pyrophosphate

Maize was grown on each of soils at 4 levels of P. 0, 25, 50 and 75 mg /l soil. Each pot contained 4.5 l of soil and supported the growth of maize(MM752) for eight weeks. The above ground portion was havested

Mineralogy of the soils

The mineralogical analysis was semi quantitative and give only limited information about the amounts of each mineral. However, Guldberg (unpublished) found some tendencies.

All the soils have kaolinite as their dominant clay mineral and quartz dominating their coarser fractions. Mica is detected in most of the soils, either in the clay or the silt fraction. The Aluminium oxide gibbsite is found in about half of the soils, but its occurrence does not seem to have any influence on the phosphorus situation in the soil.

Two iron oxides are detected, Goethite in all the soils and hematite in less than half of them. There seems to be no connection between amount of Goethite and adsorbed phosphorus or buffer capacity. There are a tendency towards higher adsorption as the amount of Gibbsite increases. The buffer capacity also increases but less distinct.

The soils containing no or little hematite generally have a lower adsorption than those containing more. This tendency is even stronger for the buffer capacity, it also increases with increasing amount of hematite. Since this mineral is so red that it often colours the entire soil one can use the red colour as a guideline and expect a red soil to need less phosphorus than a yellow one (Guldberg M, unpublished)

Only the Soils from Lubu Valley and Kasempa from Solwezi had a considerable amount of Mica and all these soils have a very low adsorption and buffer capacity. The rest of the soils have either no or only traces of mica and there are no difference in adsorption or buffer capacity between those two groups.

Tab. 5. Mineral content in the clay fraction of 17 soils from the HRZ

Soils	Site location	Kaolinite	Mica	Gibsite	Goethite	Hematite
Kawambwa	Mambwa	000	(0)	(0)		
Mufulira	Mambwa	000	(0)		0	
Katito	Nell	000	(0)		0	
Kateshi	Kateshi	000				(0)
Misamfu red	Mrrs	000	(0)		0	(0)
Misamfu yellow	Mrrs	000		(0)		(0)
Mufulira	Mrrs	000	00	0		0
Konkola	Lucheche	000	(0)		0	0
Konkola	Katito	000		(0)	0	(0)
Malashi	Malashi	000		0	0	0
Meheba	Mutanda	000		00	00	0
Misamfu yellow	Lubu	00			00	(0)
Mufulira	Lubu	000		00		0
Konkola	Lubu	000	0	(0)	0	0
Meheba	Kananshi	000		0	0	0
Kasempa	Kananshi	000		0	0	(0)
Chafukuma	Chafukuma	000	(0)	00	(0)	0

000 = Dominated by
00 = Contains appreciable amounts
0 = contents little amouts
(0) = Contents traces

The minerals were determined from the X-ray diffractograms by the peak corresponding to:

KAOLINITE: d= 7.13, 3.58 and 2.00
MICA: d= 10.28, 5.07 and 3.35
QUARTZ: d= 4.32, 3.38 and 1.82
FELTSPAR:
GOETHITE: d= 4.13, 2.67 and 2.39 GIBBSITE : d= 4.85, 3.33, 2.39 and 1.79
HEMATITE: d= 2.70, 2.52

Ref. U.Schwertmann and r.M.Taylor (1977), PA HO HSU (1977), j.D.Dixon (1977), D.S.Fanning and V.Z.

Keramidas (1977).

Total P

Content of total P varies from 60 to 1750 ppm, although 80% of soils had values below 200 ppm. This picture fits well with Dabin (1980), who states that total P in tropical soils varies from 50 to 2000 ppm, with common values below 200 ppm. Sanchez (1976) notices that besides the commonly low content of total P in most tropical soils one often finds Oxisols with a very high content.

Available P

The content of extactable Phosphorus is also very low. Using Bray 1 80 % of the soil have a content lover than 15 ppm and are than considered to be low in available P (Thomas and Peaslee, 1973). Two of my soils has a medium and two a high content of Bray P.

Both total P and Bray 1 is high for the soils that does not require P and low for all the soils that respond to phosphorus fertilizer. The different soils vary more in level of P at the different levels of fertilizer than they vary in response to the fertilizer.

Table 6. Selected soil properties of of 17 soils from the HRZ

Soil series	Site location	pH	†O.M.	§Org C	Clay	Bray 1	Olsen	Organic P	Total P
				....................(%).................			......................pmm......................		
Kawambwa	Mambwa	4.1	5.9	1.6	21	7.2	1.3	62	123
Mufulira	Mambwa	3.8	5.0	1.2	15	9.1	1.8	65	135
Katiti	Nell farm	4.4	8.4	2.4	18	8.5	2.3	125	240
Kateshi	Kasama	4.1	5.8	1.7	16	14.4	2.4	69	155
Misamfu red	Kasama	4.1	4.4	1.2	10	26.7	8.3	65	233
Misamfu yellow	Kasama	3.9	4.3	1.2	10	21.6	5.8	88	199
Mufulira	Kasama	3.9	2.6	0.7	7	6.7	0.6	50	120
Konkola	Lucheche	3.8	2.5	1.4	36	5.6	-	80	213
Konkola	Katito	3.8	7.8	1.3	30	10.4	0.6	107	210
Malashi	Mpika	5.0	0.2	2.4	32	17.3	11.4	170	783
Meheba	Mutanda	4.5	8.6	2.6	37	7.0	5.4	203	307
Misamfu yellow	Chinsali	5.0	2.1	0.8	4	22.4	2.4	32	100
Mufulira	Chinsali	5.0	1.8	0.6	5	4.8	0.9	27	55
Konkola	Chinsali	5.6	3.7	1.0	14	13.0	2.3	60	185
Meheba	Solwezi	4.3	1.0	3.0	30	22.6	56.5	412	1680
Kasempa	Solwezi	4.5	5.2	1.4	16	-	0.6	87	153
Chafukuma	Solwezi	5.1	9.5	2.9	26	46.2	24.4	253	973

† O.M.= Organic matter
§ Org. C=Organic Carbon

Table 7. Soil properties in unfertilized soil used for the pot trial.

Soil seies	Site	K	Ca	Mg	Na	Fe	Mn	+Al
		......................m.e. 100g^{-1}						
Kawambwa		0.12	0.92	0.17	0.09	0.01	0.03	0.30
Mufulira	Mambwa	0.17	0.48	0.31	0.05	0.00	0.04	0.30
Katiti	Nell farm	0.47	2.29	1.68	0.03	0.00	0.25	1.00
Kateshi	Kasama	0.10	1.24	0.65	0.01	0.00	0.04	1.00
Misamfu red	Kasama	0.09	1.27	0.59	0.01	0.01	0.03	0.17
Misamfu yellow	Kasama	0.12	1.03	0.61	0.00	0.00	0.03	1.11
Mufulira	Kasama	0.14	0.36	0.23	0.02	0.01	0.06	0.78
Konkola	Lucheche	0.31	0.54	0.21	0.02	0.01	0.07	1.11
Konkola	Katito	0.31	0.81	0.43	0.00	0.00	0.16	1.11
Malashi	Mpika	0.44	4.72	1.65	0.01	0.01	0.16	0.06
Meheba	Mutanda	0.41	0.78	0.54	0.07	0.00	0.09	1.39
Misamfu yellow	Chinsali	0.09	1.46	0.46	0.01	0.00	0.08	-
Mufulira	Chinsali	0.13	0.96	0.36	0.00	0.00	0.09	-
Konkola	Chinsali	0.14	1.96	0.73	0.00	0.00	0.20	-
Meheba	K Solwezi	0.61	1.37	0.91	0.01	0.00	0.10	1.50
Kasempa	Solwezi	0.32	1.15	0.99	0.00	0.01	0.01	0.80
Chafukuma	Solwezi	0.55	2.37	1.73	0.00	0.01	0.02	-

† Data on extrctable Al is from soil survey reports

Adsorption capacities of 17 soils from the HRZ

Amount of Phosphorus adsorbed at standard concentration 200g P/l is often used as a measurement on the soil's adsorption capacity (Juo and Fox, 1977). The soils in this investigation can be classified as low and medium adsorbing soils.

The soils from the same area have similar adsorption patterns even though they are classified in different soil series. Within each area the soils classified as Konkola adsorb more Phosphorus than the other soil series in that area, but the effect of area clearly dominates as an explaining factor.

In Mbala area the soils adsorb from 103 to 174 and are soils in the lower range of medium adsorbing soils. Kasama area has soils which adsorbs about 100 g P/g soil.

The soils at Misamfu Regional Research Station adsorb less and are classified as low adsorbing, while the soils from Mamba and Kateshi adsorb more than 100 and therefore are medium adsorbing soils.

The three soils from Lubu Valley have the lowest adsorbing capacities, ranging from 19.5 to 38. The soil from Mpika is also in the low range of medium adsorbing soils.

In Solwezi soils adsorb more phosphorus, with one exception, they adsorb between 220 and 240 g P/g soil.

Properties affecting phosphorus adsorption.

Content of clay is the most dominant factor explaining phosphorus adsorption. The low sorbing soils have a low content of clay and vice versa. The large amount of binding sites in a clay comparatively to soils with coarser structure can explain this. Aluminium, and to lesser extent iron extracted with pyrophosphate contribute significantly in explaining the variation in Phosphorus Adsorption in these Soils. These are the Iron and Aluminium oxides assumed to be connected to the organic complexes.

The total amount of Iron and Aluminium oxides extracted with dithionite also increase with the soils ability to adsorb Phosphorus, but the correlation here are weaker, especially for Iron oxides.

Phosphorus content in the soil does not correlate with phosphorus adsorption. Two of the higher adsorbing soils have exteme high values of both total and extractable phosphorus while the rest of the soils show no correlation .

Organic matter is positively correlated to the adsorption of Phosphorus. This may be connected to he positive correlation of Organo Iron and Aluminium oxides.

CEC was found to be positively correlated to the phosphorus adsorption capacities of these soils. This may be a secondary correlation, since CEC is depending both on organic matter and clay content of the soil.

There are no correlation between phosphorus adsorption and pH. Aluminium and Iron oxides are most important factors explaining phosphorus adsorption.

Behavior of Phosphorus in 17 soils from the HRZ

Both available P and yield are generally low with the exception of 4 soils. Malashi, Chafukuma and Meheba (Kananshi) are rich in both total P and available P. In this regards the behavour P on these is very different from the other soils studied.

The plants took up from 10 to 50 % of the P available. The sum of P taken up by plants and available P after harvest are from 70 to 134 percent of initial P. The P removed plus available P left in the soil is close to 100% of initial available P indicates that very little P desorption from the soil. It seems the adsorbed P is firmly held.

As P is applied the amount of available P increases, more in the soils with low P adsorption capacity and less in those with high. The P in yield also increases as P is applied in increasing amounts. The soil with low initial available P naturally has a higher increase in yield P than the soils naturally high in available P (Gulberg M, unpublished).

The soils from Mbala region are both low in initial available P and have a relatively high P adsorption capacity. The increase in available P is therefore low and the P removed from the soil by plants also low. This can be seen in connection with the relatively high P adsorption in these soils. The major part of the fertilizer P given to these soils is firm held by the soil.

Soils from Chinsali has a medium to low initial available P and a very low P adsorption capacity. The initial yield therefore is low and the increase in P taken up by plants are high as well as the increase in P availability. In Misamfu yellow and Mufulira about half of the applied

P is in taken up by plants or in the available form. Konkola has a larger proportion in a more firm form, as its adsorption capacity is slightly higher.

Malashi soil at Mpika has a relatively high P adsorption capacity. There are only a very small increase in available P as P is applied and a large proportion of the applied P is therefore firmly held.

The soils in Kasama area has a low to medium content of initial available P and a low capacity to adsorb P. The P uptake is therefore low without P application and increases slowly as P is applied. The soils show a clear linear to exponential increase in available P with increasing P application. Malashi has a medium initial content of available P and only a slight linear increase as P is applied.

In Solwezi area the soils have a relatively high P adsorption capacity, but differ widely in P content. Kasempa and Meheba (Mutanda) has a low both total and available P and therefore a low P uptake without P application. As P is applied both P uptake and P availability increases. Meheba, Mutanda that has a relatively high adsorption only has a slight increase in available P. Chafukuma and Meheba at Kananshi both have very high values of initial available P. When P is applied there is only a slight increase in available P due to a relatively high capacity to adsorb P. They have very high content of both total and avaiable P and are not very much influenced by the application of P.

Table 8. Maize response to P on 17 soils from the HRZ

| Soil series | Site location | P Applied mg P l⁻¹ soil | | | |
		0	25	50	75
		........Dry biomass g/pot			
Kawambwa	Mambwa	60	247	263	236
Mufulira	Mambwa	76	255	334	392
Katito	Nell farm	98	276	331	365
Kateshi	Kasama	145	256	312	288
Misamfu red	Kasama	286	299	338	315
Misamfu yellow	Kasama	213	254	321	327
Mufulira	Kasama	67	310	264	372
Konkola	Lucheche	55	192	407	310
Konkola	Katito	73	290	259	341
Malashi	Mpika	363	247	247	275
Meheba	Mutanda	158	329	397	359
Misamfu yellow	Chinsali	98	207	173	212
Mufulira	Chinsali	83	331	363	337
Konkola	Chinsali	167	308	363	298
Meheba	Solwezi	422	439	387	392
Kasempa	Solwezi	82	274	416	399
Chafukuma	Solwezi	432	429	419	439

The 17 soils could be grouped in three groups according to their response to P application:

1. high yield without P, no effect of P application

2.Medium high yield without P, response to P application

3. Low yield without P, clear response to P application

No response to P

Maize dry biomass g/pot vs **Applied P (mg P/l soil)**
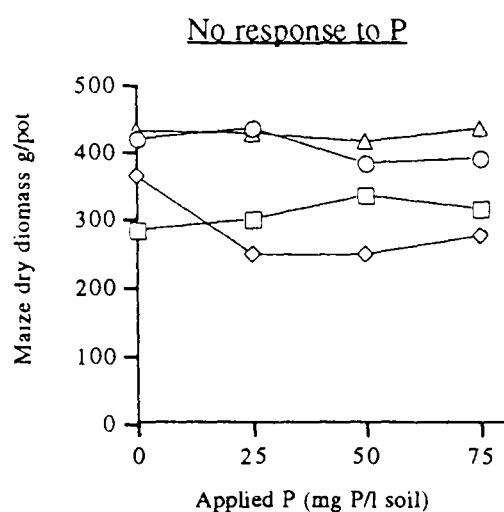
Symbol	Soil series and location
□	Misamfu red at Misamfu, Kasama
◇	Malashi at Malashi, Mpika
○	Meheba at Kasanashi, Solwezi
△	Chafukuma at Chafukuma, Solwezi

Moderate response to P

Maize dry biomass g/pot vs **P applied mg P /l soil**
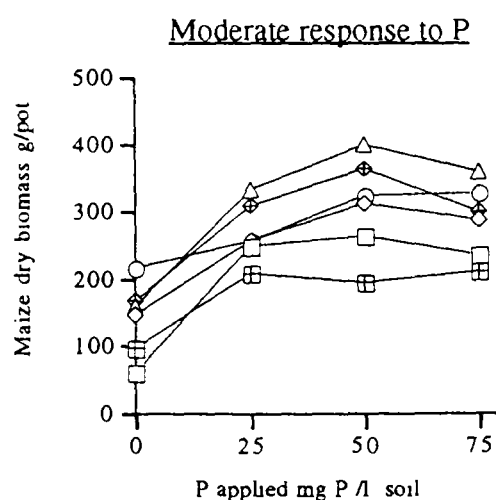
Symbol	Soil series and location
□	Kawambwa
◇	Kateshi at Kateshi farm, Kasama
○	Misamfu Yellow at Misamfu, Kasama
△	Meheba at Mutanda, Solwezi
⊞	Misamfu yellow at Chansali
◈	Konkola at Lucheche, Mbala

High response to P

Maize dry biomass g/pot vs **Applied P (mg P/l soil)**
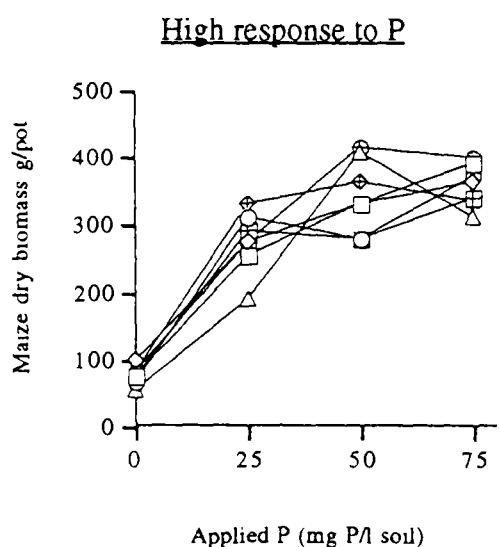
Symbol	Soil series and location
□	Mufulira at Mambwa, Kasma
◇	Kitito at Nell farm, Mbala
○	Mufulira at Misamfu, Kasama
△	Nkonlola at Luheche, Mbala
⊞	Konkola at Katito farm, Mbala
◈	Mufulira at Lubwa, Chinsali
⊕	Kasaempa at Kasanshi, Solwezi

Fig. 6 Graphs showing soil with no, moderate and high response to applied phosphorus

Relationship between initial available P and crop yield

There is a positive relationship between the initial phosphorus level in the soil and the relative crop yield. Both the Olsen and Bray P1 are correlated to the relative yield of maize biomass. However, this relationship was stronger with the Olsen than the Bray 1method with r^2 values of 0.91 and 0.73 respectively (Figures 7 & 8). This suggests that in these soil the Olsen method for P determination is better than the Bray method.
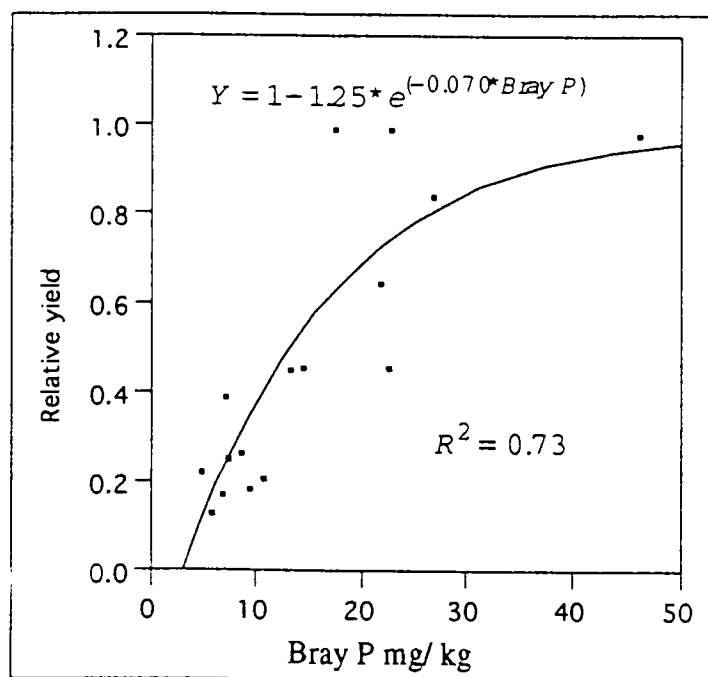
Fig 7. The relationship between intial measured Bray 1 P and the relative yield of maize biomass from a pot study on 17 soils from northern Zambia
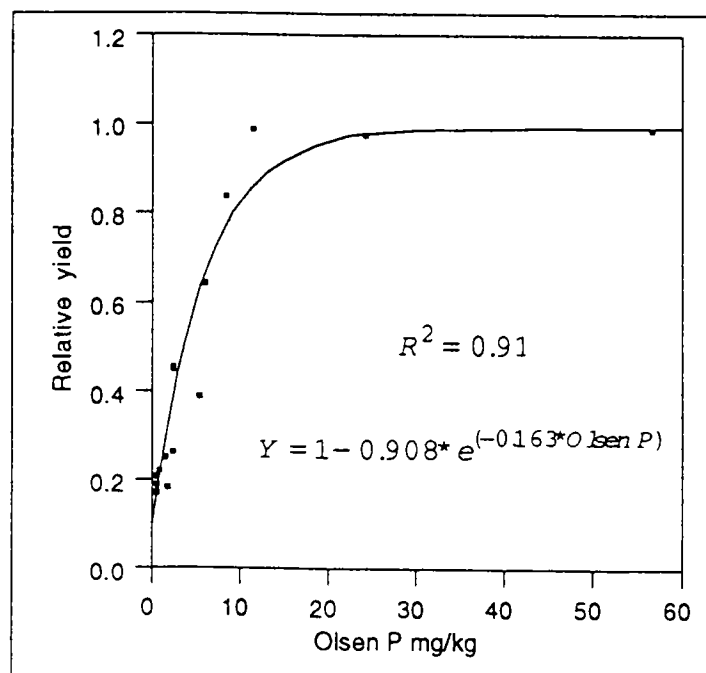
Fig. 8. The relationship between intial measured Olsen P and the relative yield of maize biomass from a pot study on 17 soils from northern Zambia

The relationship between the initial measured organic P and the relative yield of maize biomass is very weak. This suggests that the organic P analytical method is not a good indicator for the anticipated yield on these soils (Fig. 9)
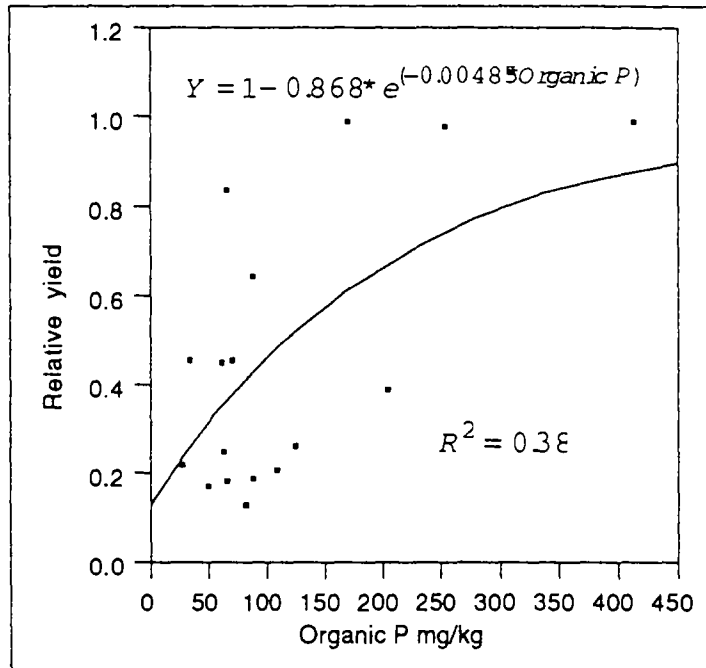
Fig. 9. The relationship between intial measured organic P and the relative yield of maize biomass from a pot study on 17 soils from northern Zambia.

Model for Bray 1 available P

A model to predict the amount of available P in the soil after the addition fertilizer P was developed by a non-linear regression approach. Available P is affected by the initial P in the soil plus amount of fertilizer P added in kg ha^{-1}. The model is represented by the following equation..

Bray P=Initial Bray P+ 1.609*(fertilizer P kg ha^{-1})$^{0.061}$

The relationship is quite strong and has an r^2 value of 0.93 (Fig. 10) The model can therefore be used to predict the amount of available in the soil given the amount of applied fertilizer P in kg ha-1. It can also be used to calculate the amount of fertilizer P to be added in order to achieve a certain amount of available P.
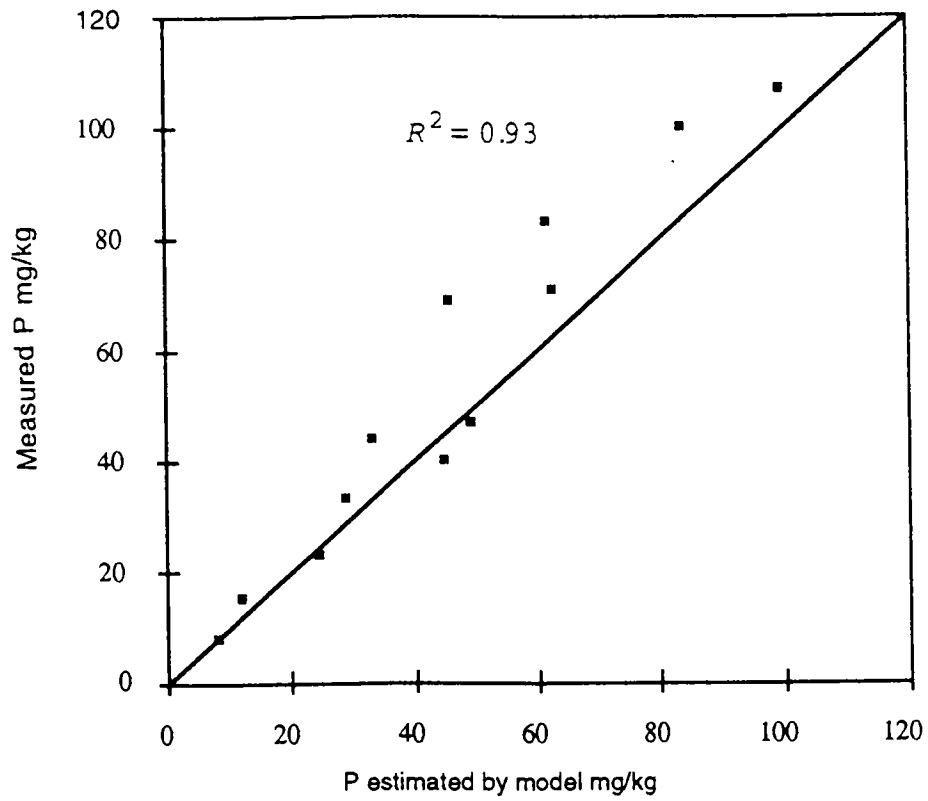
Fig. 10. The relationship between measured P and the P estimated by the model

CROP RESPONSE TO PHOSPHORUS FERTILIZER ON SOILS WITH DIFFERENT ADSORPTION CAPACITIES.

The objectives of these investigations are to study P needs of some crops and relate it to the adsorption capacity of the soil and then work out recommendations to maintain optimum crop production on these soils.

Four soils of various P adsorption were selected for field trials within high rainfall area of Zambia Misamfu Red (Misamfu Regional Research Station) has a low capacity, Konkola (Lucheche Sub Research Station) has medium, Malashi (Malashi Sub Research Station) and Meheba (Mutanda Research Station) have medium/high capacity to adsorb P.

Table 9. Some of the important chemical characteristics of the soils

Soil type	pH CaCl$_2$	†KCl Al	Al Sat. %	†CEC	C Org %	P Bray 1 ppm	Adsorbed P µg P g^{-1}	Adsorption class
Konkola	4.4	1.11	48	2.2	0.9	4	180	Medium adsorbing
Maheba	4.3	1.39	61	2.3	1.6	5	290	Medium/high adsorbing
Misamfu Red	4.7	0.17			0.8	2.5	80	low adsorbing
Malashi	5.4	0.06	3	5.2	1.8	16	288	Medium/high adsorbing

† Units m.e. 100g^{-1}
Source (Gulberg M, unpublished)

On Konkola and Meheba, soils with low pH lime was also included in a Split Plot Design with three replicates and lime on the main plots and P on sub plots. Misamfu Red got a basal dressing of lime and Malashi got no lime.

Maize response to first year application

On Konkola and Meheba, P levels of lime were: 0, 0.5 and 1 times the exchangeable aluminium content, and those of P were 0, 20, 40, 80 and 160 kg P ha^{-1}. Maize (MM 752) was the test crop.

At Misamfu a small amount of lime was applied as a basal dressing and at Malashi no lime was applied. These two trials were laid out in a Randomized Complete Block Design with three replicates. Levels of P were the same as for Konkola and Meheba. At Misamfu maize (MM 752) and groundnuts (Chalimbana) and at Malashi maize (MM 752) and soyabeans (Kaleya) were use as test crops.

All crops, except soyabeans got 40 kg K ha^{-1} as potassium chloride, 40 kg N ha^{-1} as ammonium nitrate, 0.5 kg B ha^{-1} as solubor and 12.8 kg S ha^{-1} as part of triple superphosphate and/or as gypsum as basal dressing. The soyabeans got 20 kg Nha^{-1} and otherwise the same basal dressig as the other crops. Maize on Misamfu Red, Malashi and Konkola soils got 40 kg N ha^{-1} as ammonium nitrate and 40 kg N ha^{-1} urea topdressings. On Meheba soil it got only 40 kg N ha^{-1} as ammonium nitrate topdressing. Zn was later applied on all maize crops as foliar spray after the crop showed clear signs of deficiency.

On Meheba P application gave a clear increase in the yield at all the levels, The low level of initial P in the soil together with its high P adsorption capacity can explain this extremely high response. There was no response to lime application.

On Konkola maize responded to P application of up to 40 kg P ha^{-1}, There were differences in yield between the lime treatments. One times exch. aluminium equivalent lime dose gave the highest yield followed by no lime and 0.5 exch. aluminium equivalent dose of lime.

Table 10 Maize response to application of phosphorus on four soil series.

Phosphorus	Location				
	Lucheche	Malashi	Misamfu	Mutand	Total
Kg P ha^{-1}	...................................Maize Yield, kg ha^{-1}..............................				
0	550	3830	2700	1060	2410
20	3110	4380	3930	2850	3670
40	3830	5550	5130	3400	4360
80	4060	4320	4980	4027	4320
160	3890	5000	4320	4640	4480
LSD	1580	2000	2710	960	1860

On Misamfu Red, the highest maize yield was obtained at 40 kg P ha^{-1}, but the differences in yield amongst the treatments were not found to be significant, Groundnuts did not respond to P application. On Malashi both maize and soyabeans gave highest yield at 40 kg P ha^{-1}, but the differences between the treatments were not significant.

Table.11. Maize response to lime and phosphorus application on Konkola and Maheba soil series.

Phosphorus	Konkola			Maheba		
	no lime	0.56	1.12	No lime	0.56	1.12
Kg P ha^{-1}	....Maize Yield. kg ha^{-1}..............................					
0	600	180	890	110	1160	920
20	3520	2460	3340	2870	2810	2850
40	3280	3190	5020	3460	3350	3380
80	3830	3560	4800	4150	4240	3690
160	3860	3480	4340	4730	5020	4180

In general there was a linear relation between yield and P fertilization up to 40 kg P ha^{-1}, but the response was different from soil to soil. On Konkola and Meheba soil series there was very little growth without P application and the yield increased drastically as P was added. The relatively high capacity to adsorb P together with the low initial available P can explain the high response in these soils. The low pH in both these soils might have an effect on the response to P.

On Misamfu Red and Malashi soil series yields were reasonably good even without P, and they did not change much as P was added. Misamfu Red has a low adsorption capacity and the P left in the soil after the long fallow was enough to give a reasonable crop. On the other hand, Malashi has a relatively high adsorption capacity, and it is surprising to find such a low response to P application on it. The high initial available P together with the low response to P suggests that this soil not only has a high capacity to adsorb P but also a high capacity to release it during the growing season (M. Guldberg unpublished).

In the Season the plots were split, one half got no P and the other half an amount corresponding to first years application. The treatments were then in kg P ha^{-1} (1st year + 2nd year) 0+0, 0+40, 20+0, 20+20, 40+0, 40+40, 80+0, 80+20, 160+0, 160+20. Maize MM752 was used as a test crop. All treatments got 50 kg K ha^{-1} as potassium chloride, 50 kg N ha^{-1} as ammonium nitrate, 0.5 kg B ha^{-1} as solubor and 5 kg Zn ha^{-1} as zinc sulfate as basal dressing before planting. Each treatment also got 20 kg S ha^{-1} either from TSP or as gypsum, depending on the treatments. Two topdressings of 50 kg N ha^{-1} as ammonium nitrate was given.

Residual effect of P on maize growth

The four soils are very different in their response to phosphorus application. The residual phosphorus give a very good effect, and shows that even though P are adsorbed by the soil, it is also released in a plant available form the following growing season. Malashi supports the

plants with enough P without any application and give very good yields. Misamfu Red and Meheba also supports plant production with P enough for a small yield, but the residual P increases the yield. 40 kg Pha⁻¹ given last year gives the best result. Konkola can not support any growth without P application, but the residual P can fully support the growth. In this soil 80 kg P ha⁻¹ was needed to give an optimum growth.

Table 12. Residual effect of P on maize yield (second year after P appication)

Rate of P	Location							
	Misamfu		Malashi		Konkola		Meheba	
	1987	1988	1987	1988	1987	1988	1987	1988
kg P ha⁻¹	Maize yield kg ha⁻¹							
0	2700	3650	3830	8500	790	560	1070	2960
20	3930	4190	4380	8570	2490	3110	2850	3890
40	5130	5510	5550	8580	4000	3830	3400	4620
80	4980	5130	4320	8690	5880	4060	4030	4340
160	4330	5980	5000	9170	6740	3890	4640	5590

Table 13. Maize response residual application of lime and phosphorus

Phosphours	Konkola			Maheba		
	†No lime	0.56	1.12	No lime	0.7	1.40
Kg P/ha	Maize Yield, kgha⁻¹					
0	950	480	930	2910	3050	2910
20	2800	1450	3220	3070	3910	4700
40	4720	2380	4900	3690	4290	5830
80	5460	5140	7040	4160	3330	5520
1600	7420	5420	7380	4480	5460	6830

The effect second application of P on maize growth

On Malashi there are no effect of adding P. On Misamfu Red thereare a clear effect of 2nd years P up to 40 kg P ha⁻¹. Higher applications give a decrease in the yield. Here we get an increase in the yield of all the second year applications except fo 40 kg P ha⁻¹. On Konkola we get a strong response to P application up to 40 kg P ha⁻¹.

Table 14. Maize response to second year application of phosphorus

| Rate of P | Location | | | |
	Misamfu	Malashi	Konkola	Meheba
0 + 40	5070	8780	5000	5020
20 + 20	4960	8510	5230	4550
40 + 40	7030	8880	6730	5250
80 + 20	5270	8780	6440	4720
160 + 20	6280	9370	6820	5650

Table 15. Maize response to residual lime and second year application of phosphorus

| Phosphours | Konkola | | | Maheba | | |
	†No lime	0.56	1.12	No lime	0.7	1.40
0 + 40	4890	3850	6260	4430	4800	5820
20 + 20	5900	3950	5860	4230	4490	4920
40 + 40	6550	5730	7830	5130	4690	5930
80 + 20	6270	5310	7730	4760	3730	5660
160 + 20	7730	5700	7040	5560	5360	5930

Fate of P in maize production

During maize production P is taken up from the soil into the crop and removed from the soil Konkola has little available and relatively high P adsorption capacity. Despite relatively high total P growth without P application is very low. Total removal of P is also low. The amount of available P does not change significantly as P is removed from the soil. The soil seek to keep an equilibrium between firmly adsorbed P and available P and as available P is removed, the soil provides more from the labil pool.

As P is applied P uptake and yield increase rapidly and increase drasticly after 40 kg P ha^{-1}. When more than 20 kg P ha^{-1} is applied more P is applied to the soil than what is taken up by the soil. Higher applications than 40 kg P ha^{-1} do not give a large increase in P uptake but both available P and P adsorbed firmly increase. The uptake of P is higher the second year after application of P, something which indicates that the firmly held P really is desorbed as P is removed from the soil.

Table 16. Fate of soil and fertilizer phosphorus in four soils after the second harvest of maize at four five levels of applied Phosphorus.

	Applied P	Available P	P in yield 87	P in yield 88	sorbed P[†]
Misamfu red					
	0	31.77	5.68	8.5	0
	20	37.88	8.15	8.5	0
	40	37.88	11.02	9.64	0
	80	57.03	10.7	11.28	0.99
	160	73.73	9.24	11.56	65.47
Konkola					
	0	7.76	2.99	3.04	0
	20	11.16	6.93	6.61	0
	40	10.76	11.14	8.42	9.68
	80	31.65	10.23	15.44	22.68
	160	56.2	9.69	20.76	73.35
Meheba					
	0	6.48	2.72	7.14	0
	20	9.18	5.46	9.06	0
	40	14.75	6.45	13.26	5.54
	80	32.11	7.02	11.94	28.93
	160	53.21	8.24	16.36	82.19

† Sorbed P = applied P- (Available P + P in yield)
Source (Guldberg M. unpublished)

Misamfu Red is a soil with low total amount of P, a low P adsorpton and a medium amount of available P. The yields in without P fertilization are resonable. P uptake over two seasons are the same as initial available, but this do not affect the level of available P. There is a small increase in total P uptake for the first increments of P and then it is stable. Other factors than P determines P uptake. Available P increase as amount of applied P increases. Net firm adsorption is only after application of 40 kg P ha-1.

Malashi soil is a medium adsorbing soil containing much available and very much total P. The yield over two seasons with no P fertilizer exeeds initial available P and it does not influence the level of available P. The yields are very high the second season resulting in large amounts of P removals from the soil. Level of P fertilization do not influence yield or P uptake, but the amount of available P increase. In this soil there are no net firm adsorption before higher applications than 65 kg P.

Conclusions

The conclusions we can draw from this is that in general 40 kg P ha-1 each year will give the best yield, but that acceptable yields can be obtained even if you drop P applications on previously well fertilized soil. 20 kg P ha-1 also generally give acceptable yields, and have a certain residual effect. The differences in the soils responses to P suggests a differentiated use of P fertilizer.

EVALUATION OF INDIGENOUS ROCK PHOSPHATES AS A SOURCE OF PHOSPHORUS

Phosphorus (P) deficiency is one of the major limiting factor in crop production in Zambia. Many soils in the region are low in both total and available P. A survey of the soils in the region indicate widespread inherent P deficiency (3 - 12ppm P by Bray 1 method) (SPRP, 1989) and low to high P sorption capacities in the effective rooting zone (Guldberg, 1985). Field studies conducted by the soil productivity research programme (SPRP, 1986) revealed that crops seldom produce economical yields without application of P in most of these soils.

With the recent removal of government subsidies on agricultural inputs, the high cost of conventional water soluble P fertilizers are increasingly becoming a costlier proposition in the agriculture sector due to rising cost of the inputs, principally sulphur and energy. Since almost all the current requirements of phosphatic fertilizers in the country are met through imports (over 2000 000 tonnes per year), there is a tremendous drain of foreign exchange on the national economy. Sometimes the problem of lack of foreign exchange, transport, storage facilities etc. lead to scarcity of phosphatic fertilizers in different parts of the country and small and marginal farmers suffer the most. Therefore, there is an immediate need to develop national industry for phosphatic fertilizers in order to reduce the problem of their scarcity by using indigenous input materials such as Rock phosphates.

Efforts have, therefore, been made in recent years to find alternative sources of supplying P for crop production. Attention has focused on the use of low-cost indigenous materials such as locally available phosphate rocks (PR) deposit and their derivatives.

Indigenous rock phosphate were tried as sources of P in highly acidic soils for different important crops. The only problem about the indigenous rocks so far discovered is that they are apatites of igneous origin associated with syenites and carbonatites and as such they may not be good sources of P. On the other hand, since they are found in economically exploitable deposits, the potential as direct or indirect source of plant available form of P needed to be evaluated.

TYPES OF PHOSPHATE ROCKS

There are five known phosphate rocks deposits in Zambia. All the five are of igneous origin. Syenite related phosphate rocks deposits are found in Chilembwe area of eastern province and Mumbwa north of central province. Carbonatite related phosphate rocks deposits are found at Kaluwe and Rufunsa in Lusaka province and at Nkombwa hill in Northern province. All these deposits have been explored by the Mineral Exploration department (MINEX).

Chilembwe PR

The *Chilembwe PR deposit* is associated with syenites varying in composition from mica syenites to monzonites and the total tonnage of the ore is 1.64 Mt.. The phosphorus content varies between 8-23% P_2O_5 with the average value of 15.2%.

Table 17. Chemical composition of Zambian phosphate rocks

Source	P2O5		Oxides					Quantity
	Total	Citrate[†]	Fe+Al	Ca	SiO2	MgO	MnO	
	.... %							M /metric tonnes[§]
Chilembwe	15.2	1.3	32.8	27.1	7.11	8.60	0.16	1.64
Nkombwa	9.3	0.3	18.0	11.5	19.54	11.11	1.60	130.00
Kaluwe	2.8	0.1	48.1	3.5	4.68	0.56	0.30	200.00
Mumbwa	28.0	1.0	32.2	20.4	10.18	0.09	0.10	-
Rufunsa	3.1	-	-	-	-	-	-	-

†= Citrate soluble phosphorus
§=Quantity in Million Metric Tonnes

(Source: Minex & Jica, 1986)

Mumbwa North PR

The *Mumbwa North PR deposit* is of similar mineral composition as Chilembwe, with an average of 10% total P_2O_5 over 50m depth. Additionally, a number of small but rich apatite bodies (30-35% P_2O_5) stretching along a major fault zone have been recently located. The ore occurs as small outcrops scattered in the area. Small scale selective mining can be very effective.

Nkombwe hill PR

The *Nkombwe hill PR* deposit is a dolomite ankeritic carbonatite with an average ore grade of 9.3 % P_2O_5. Both soil and rock samples contain base metals and rare earth: cerium (1.5 %), lanthanum (0.75%), barium and strotium (1%), manganese is up to 10 %. The highest values of thorium are in the range of 250-400 mg kg⁻¹ PR

Kaluwe PR

The *Kaluwe PR* deposit consist of carbonates, apatite magnetite and some pyrochlore. It has 2.5-3.5 % P_2O_5. Beneficiation of this phosphate rock to 30 % P_2O_5 is possible but uneconomical, and the deposit is probably more useful as a lime source (Zambezi and Chipola, 1991).

DIRECT APPLICATION OF GROUND PHOSPHATE ROCK

Between 1984 and 1992 Chilembwe and Mumbwe phosphate rock was tested for their agronomic suitability as sources of phosphorus for plant growth. The phosphate rock was finely ground and tested for directly application. Apart from grinding the rock did not receive any other treatment and the chemical composition remained unchanged. After grinding the material was bagged and sent for agronomic evaluation.

Table 18. Particle size analysis of fineness of PR used

Mesh	Particle size (mm)	% Ore
+ 48	+ 0.297	14.9
- 48 + 80	- 0.297 + 0.177	21.9
- 80 + 100	- 0.177 + 0.150	26.2
- 100	- 0.150	37.0
		100.0

(Source: Minex, 1987)

Agronomic Evaluation of Chilembwe PR

Chilembwe PR was compared to TSP and TSP plus lime. TSP was used as a standard of comparison. The trial was conducted on Mufulira, Misamfu and Konkola soil series. These soils are low in available phosphorus, have a low pH and the aluminium saturation can vary from 5 to 64 %. These sources of P were tested on Maize (*Zea mays*), groundnut (*Arachis hypogaea*), sunflower (*Helianthus Annuus*), common beans (*Phaseeolus vulgaris*) and soyabeans (*Glycine max. L. merr*). Phosphorus was applied at five rates: 0, 50, 100, 150, and 200 kg P ha^{-1} P$_2$O$_5$. Apart from phosphorus all plots received equal amounts of other nutrients: 50 kg N ha^{-1} as ammonium nitrate (maize and sunflower) with 20 kg N ha^{-1} as urea (legumes) and 40 kg K ha^{-1} as potassium chloride. All the fertilizers were broadcasted and later ridges were made. Maize and sunflower were top dressed with 50 kg N ha^{-1} as ammonium nitrate
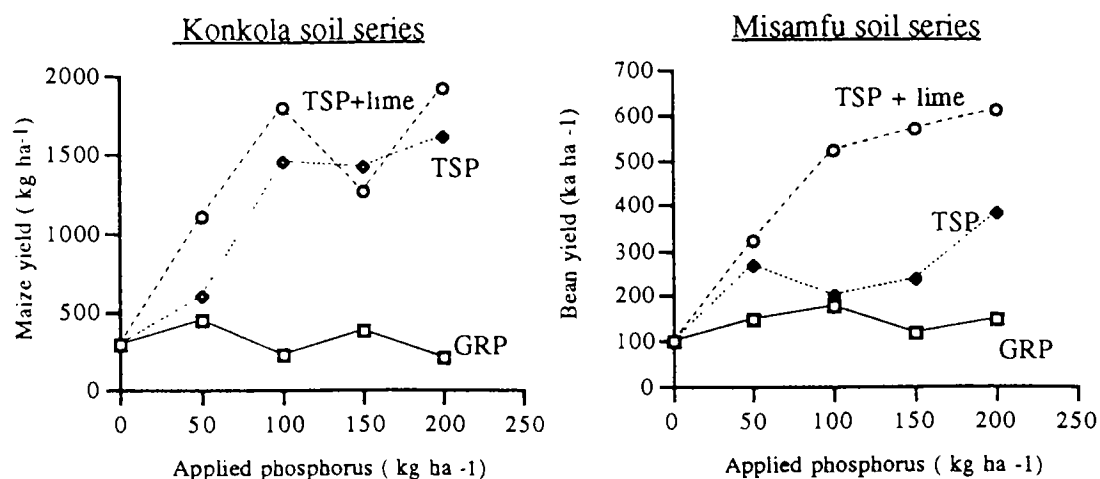
Fig. 11. Miaze and bean response to applied through GRP TSP and TSP+lime

In another trial Chilembwe PR compared to singlesuperphosphate (SSP) to assess its suitability in supplying phosphorus to wheat (*Triticum aestivum*) on Katito soil series. The rates of phosphorus were 0, 22, 44, 88 and 176 kg P ha^{-1}. All the plots received 30 kg N ha^{-1} as urea, 40 kg K ha^{-1} as potassium chloride and 150 kg ha^{-1} gypsum. All fertilizers were broadcasted and incorporated into the soil before seeding.

A one year pot study to compare the efficiency of Chilembwe PR , Gafsa PR and Chilembwe SAB-PAPR as sources of phosphorus to plant was also conducted at Mount Makulu central research station.

Table 19. Crop rsponse to applied phosphorus from different scources

Applied P (P$_2$O$_5$)	Soil Series Misamfu			Konkola		
	GRP[†]	TSP	TSP+Lime	GRP	TSP	TSP+Lime
	...................................Bean yield kg ha^{-1}...................................					
0	100	100	100	110	110	110
50	150	270	320	60	100	195
100	180	200	520	70	90	200
150	120	240	570	80	95	150
200	150	380	610	70	90	160
C.V. (%)	= 63			= 35		
Trial Mean	= 300			= 120		
S. Em.	± 111			± 24		
LSD$_{(05)}$	= 300			= 70		
	.........Sunflower yield kg ha^{-1}..............			.....Maize yield kg ha^{-1}..........		
0	140	140	140	300	300	300
50	240	330	290	450	600	1100
100	160	420	540	230	1450	1800
150	150	370	510	380	1410	1250
200	120	450	500	200	1600	1910
C.V. (%)	= 50			= 31		
Trial mean	=326 =			1002		
S. Em.	± 94			± 156		
LSD$_{(05)}$	= 180			= 500		

† GRP = P applied through Ground Rock Phosphate,
TSP = P applied through triple superphosphate

From these investigation carried out from 1984 and 1986 it has been found that direct application of Chilembwe phosphate rocks to all test crops was generally ineffective as a Phosphorus source. The application of Chilembwe phosphate rock had very little or no effect at all on crop yield on both Mufulira and Misamfu soil series in all the years (Fig 11). This poor response to application chilembwe phosphate was more prominent in maize and sunflower. On the other hand the application of TSP, and TSP plus lime increased crop yield on both soils. When assessed on Katito soil series with SSP with wheat as a test, Chilembwe PR was again inferior and hardly any crop response was observed. In contrast there was linear response to applied phosphorus through SSP with increase in P rates.

Agronomic evaluation of Mumbwa PR

Mumbwe Phosphate rock was also tested for its agronomic suitability as a source of P for plant growth. It was compared to TSP, Fused magnesium phosphate (FMP) and Partially Acidulated Phosphate Rock (PAPR). It was tested on Konkola and Mufulira soil series and the crops used were: maize, Soyabean, finger millet, groundnut and common beans. For finger millet, beans and groundnut phosphorus was applied at the rate of 0, 10, 20, and 30 kg P ha^{-1}. Maize and groundnut received 0, 20, 40 and 60 kg P ha^{-1}. All plots received equal amounts of other nutrients: 40 kg K ha^{-1} applied as potassium chloride, 50 kg N ha^{-1} as ammonium nitrate (for Maize and millet) and 20 kg N ha^{-1} as starter nitrogen for beans and groundnut. Maize and finger millet were top dressed with 50 kg N ha^{-1} applied as ammonium nitrate.
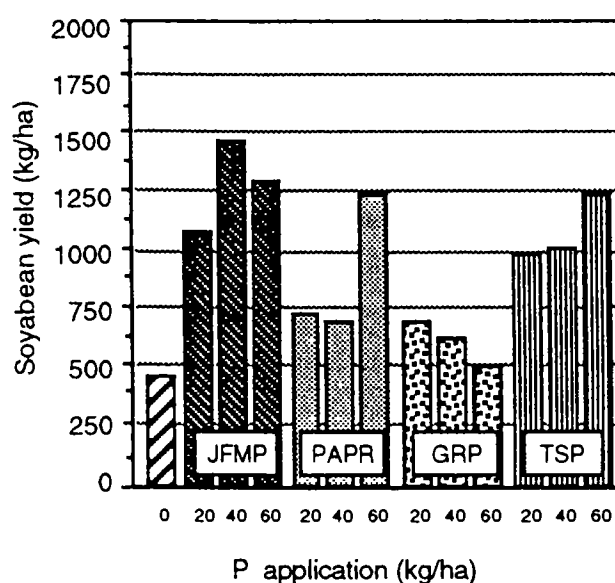
Fig. 12. Soyabean yield under varying amounts of phosphorus (*high input*) applied as Japanese fused magnesium phosphate (JFMP), partially acidulated phosphate rock (PAPR), Mumbwa ground rock phosphate (GRP), triple super phosphate (TSP).

Mumbwe phosphate rock confirmed that the phosphate rocks were inferior sources of phosphorus. Despite three years of application, Mumbwa PR had no effect on crop yield. The Mumbwe phosphate rock was also found to be agronomically an inferior source of P for all the crops tested and on both the soils used (Fig. 12)

Discussion and Conclusions

These experiment thus indicate the unsuitability of GRP as a source of P. It can be concluded that direct application of Chilembwe and Mumbwa phosphate rock was inferior to PAPR, TSP and / or SSP and did not prove of any agronomic value to the whole range of annual short duration crops tested. It appears that even after three years the GRP mixed in the soil did not

decompose to release plant available P. The poor performance of Chilembwe and Mumbwa is attributed to them having low reactivity and low citrate soluble phosphorus (1.3 % and 1.0 % P_2O_5 for Chilembwe and Mumbwe respectively). The low amounts of soluble phosphorus is as a result of the igneous parent material. Igneous phosphate rocks are not good sources of phosphorus for direct application as compared to sedimentary ones. In addition, the presence of high extractable soil aluminium and iron could contribute to the reduction of available P depending on the proportion of $Al(OH)_2H_2PO_4$ and $Fe(OH)_2H_2PO_4$ formed in the soil.

EVALUATION OF FUSED MAGNESIUM PHOSPHATE (FMP)

It is well known that igneous rock phosphates as compared to sedimentary ones are not good sources of P for direct application. They, however, become effective sources of P if they are beneficiated so that their igneous structure is broken by partial or complete acidulation through fusion process. Fusion of igneous rock phosphate with indigenously available serpentine (a magnesium based rock) to give fused magnesium phosphate (FMP) may be a cheap and simple process possible locally in Zambia. Fused magnesium phosphate (FMP) is a thermal phosphate produced under very high temperatures. Phosphate rock together with serpentine are subjected to extreme heat (1200°C) to produce molten glass. Upon cooling the glass is broken and ground to fine grains. In Zambia there are huge deposits of phosphate rocks as mentioned earlier. The serpentine deposit is located 400 km north of Lusaka.

Characteristics of FMP

Fused magnesium phosphate has the major part of its total soluble P in weak acids such as citric acid. It contains 9.5% total and 9.0% citrate soluble P. In addition to phosphate, FMP contains other components such as magnesium (8-11% MgO), calcium (28-35% CaO), silica (18-24% SiO_2). Fused magnesium phosphate can thus be an effective source of calcium and magnesium in soils of northern Zambia which are low or deficient in these elements, and can have a liming effect on aluminium saturation.

FMP might be lightly superior to superphosphates because it has low solubility in water, supplying nutrient steadily to the crop, while water-soluble phosphatic fertilizers such as TSP or SSP are readily fixed by active aluminium and iron oxides in the soil and become ineffective. Fused Magnesium Phosphate is dissolved by weak acids present in the soil or secreted by plant roots.

However, because of its fine grained glass it is very unpleasant during handling especially with bare hands. FMP holds promise if it is blended with K fertilizers and then compounded with N fertilizers.

Experimental Location and soil types

A series of field studies were conducted between 1984 and 1986 on Misamfu sandy loam (Ultic-Haplustox) and Mufulira sandy clay loam (Oxic Plaleustult) at Misamfu Research station in Kasama, and on Konkola clay loam (Rhodic Paleustult) at Lucheche sub-research station in Mbala and on Katito soil series at Katito farm in Mbala. FMP was tested in comparison to TSP and/or SSP and TSP plus lime.

Analytical results of the soil showed that the texture was mainly sandy loam at 0-20 cm for Misamfu soil series, sandy clay loam for Mufulira, and clay loam for Konkola soil series. All soils had pH of less than 4.5 with Al^{3+} saturation ranging from 40% to 80%. Although the absolute levels of exchangeable Al^{3+} was not very high its relative value of saturation was high due to the low effective cation exchange capacity (ECEC) of the soil. The initial levels of available P was very low, exchangeable K^+ was above the moderate levels (> 0.5 m.e./100g) in all the soil series.

Table 20. Pysico-chemical properties of soil sampled at the beginning of the experiments on three different soil series.

Soil Series	Depth (cm)	Sand (%)	Clay (%)	pH CaCl₂	Org C. (%)	Avail P (ppm)	Exchangeable Cations m.e./100g					Al^{3+} (%)
							Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	ECEC	
Mufulira	0-10	73	17	4.3	0.65	5	0.8	0.2	0.4	0.2	1.6	50
(SCL)[†]	10-20	60	29	4.2	0.57	2	1.1	-	0.3	0.3	1.7	65
Misamfu	0-10	78	18	4.9	1.50	13	TR[§]	1.3	1.3	0.2	2.8	-
(SL)	10-20	78	19	4.2	0.81	5	1.1	-	0.2	0.1	1.4	79
Konkola	0-10	52	21	4.5	2.5	4	1.2	0.8	0.68	0.1	2.8	39
(CL)	10-20	40	34	4.2	1.2	2	1.7	0.1	0.06	2.0	2.0	76

† SCL = sandy clay loam, SL = sandy loam, CL = clay loam
§ TR = trace

Agronomic Evaluation of JFMP

At Misamfu Research station, maize and groundnut were grown in rotation on both soil series. On Konkola soil series, a bean-maize rotation was used during direct application of FMP and maize-Soyabean rotation for residual FMP evaluation.

Five rates of P: 0, 50, 100, 150, and 200 kg ha⁻¹ P_2O_5 were applied through FMP, TSP, and TSP+2 tonnes lime per ha applied only at the start of the experiment. Phosphorus was applied in the first and second seasons. The residual effect of these treatment was tested in the third season. Basal doses of N and K at the rates of 50 kg and 40 kg ha⁻¹, respectively, were applied

as ammonium nitrate and potassium chloride to each crop in the rotation. Only the maize crop was top dressed with 50 kg N ha⁻¹.

Table 21. Crop response applied P from different sources

Applied P	Soil Series								
(P₂O₅)	Misamfu			Mufulira			Konkola		
	FMP[†]	TSP	TSP+Lime	FMP	TSP	TSP+Lime	FMP	TSP	TSP+Lime
	.... Groundnut yield kg ha⁻¹						...... Bean Yield kg ha⁻¹		
0	690	690	690	1050	1050	1050	80	80	80
50	900	680	1410	1390	1260	1490	110	90	140
100	1200	670	1350	1590	1580	1690	150	100	170
150	1150	890	1300	1520	1410	1560	230	90	140
200	1400	900	1000	1580	1600	1540	160	110	180

C.V. (%)   = 17   =   17   =   40
Trial Mean =1494   = 1494   = 142
S. Em.   ± 130   ±   130   ±   28
LSD(05)   =n.s.[§]   =   n.s.   =   80

	.... Maize yield kg ha⁻¹								
0	2700	2700	2700	650	650	650			
50	1050	1500	3400	1850	3250	3050			
100	2450	1400	3900	3410	3820	3510			
150	2500	1350	3000	3820	3250	3820			
200	2900	1100	1500	3400	3500	4150			

C.V. (%)   = 63   =   25
Trial Mean = 300   = 3325
S. Em.   ± 111   ±   414
LSD(05)   = 300   = 1100

† FMP = P applied through Fused magnesium Phosphate,
  TSP = P applied through triple superphosphate
§ n.s. Non significant at (P = 0.05)

Table 22. Crop response to applied P on Misamfu, Mufulira and Konkola

Applied P	Soil Series								
(P_2O_5)	Misamfu			Mufulira			Konkola		
	FMP[†]	TSP	TSP+Lime	FMP	TSP	TSP+Lime	FMP	TSP	TSP+Lime
	Groundnut yield kg ha^{-1}								
0	450	450	450	200	200	200	50	50	50
50	470	290	580	910	600	800	170	150	240
100	710	310	710	750	820	1220	220	160	190
150	800	360	360	960	800	820	250	190	130
200	820	600	520	1100	1150	800	230	150	160
C.V. (%)	*= 34*			*= 23*			*= 32*		
Trial Mean	*= 555*			*= 824*			*= 179*		
S. Em.	*± 108*			*± 109*			*± 28*		
LSD(05)	*= 320*			*380*			*= 80*		
	Maize yield kg ha^{-1}								
0	3300	3300	3300	4650	4650	4650	100	100	100
50	3800	3650	5650	8010	7120	7810	1100	1900	3400
100	5000	4720	5800	9000	10650	9110	2200	2600	3500
150	6000	4210	6820	8620	8700	9600	2800	4200	3600
200	5410	4850	4250	8910	10200	10000	3100	2800	4200
C.V. (%)	*= 37*			*= 17*			*= 36*		
Trial Mean	*= 4919*			*= 8646*			*= 2861*		
S. Em.	*± 898*			*± 744*			*± 569*		
LSD(05)	*= n.s.*			*= 2100*			*= 1500*		

† FMP = P applied through Fused magnesium Phosphate,
  TSP = P applied through triple superphosphate
§ n.s. Non significant

The results of crop yield on Misamfu soil series indicate the application of P had no effect on maize yield in all the cropping seasons. Groundnut was found to be more responsive to applied P than maize, and the response was recorded right from the first season. Groundnut responded to FMP application starting from 50 kg ha^{-1} P_2O_5 up to the highest dose. TSP + lime gave responses from 50 kg ha^{-1} dose to 150 kg ha^{-1}. Groundnut responded to TSP starting at 100 kg ha^{-1} and above.

On Mufulira soil series groundnut responded to P applied through TSP or FMP at 100 kg ha^{-1} Maize response was obtained starting at 50 kg ha^{-1} for both P sources. For both the test crops grown on Mufulira soil series, it is evident that P fertilisation and perhaps not liming was important and that FMP was as effective a source of P as TSP.

Maize responded to residual effects of applied P from all the sources. The yields increased steadily with increasing rates of P application up to 100 and 150 kg ha^{-1} in case of TSP and

FMP respectively. TSP+lime was however, superior to either FMP or TSP at the same or higher rates. Groundnut responded to residual P from all the sources.

On Konkola soil series, a bean/maize rotation was used during direct application of FMP and a maize-groundnut rotation for residual evaluation. During direct application, lime was found to be important. Maize responded with only 50 kg ha^{-1} P$_2$O$_5$ when applied through FMP. When beans was used both lime and P were important and yield responses were obtained at 100 and 150 kg ha^{-1} P$_2$O$_5$ TSP plus lime and FMP respectively. Both maize and groundnut responded to residual effects of applied P from all the sources.

On Katito soil series, FMP was tested with SSP and wheat as the test crop. There were linear responses to applied P through FMP and SSP with increasing P rates. FMP was found to be as effective agronomically as SSP (Zambia-Canada wheat Research Project, 1987).
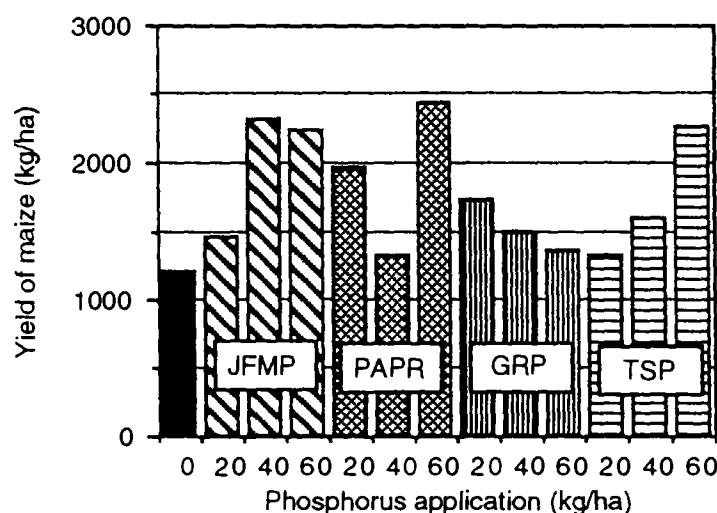

Fig. 13. Maize yield as a function of different sources and amounts of applied phosphorus.

Discussion and Conclusions

These multi-location and mult-crop rotational field experiments conducted for three cropping seasons give sufficient evidence that FMP is an effective source of plant available P. Often FMP gave higher yield in all test crops compared to TSP + lime (Fig. 13). This suggests that FMP in addition to phosphorus also possesses some liming value. It had better residual effect to the crop compared superphosphates. Groundnut responded very well to residual P from all the sources. It is evident that FMP is an effective source of plant available P as TSP and SPP.

FMP is superior to superphosphates in that it also contains magnesium, calcium and silica and has a liming effect. It thus decreases aluminium saturation and increases the calcium and magnesium content of the top-soil of these soils which are deficient in these elements.

Fusion of igneous rock phosphate with indigenously available serpentine to give FMP may be a cheap and simple process possible within Zambia since the raw material are locally available.

The economic feasibility of the production of FMP and derivatives of phosphates rock should therefore be worked out by relevant authorities for use on acid infertile soils in the region.

EVALUATION OF PARTIALLY ACIDULATED PHOSPHATE ROCK

Field Studies conducted by the Soil Productivity Research Programme Between 1984 and 1992 using finely ground, indigenous PR from Chilembwe and Mumbwa deposits which are of igneous origin, in the high rainfall zone of Zambia conclude that direct PR applications were not effective sources of P for the whole range of annual short duration crops tested (SPRP, 1986).

Partial or complete acidulation with sulphuric acid of these phophate rocks represents a technology that can be used to produce highly effective P fertilizers from these deposits.
The principle behind the partial acidulation of phosphate rock lies in the fact that sulphuric acid reacts with the apatite mineral to produce the monocalcium phosphate monohydrate, calcium fluoride and calcium sulphate.

A fully acidulated rock phosphate decribes a phosphate rock that has been treated with a sufficient quantiy of acid to convert all the phosphate to water-soluble form (monocalcium phosphate monohydrate). A partially acidulated phosphate rock (PAPR) refers to an under-acidulated product that has been treated with only a portion of the acid (usually sulphuric acid or phosphoric acid) required for fully acidulation. The proportion of the acid added is expressed as a percentage of the total quantity rock Thus, if a particular fully acidulated rock requires 604 kg of 100% sulphuric acid per tonne of rock, a 50% acidulated product would use 302 kg of 100% sulphuric acid per tonne of rock.

Field experiments conducted in northern Zambia have demonstrated that 50% partial acidulation of PR with sulphuric acid to produce Sulphuric acid based (SAB-PARP-50) PAPR can be agronomically as effective as the water soluble, imported SSP or TSP (SPRP 1989; Mapiki and Singh, 1990; Priri et al., 1991).

Field evaluations ware carried out in assessing the agronomic effectiveness of SAB-PAPR-50 in comparison to that of TSP and SSP under different cropping sequence and soil types.

The Chilembwe PR was beneficiated and partially acidulated with 50% sulphuric acid at Muscle Shoals, Alabama, to produce Chilembwe SAB-PAPR-50 which contained, respectively 20.2 and 2.0% total and citrate soluble P_2O_5 and in addition 12%S. All these materials were tested for agronomic effectiveness with a standard fertilizer of TSP or SSP at rates of 0, 10, 20, and 30 kg P/ha-1 (low P input) and at 0, 20, 40, and 60 Kg Pha^{-1} (high P input) arranged in a randomized complete block design with four replications.

The SAB-PAPR-50 field experiments were on Mufulira and Konkola soil series only. The experiments on Mufulira soils series were conducted with maize cv MMV612 and soyabean cv Hernon-147 for high P input and with groundnut cv Chalimbana, fingermillet cv Carioca, for low P input. Those on Konkola soil series were conducted only in 1987/88 cropping season with maize and fingermillet as test crops. The low P input evaluation was later extrapolated to two other locations namely, Mpika and Mutanda on Malashi and Maheba soil series, respectively. The TSP in this regard was replaced by SSP standard.

All plots received in addition, basal dressings of 40kg K ha^{-1} as KCl and 50 kg N ha^{-1} as NH_4NO_3 for maize and fingermillet and 20 kg N ha^{-1} as urea as starter N for beans and groundnuts were applied. Maize and fingermillet were later top dressed with 50 kg N ha^{-1} through NH_4NO_3. Relative agronomic effectiveness was estimated as percent yield of PAPR relative to the standard TSP or SSP (Sanchez, 1982; Munyinda, 1988; Chien and Hammond, 1987).

Sulphuric Acid-basedd PAPR-50 vs TSP Standard

On Konkola soil series, maize responded to all P treatments (Table 23). There was a significant (p = 0.05) difference between the check treatment and treatments receiving P. The linear response to rates of P was non-significant (p= 0.16). With fingermillet PAPR significantly (p= 0.05) out-yielded TSP at P at rates of 10 and 20 kg P ha^{-1} (Table 23).

The SAB-PAPR-50 was agronomically superior to standard TSP with its efficiency being 75% more than the standard TSP.

Table 23. Evaluation of SAB-PAPR-50 with TSP on Mufulira and Konkola soil series

Year	Crop	Source	Applied phosphorus Kg ha^{-1}				Crop	0	20	40	60
			0	10	20	30					
Mufulira soil series											
1988	F/millet	TSP	1603	2341	3004	2662	Maize	1832	3172	3820	4267
		PAPR	1603	2455	2750	3460		1832	3850	2575	5279
1989	Grdnut	TSP	861	827	1034	1031	Maize	2509	4545	4421	4601
		PAPR	861	705	873	893		2509	3724	4002	4290
1990	Bean	TSP	190	210	300	400	Soybean	400	1010	1100	1250
		PAPR	190	160	190	290		400	750	745	2015
1991	F/millet	TSP	900	850	955	1025	Maize	1600	3100	4512	4102
		PAPR	900	1400	2450	1500		1600	4620	2650	5102
1992		TSP	564	830	1197	1457		1981	1893	1738	2015
	Bean	PAPR	564	822	808	1489	Soybean	1981	2270	1642	2111
Konkola soil series											
1988	F/millet	TSP	940	993	1013	1726		992	2594	2435	3486
		PAPR	940	1522	2434	1457	Maize	992	2654	3390	3615

On Mufulira soil series, maize was mono-cropped for two seasons between 1987 and 1989 and thenceforth soyabean was introduced in rotation (Table 23). In both the years SAB-PAPR-50 was generally agronomically as suitable as standard TSP. Relative agronomic effectiveness of PAPR was gnerally higher than that of TSP in the first cropping season. In the following year, there was a highly significant (p = 0.01) maize response to P applications, but with no significant yield differences between PAPR-50 and standard TSP. The response to applied P through PAPR was linear with yields and RAE increasing with rates (Table 23).

Crop response to various P rates through TSP was not significant although it significantly (p = 0.01) differed from the zero P treatment. The soyabean response to P was equally significant in the third year but less so in the fifth year. In both occasions, the response to P through PAPR-50 applied at 60 kg ha^{-1} was either equal or superior to that of TSP (Table 23). On another site of Mufulira soil series, fingermillet, groundnut, and beans were grown in rotation. Fingermillet positively responded to P through PAPR- 50 and TSP in 1988 but did not respond to TSP in 1991. However, the response to PAPR-50 or TSP suggesting that groundnut was not a high P demanding crop.

A slight groundnut yield was however, observed at 20 and 30 kg P ha-1 through TSP. There was a positive bean response to P applications, especially so in the 1992 crop where PAPR-50 was agronomically as effective as TSP (Table 23). Relative agronomic effectiveness of PAPR-50 was high with an r-value of 58% as compared to TSP with an r-value of 74%.

Sulphuric Acid-Based PAPR-50 vs SSP standard

Sulphuric acid-based PAPR-50 was evaluated for its agronomic effectiveness with SSP as standard in a multilocational trial. At Misamfu on Mufulira soil series there was hardly any response of beans to P applications. Soyabean response varied. The PAPR-50 out- yielded SSP at 10 and 30 kg P ha^{-1}.

At Lucheche on Konkola soil series, bean response to P applications was very significant with PAPR-50 being superior to SSP at all levels. With maize however, SSP was superior, especially at levels higher than 10kg P ha^{-1}

Relative agronomic effectiveness

Relative agronomic effectiveness (RAE) was calculated as:

$$RAE(\%) = \left(\frac{\text{Yield of PAPR - 50 - Yield of control}}{\text{Yield of TSP / SSP - Yield of Control}} \right) \times 100$$

Agronomic evaluations of PAPR-50 vs TSP showed a closer compairson with RAE ranging from 60 - 166% (maize) and from 33 - 103% (beans).

In a number of cases the RAE exceeded that of TSP presumably because TSP was readily fixed by the soil whereas, the PAPR was usually available for plant uptake. According to Munyinda and Mapiki (1993) this normally happens in acid soils. With SSP however, the comparison was inconsistent as evidenced in Table 24. The reason for this inconsistency is unexplained given the absence of soil and plant analysis data.

Table 24. Relative effectiveness of SAB-PAPR-50 to standard TSP and SSP

Year	Soil series		Rate of application				Soil series	Rate of application			
			20	40	60	Mean		10	20	30	Mean
			RAE (%)					RAE (%)			
1989	Mufulira (maize)	SSP	100	100	100	100	Mufulira (bean)	100	100	100	100
		PARP	60	78	85	95		33	59	43	45
1992	Konkola (maize)	SSP	100	100	100	100	Mufulira (bean)	100	100	100	100
		PARP	103	166	105	125		97	39	103	80
1990	Mufulira (bean)	SSP	100	100	100	100	Malashi (maize)	100	100	100	100
		PARP	-	56	-	56		0.01	19	-	19
1991	Konkola (maize)	SSP	100	100	100	100	Malashi (soyabean)	100	100	100	100
		PARP	116	0.1	24	70		346	-	62	136

Conclusions

The crop reswponse data used to evaluate SAB-PAPR-50 suggest that this fertilizer can be as effective as readily louble conventional P fertilizers. The data presented also suggests that crop responses may be varied with some crops showing high responses while others are not responsive. Benchmark soils used for this evaluation vary widely in respect of P availability once P is applied. Systematic soil analysis may be able to elucidate some of the yield discrepancies encountered in this study.

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