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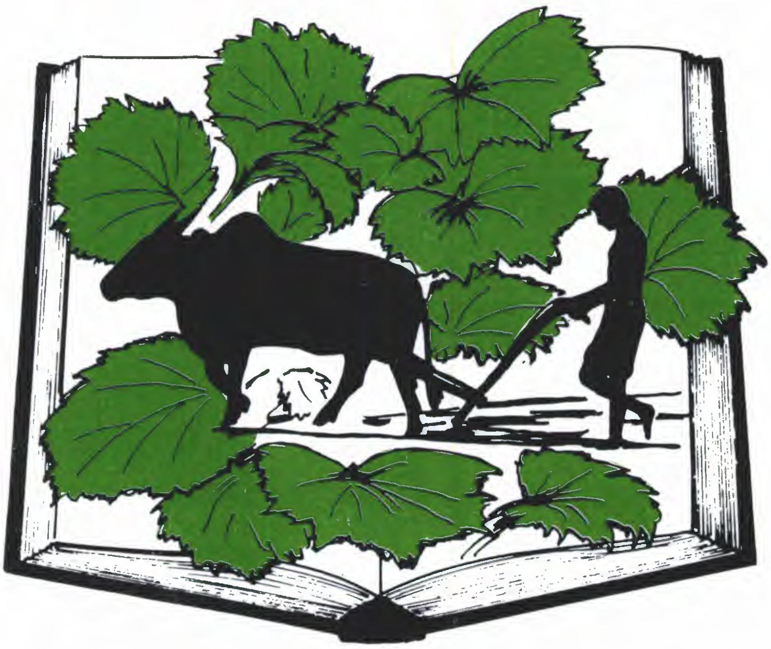
AGRONOMIC POTENTIAL OF INDIGENOUS PHOSPHATE ROCKS AS A PHOSPHORUS FERTILIZER IN ZAMBIA

(INTERIM REPORT)

A. MAPIKI AND B.R. SINGH



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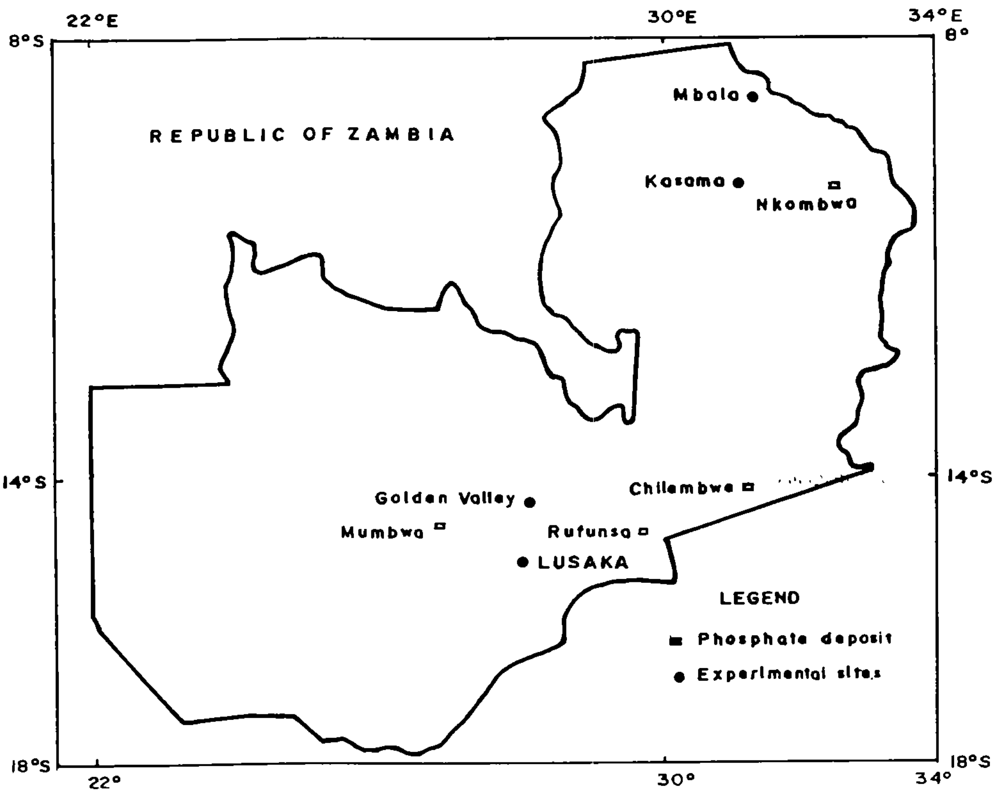

DEPARTMENT OF AGRICULTURE

SOIL PRODUCTIVITY RESEARCH PROGRAMME

Misamfu Research Station, Kasama, Zambia

March, 1990

[Funded by Norad]

PREFACE

Region III comprising the high rainfall areas of Northern Zambia is the potential bread basket of Zambia because of its reliable rainfall and vast areas of land which are agriculturally underexploited. However, a survey of the soils in this region indicated a widespread inherent phosphorus deficiency. Studies conducted by Soil Productivity Research Programme (SPRP) revealed that crops seldom produced yields without additional phosphorous applications. This in turn justified a rigorous phosphorus research programme. The efforts were directed towards the use of indigenously available phosphate rocks which often have been found to be a good phosphorus source in acid soils of the tropics.

Application of unacidulated phosphate rocks and partial acidulation were considered as alternatives to soluble triple super phosphate and single superphosphate. The merits and shortcomings of these materials are discussed. Conclusions and recommendations in this report will enlighten the readers the efforts so far pursued in this field. Areas of future research and validation are highlighted.

The goal is clear:- with large indigenous phosphate rock reserves, possibilities of having a phosphate plant hold tremendous potential.

SPRP wishes to acknowledge the cooperation and support from the Ministry of Agriculture and especially from Dr. Kalaluka Munyinda, the Assistant Director of Agriculture (Research). The assistance from MINEX Ltd., and the International Fertilizer Development Centre, USA in processing and providing the fertilizer materials for testing is gratefully acknowledged. We also express our thanks to NORAD for financial assistance and NORAGRIC for its professional support. This work is evidence of the Zambian government's commitment to research and its involvement in developing judicious use of natural resources available in the country.

Adne Haland (Ph.D)
Project Coordinator
Misamfu March, 1990.

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LIST OF FIGURES AND TABLES

1. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

From the information and results presented in this report, following conclusions can be drawn and recommendations be made for future actions:

1.1 CONCLUSIONS

I. Most of the soils in the high rainfall areas are low or deficient in P. Crops seldom produce economic yields without additional P application.

II. Fertilizer consumption in this region is rapidly increasing and the P requirements may increase at a faster rate in future when more lands are brought under semi-commercial or commercial agriculture in this region.

III. There are five known phosphate rock (PR) deposits in Zambia, of which two, Chilembwe and Mumbwa, hold promise for their exploitation for agricultural use.

IV. Proven reserves of these deposits are of commercial nature but all of these deposits are of igneous origin.

V. Some PRs contains high amounts of Al, Fe, and Mn oxides and may not be suitable for acid soils.

VI. Direct application of ground phosphate rock did not prove of any agronomic value for any of the crops tested even in the highly acidic soils.

VII. Poor performance of PR tested was attributed to the following:-

a. Very low citrate soluble P (about 1%) content,

b. Igneous parent material of PR,

c. Low reactivity of PR.

VIII. Partial or complete acidulation of PR represents an alternative means of producing agronomically effective P fertilizers from indigenous PR resources which may otherwise be unsuitable for use as fertilizer.

IX. In a highly P deficient and high P fixing soil (eg. Konkola Soil Series), PAPR often gave better results for the crops tested.

X. In a low P fixing soil (e.g. Mufurlira) PAPR was nearly as effective as TSP for maize and finger millet crops but only half as effective for beans.

XI. Fused magnesium phosphate (FMP) was generally found as effective source of P as TSP and often FMP gave higher yields of tested crops as compared to Triple Super Phosphate (TSP) without lime. This suggest that FMP in addition to phosphorus also possesses some liming values.

XII. Although yield relative agronomic effectiveness of both PAPR and FMP varied considerably among crops and among P rates, it was, on average, near to that of TSP.

XIII. The results of these studies from Northern Zambia and especially with PAPR are similar to those from other parts of the tropics. It has been shown consistently that the response curves for products with only 50% of the P applied in water soluble form are similar to those of highly soluble P fertilizers.

XIV. Both PAPR and FMP proved suitable alternatives to highly soluble P fertilizers in these investigations but PAPR seems to be a better choice for Zambian conditions for the following reasons:

a. PAPR of Zambian PR performed much better than FMP of the same PR. Only the Japanese FMP was found equal to PAPR but it will involve foreign exchange and importation and may not be economically viable.

b. Both ingredients for PAPR production, phosphate rock and sulphuric acid, are available in abundance within the country.

c. PAPR can also supply S to the plant in addition to P. Sulphur can often be the third limiting nutrient in the highly acidic soils of Northern Zambia.

d. Physical and chemical properties of PAPR products are better than FMP and make it suitable for bulk blending with other fertilizers e.g. urea.

e. The fine grained glass texture of FMP makes handling difficult and especially under manual operations of fertilisation in the field.

f. Some of the undesired elements and other impurities present in Zambian PRs may be removed during the beneficiation process of PAPR, thus avoiding excessive metal accumulation and concentration in the soil.

XV. Assuming that the use of phosphate fertilizers in the acid soils of Zambia may reach the level of 8 000 tonnes of P_2O_5 per year, the proven reserves of Chilembwe PR of 1.64 million tonnes should last for about 30 years. If however, some of the Mumbwa PR could also be used for this purpose, then the life span of proven PR reserves will extend beyond 30 years.

XVI. The use of PAPR should not be considered as a substitute to processed fertilizers in the whole sector of agriculture but rather as a supplemental low-cost fertilizer based on indigenous raw materials for resource-poor segments of the farming community.

1.2 RECOMMENDATIONS

1.2.1 Research and Validation

I. Work on the agronomic evaluation of PAPR should be expanded to more experimental sites with varying soil properties and in different agroecological zones.

II. In addition to Chilembwe PAPR, other PRs (e.g. Mumbwa) should also be tried for acidulation and tested for its agronomic effectiveness.

III. The effect of soil factors such as soil pH, P retention capacity, and organic matter on the solubility of P from different PRs, should be studied.

IV. The long term residual effect of PAPR on crop yield and soil productivity be evaluated..

V. Existing soil test methods used for P determination from highly soluble P fertilizers often fail to predict available P from PR sources and hence more research is needed to develop a suitable soil test for a given PR-soil-plant system.

VI. Since PAPR has shown comparable agronomic effectiveness in several of the Soils Research experiments, the validation of this technology on farmers' fields be taken up by the Adaptive Research Planning Team (ARPT) for the next cropping season.

VII. The agronomic effectiveness of PAPR-50 blended with urea and other N-fertilizers and with potassium-based fertilizers should also be evaluated.

VIII. For crops demanding high levels of phosphorus in the soil in the early growth stages, mixing of PAPR with soluble P fertilizers (SSP or TSP) could be investigated.

1.2.2. Commercial exploitation

I. The economic feasibility of the production of PAPR and/or FMP should be worked out. Agronomic evaluation favours PAPR for the reasons previously given under conclusions.

II. Commercial exploitation of Chilembwe PR for PAPR production should be seriously considered by the Ministry of Agriculture and other agencies involved e.g. Minex and ZIMCO Ltd., and Nitrogen chemicals etc.

III. Assistance from IFDC should be sought on the production technology of PAPR.

2. INTRODUCTION

One of the major problems that has inhibited the development of economically successful agriculture in many areas of the tropics is the poor soil fertility for crop production (Chien & Hammond, 1988). Many tropical regions are low in both total and available phosphorus (P), which is an essential plant nutrient. Studies in Northern Zambia revealed that crops seldom produced yields without additional phosphorus applications. In the last decade, demand has been met by imported fertilizers but this is a drain on the foreign exchange. Efforts have, therefore, been made in recent years to find alternative sources of supplying P for crop production in the high rainfall areas of Northern Zambia. Attention has focused on the use of low-cost indigenous material such as locally available phosphate rock (PR) deposits and their derivatives.

The target groups for the use of the alternative P sources are primarily the resource-poor farmers of the semi-commercial agriculture. It is known that the greatest market for the conventional fertilizers is the commercial farmers who use these fertilizers for cash crops and that the alternative sources may be most appropriate for farmers with limited capital available for the purchase of inputs.

Partially acidulated phosphate rocks (PAPRs) and direct applications of finely ground phosphate rock (PR) have been considered as alternatives to the application of costly soluble phosphorus fertilizers such as triple superphosphate (TSP) and single superphosphate (SSP) on acid, P-fixing soils (Harrison & Hedley, 1987; Hammond et al., 1980; McLean & Logan, 1970; Munyinda, 1984; Sanchez, 1981). Readily soluble phosphatic fertilizers, produced chemically, are becoming an increasingly costly proposition in the agricultural sector due to the rising cost of inputs such as sulphur and energy. Since all the current requirements of phosphatic fertilizers in Zambia are met through imports, there is a tremendous drain of foreign exchange on the national economy. Sometimes the lack of foreign exchange, late importations and delivery, poor transport network, and inadequate storage facilities lead to scarcity of phosphatic fertilizers in many parts of the country where small and marginal farmers suffer the most.

There seems, therefore, to be an immediate need to develop a national industry for phosphatic fertilizers in order to mitigate the problems of their scarcity and to control prices at reasonable levels by using indigenous materials (e.g., phosphate rocks (PR)) as much as possible. This option of solving Zambia's problem may, however, take some time and hence there is an urgent need to develop and test alternate but indigenous substitute materials as viable sources of phosphorus (Mapiki & Singh, 1987).

The purpose of this interim report is to focus on the use of indigenous PR deposits located either in Northern Province or other parts of Zambia. Indigenously available PR from Chilembwe and Mumbwa was tested in the finely ground form for direct application. Other alternatives which were also tested included (1) partially acidulated phosphate rock (PAPR) of Chilembwe origin; (2) Fused magnesium phosphate of Japanese origin as well as of Zambian origin. These materials were tested for a large number of important crops grown in the region and on some representative soil series of low pH, low P content, and high contents of Fe and Al oxides.

The main objective of this paper is to evaluate the relative effectiveness of these materials as P sources and to which degree these materials can have potential agronomic value in Zambian agriculture, especially in the high rainfall areas of Zambia.

3. FERTILIZER CONSUMPTION TRENDS IN N. PROVINCE AND IN ZAMBIA

Fertilizer sales in Northern Province for a period of 8 years (1981-1988) are shown in Fig.1. It can be seen that fertilizer sales to farmers has rapidly increased over this period, sales increasing from about 10 000 tonnes in 1980/81 to over 30 000 tonnes in the 1987/88 cropping season. It has been suggested that the supply of fertilizers had the greatest impact on maize production levels in Northern Province, relative to prices and rainfall (Behnke and Kerven, 1989). It is evident from Fig.1 that the level of maize sales in the province is closely related to the fertilizer supply. When the fertilizer supply declined (eg. 1985/86), maize sales were also reduced.

The fertilizer consumption from 1978 to 1987 for the whole country is depicted in Fig. 2. It can be seen from Fig. 2 that the total consumption of fertilizers has nearly doubled during the period under report. Not only the total consumption of fertilizers was doubled, but also the consumption of phosphate fertilizer was proportionately increased during the same period. If the trend in phosphate fertilizer consumption continued in the nineties with the same pace as in the eighties, the requirement of phosphate fertilizers may further increase as more lands in region 3, where P fertilizer efficiency is low due to P fixation in the soils, are brought under semi-commercial or commercial agriculture.

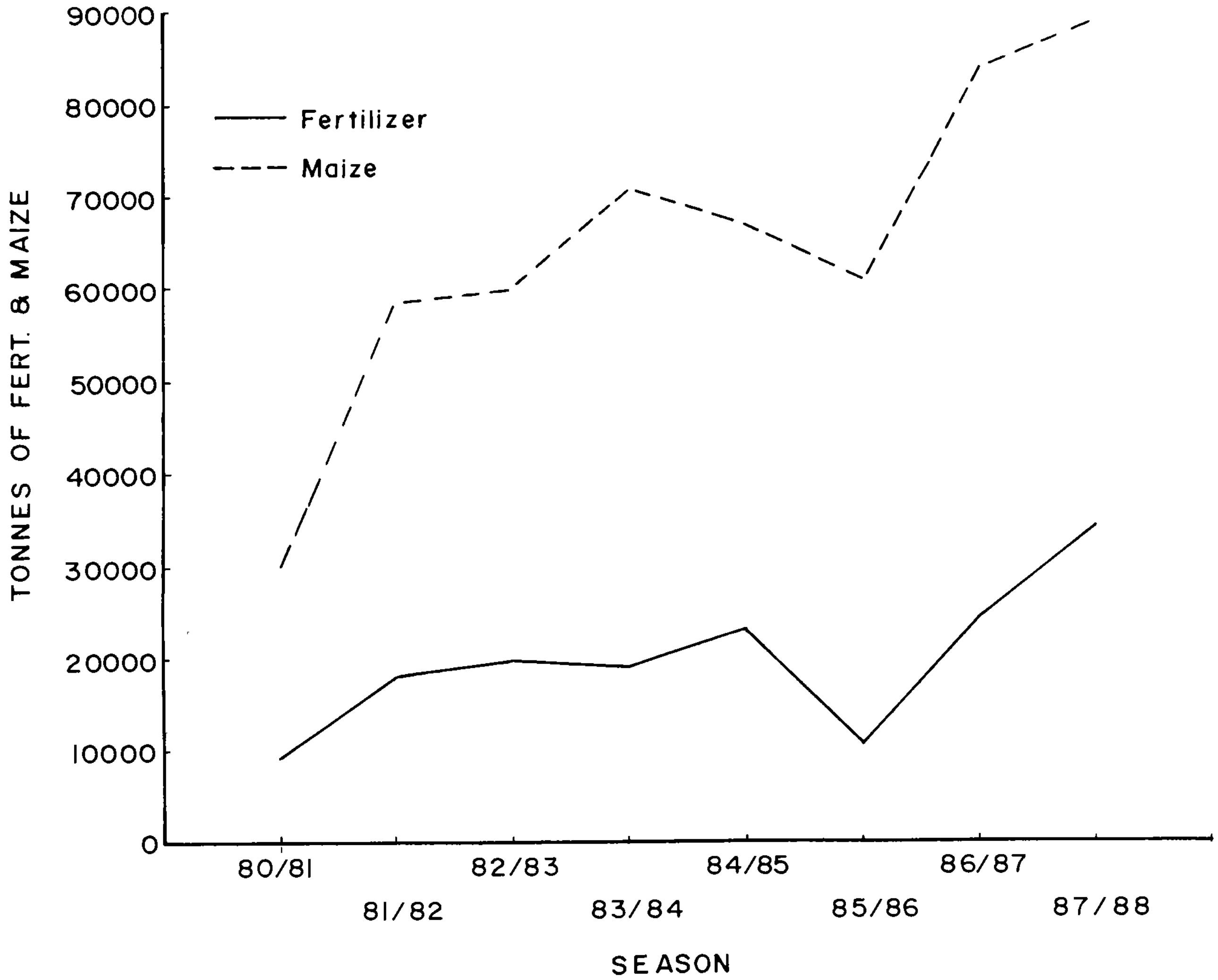


Fig.1 FERTILIZER AND MAIZE SALES BY N.C.U (1980-88)
IN NORTHERN PROVINCE (SOURCE: N.C.U)

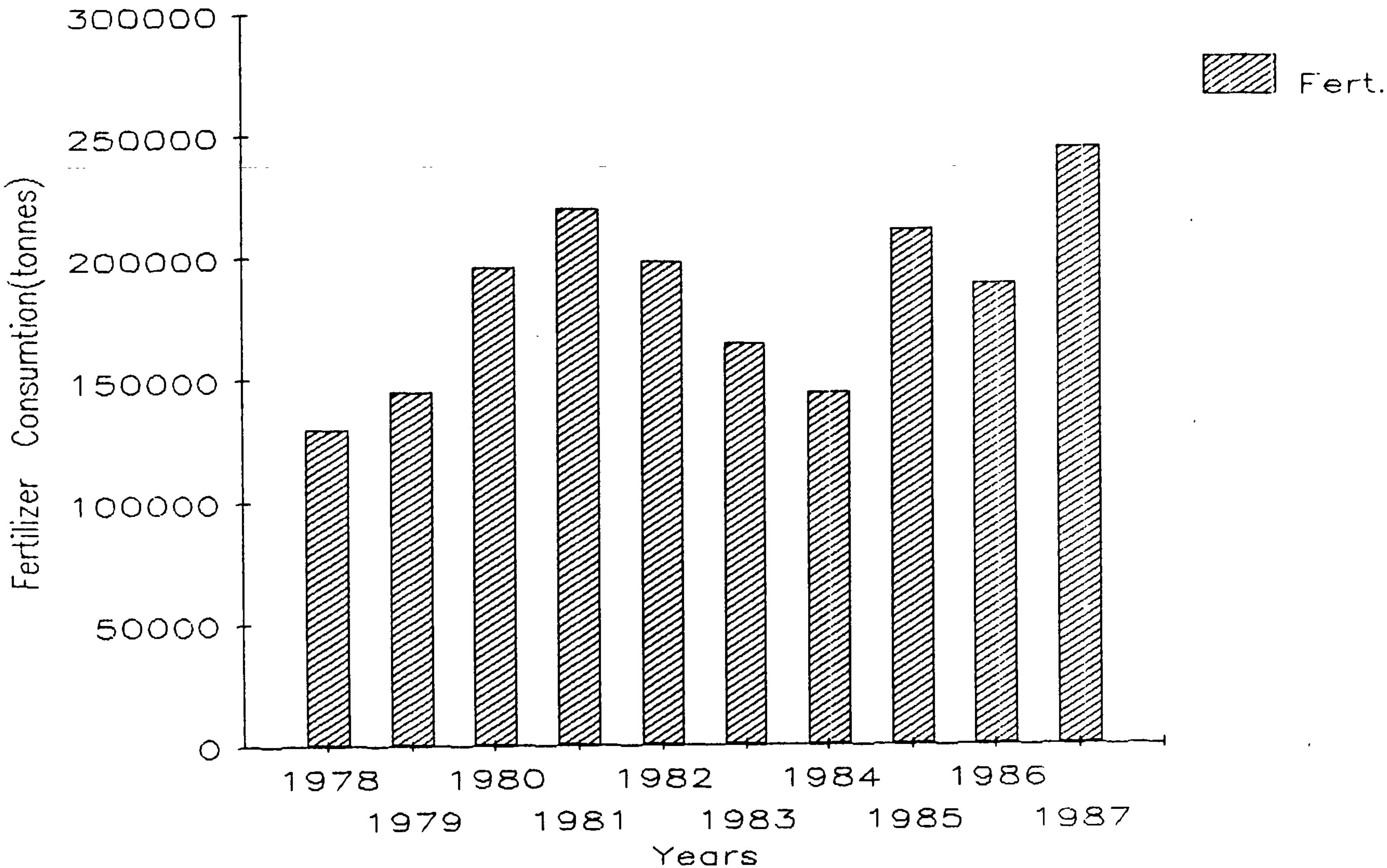


Fig.2. Fertilizer consumption in Zambia(Source:NAMBOARD,1988)

These increasing demands of P fertilizers will require more efforts in search of alternative sources of P which are locally available and which could be made into more soluble forms by physical or chemical alterations in their composition.

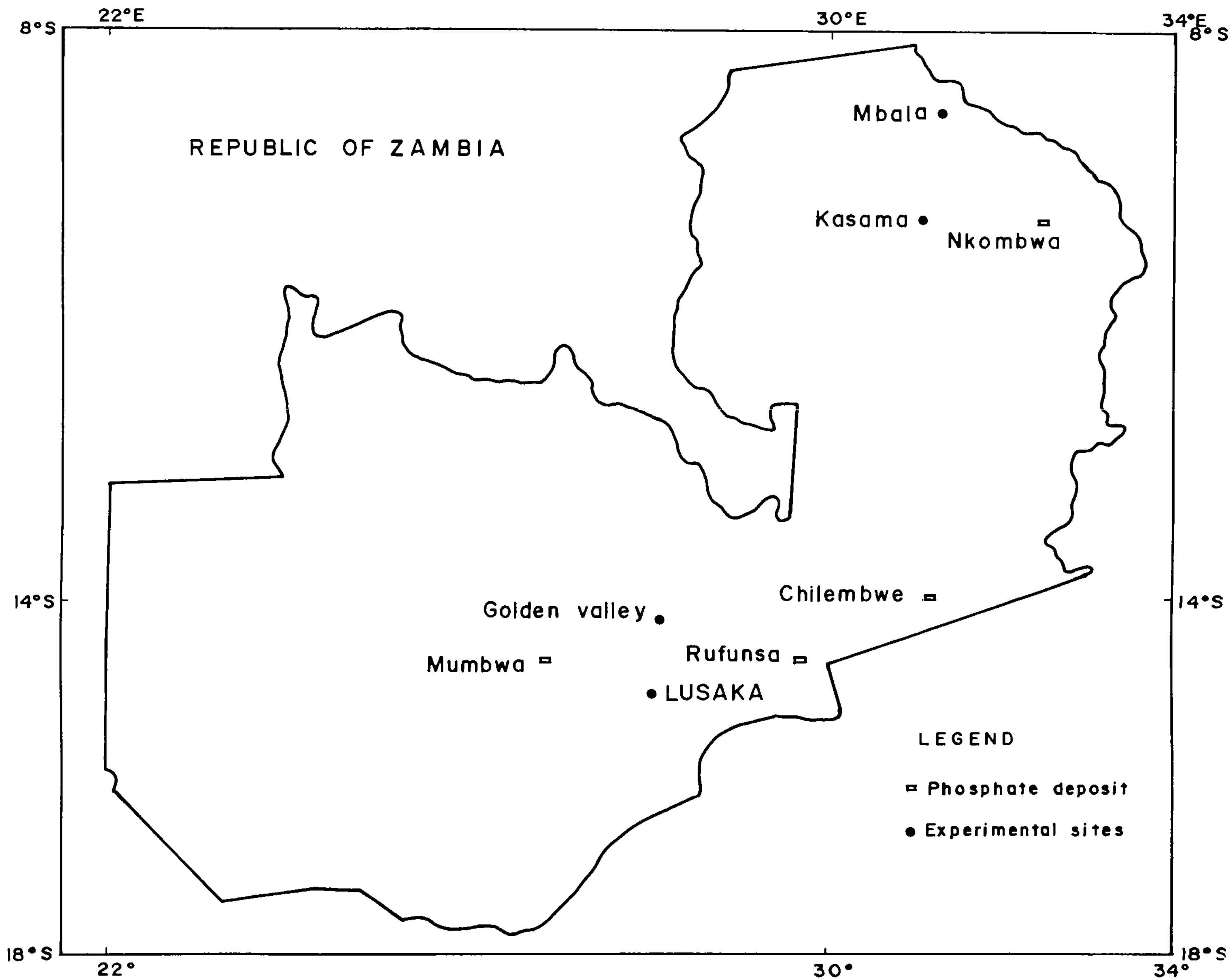
4. PHOSPHATE ROCK RESERVES IN ZAMBIA

4.1 Type of phosphate rocks

There are five known phosphate rock (PR) deposits in Zambia. All the five are of igneous origin and are associated with syenite related 'vein' or 'pegmatite' mineralization and carbonatite related deposition. Syenite related phosphate rock deposits have been located in the Chilembwe area of Eastern Province (Fig.3) and in Mumbwa North of Central Province. Carbonatite related phosphate rock 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) of Zambia Industrial Mining Corporation Limited (ZIMCO).

4.2 Chemical composition

Phosphate ore at **Kaluwe** consists of carbonates, apatite, magnetite and some pyrochlore. The deposit consists of sovite layers of carbonates, apatite, magnetite and a little pyrochlore. Particular blocks average 2.5 - 3.5 % P_2O_5 (Table.1). Beneficiation of the phosphate rock material is uneconomical, and the deposit is probably more useful as a lime source. About 0.5 million metric tonnes of alkaline soils derived from carbonatite and enriched in P_2O_5 (5-7%) may be of potential use for direct application.



Fig·3 Rock phosphate deposits and experimental sites in Zambia

At **Nkombwa Hill**, the ore is a dolomite ankeritic carbonatite with an average ore grade of 9.3% P_2O_5. Phosphate occurs mainly in the form of **isokite** associated with the carbonates together with subordinate pyrochlore and apatite. Both soil and rock samples contain base metals and rare earths. Cerium values in the soil range up to 1.5% with lanthanum showing the same pattern at about 0.75% level. Barium and strontium values are around 1% and manganese up to 10%. The highest thorium values are in the range of 250 - 400 mg/kg PR.

The **Chilembwe deposit** constitutes four ore bodies associated with the syenites varying in composition from mica syenites to monzonites. The apatite rock is in the form of massive lenses comprising apatite, quartz, alkali feldspars, mica/or amphibole. The mineralization appears to be due to late magmatic segregation of alkali igneous rocks. The phosphorus content varies between 8 - 23% P_2O_5 with the average value of 15.2% (Table.1).

Mumbwa 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-pegmatite bodies (30-35% P_2O_5) stretching along a major fault zone have been recently located.

Rufunsa rock deposits constitute pyroclastics and fragmental carbonatite occurring as plugs and layers. The carbonatite contains both apatite and pyrochlore. The phosphorus content is reported to be 3.1% P_2O_5.

Table 1. Chemical composition of Zambian phosphate rocks

Source	P_2O_5 Tot.	P_2O_5 Cit.Sol	CaO	SiO_2	Fe_2O_3+ Al_2O_3	MgO	MnO	Qty,Mln Mt
	Composition, weight %							
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	11.80	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	-	-	-	-	-	-	-*

* Unknown
(Source: MINEX & JICA, 1986).

4.3 Reserves and location

Kaluwe deposit is found 220 km east of Lusaka. It is 9km long and 1.2 to 2.4km wide and 244m thick. Recent exploration has indicated 200 million metric tonnes of low grade ore reserves.

Nkombwa Hill deposit is situated in North Eastern Zambia about 30 km east of Isoka off the great north road linking Zambia and Tanzania. The carbonatite plug forms a distinct hill, 300 m high, 1.5 km long and 1.25km wide. Reserves are estimated at 130 million metric tonnes of ore.

Chilembwe deposit in Eastern Province constitutes four ore bodies with dimensions varying from 5 500 m2 to a few hundred square metres surveyed to a depth of 45m. The total volume of proven reserves amounts to 1.64 million metric tonnes.

Mumbwa rock phosphate deposit is found to the west of Lusaka with unknown proven reserves.

Rufunsa rock deposit occurs in a group of four vents west of Luangwa river some 200km east of Lusaka. The phosphorus content is reported to be 3.10% P_2O_5 and the deposit is of no economic importance.

5. SOILS AND THEIR CHARACTERISTICS

As in other tropical regions of the world, soils in the high rainfall areas of Zambia are predominantly Oxisols, Ultisols, and Alfisols and are characterized by having low pH and high levels of iron and aluminum oxides. These soils have good physical properties and generally are well suited for agriculture. A survey of the soils in the region indicated widespread inherent phosphorus deficiency (generally in the range of 3-12ppm, Bray 1) and low to high P sorption capacities in the effective rooting zone (Fig.4). Selected soil chemical characteristics of the soils tested for PR use are presented in Table 2. Field experiments were conducted between 1984 and 1990 on two locations: at Misamfu Research Station in Kasama (31^{O}E, 10^{O}S) and at Lucheche Research Station and Katito farm in Mbala (31^{O}E, 8.6^{O}S) on three representative soil series belonging to Misamfu (sandy loam isohyperthermic Oxic Paleustult) and Mufulira (fine isohyperthermic Typic Kandiustult) in Kasama and Konkola (fine isohyperthermic Rhodic Paleustult). The elevation above mean sea level for all sites is about 1800m with a unimodal annual rainfall of 1200-1500 mm. Vegetation is a miombo woodland savannah.

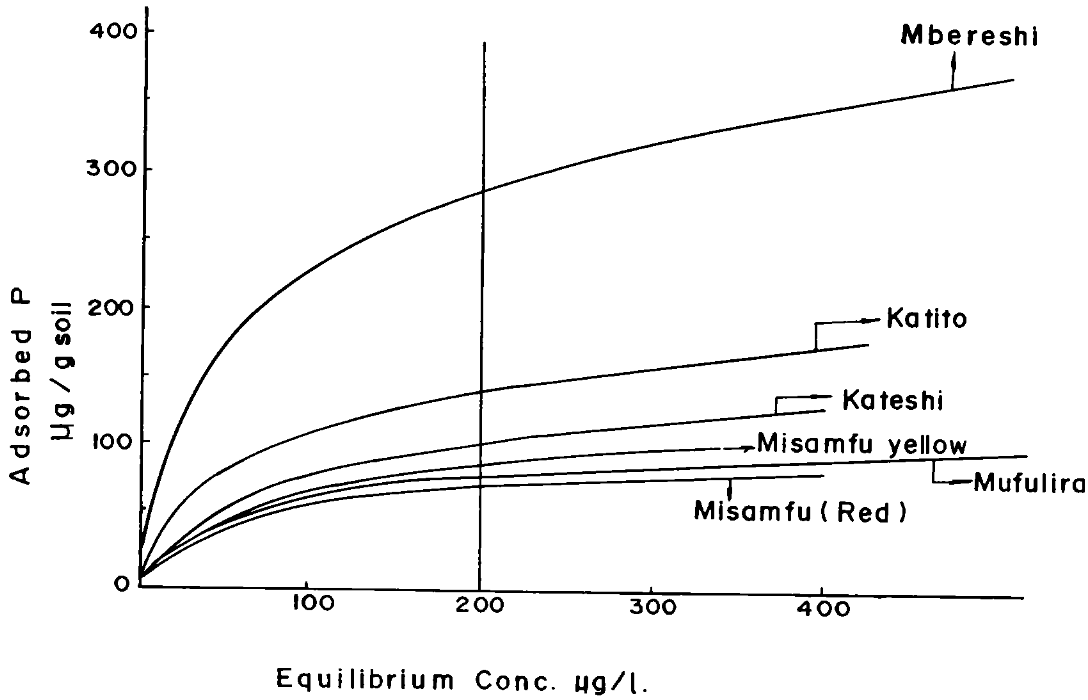


Fig. 4 Phosphorus sorption isotherms at low phosphorus concentrations for some selected soils.

(M. Guldberg, 1987)

Table 2.-Major characteristics of the soils used in the experimentation

Soil series / Horizon	Soil depth cm	% Sand	% Clay	pH		% Org. C	% Total N	Exch. Cations. m.e. /100 g.				ECEC	Avail. P	% Al^{3+}
				H_2O	$CaCl_2$			Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	Al^{3+} + Bases	(ppm)	Sat.
Mufulira SCL														
A	0-10	73	17	5.1	4.3	0.7	0.05	0.8	0.2	0.4	0.2	1.6	5	50
AB	10-20	60	29	5.1	4.2	0.6	0.04	1.1	0-	0.3	0.3	1.7		65
Misamfu SL														
A	0-10	78	18	5.9	4.9	1.5	-	TR	1.3	1.3	0.2	2.8	10	-
AB	10-21	78	19	5.2	4.2	0.8	-	1.1	-	0.2	0.1	1.4		79
Konkola CL														
A	0-11	52	21	-	4.5	2.5	0.13	1.2	0.8	0.7	0.14	2.8	4	39
AB	11-40	40	34	-	4.2	1.2	0.07	1.7	0.1	0.2	0.06	2.0	2	76

(Source: SPRP Annual Report 1986)

6. AGRONOMIC EVALUATION

6.1 Direct application of phosphate rock

The effectiveness of phosphate rock applied directly relative to soluble P fertilizers will vary from source to source depending upon the mineralogy and chemistry of each rock as well as the influence of soil, crop, environment and management factors.

When a sedimentary indigenous rock of suitable quality and reactivity is available, the use of ground phosphate rock was reported to be potentially more economic than chemically processed phosphate fertilizers on the grounds of reduced processing and transportation costs (Horn, 1977). On the other hand, it is well known that igneous phosphate rocks are not good sources of phosphorus for direct application as compared to sedimentary ones.

6.1.1 Processing of phosphate rock

Production of ground rock phosphate (PR) for direct application is a simple and cheap process which can be done locally. The ore samples for the production of PR were taken from **Chilembwe** and **Mumbwa North** deposits both of which are igneous and are associated with syenites. Apart from physical alteration of the ores, the chemical composition of the end product after grinding remains unaltered.

These samples were submitted once to a cone crusher to achieve the following fineness (Table 3):

Table 3. 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)

After achieving such fineness, the samples were bagged for agronomic evaluation.

6.1.2 Agronomic evaluation

In order to assess the inherent capability of the P containing rock to supply plant available P under a specified set of conditions, agronomic evaluation of several phosphate rocks with more than 15% of total P_2O_5 was carried out in different soils and with different crops. The main objective of this study was to assess if any of these PRs could be suitable for direct application in the highly acidic soils of Northern Zambia. A one year pot study (1980) to compare directly the efficiency of **Chilembwe phosphate rock (CPR)**, Gafsa **PR** and **Chilembwe SAB-PAPR** as sources of phosphorus to plants was condùcted at Mount Makulu

Central Research Station. **Chilembwe PR** was tested between 1984 and 1986 for agronomic effectiveness with TSP standard and TSP plus lime on Mufulira, Misamfu and Konlola soil series with maize (Zea mays), groundnuts (Arachis hypogaea), sunflower (Helianthus annuus), common beans (Phaseolus vulgaris), and soybeans (Glycine max. L. Merr) as test crops. On Katito soil series Chilembwe PR was tested with SSP as standard and with wheat (Triticum aestivum) as test crop. Between 1987 and 1990 **Mumbwa PR** was evaluated with TSP as a standard P source on Mufulira and Konkola soil series. Test crops were maize, fingermillet, groundnuts, and beans.

There was no significant ($p = 0.05$) response to P applied through Chilembwe PR in any of the soil series or the experimental sites (Figs 5&6). From investigations carried out between 1984 and 1986, it was found that direct applications of Chilembwe PR to all the test crops was generally ineffective as a P source. This finding was further confirmed in 1987 to 1989 cropping seasons when Mumbwa PR was employed. Despite three years of applications, Mumbwa PR was found to be an ineffective P source for the plants. In pot experiments Chilembwe PR demonstrated some positive response only on Misamfu soil series being 55% as efficient as TSP (Munyinda, 1987) but on other soils it was much inferior to all other forms of P.

From both greenhouse and field experiments conducted, it is, therefore, concluded that Chilembwe and Mumbwa PRs are inferior to highly reactive Gafsa PR, PAPR, and readily soluble forms of P

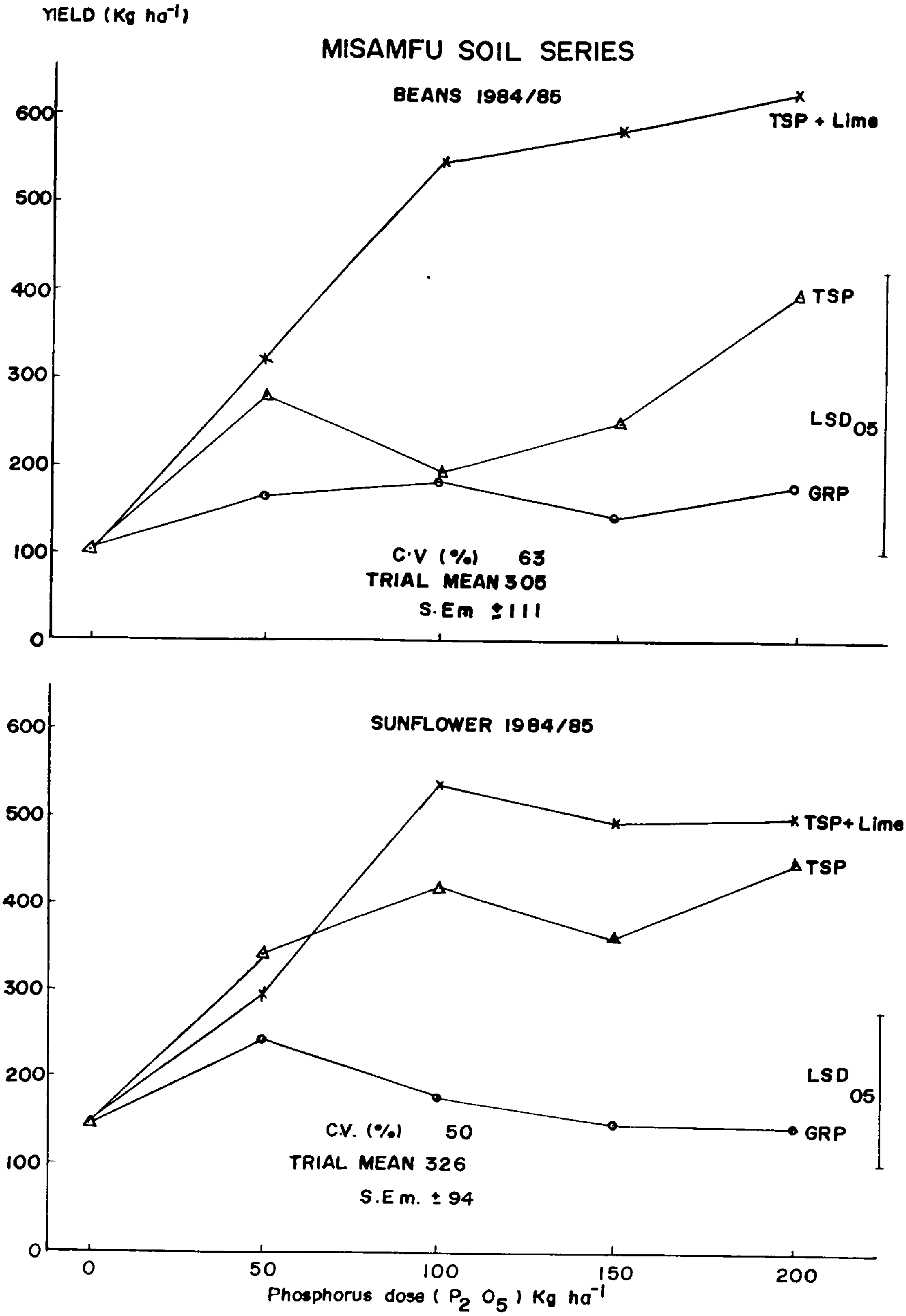


Figure 5 — Comparison of response of beans and sunflower to P applied through GRP with that through TSP with and without lime

(Source: S P R P Annual Report 1986)

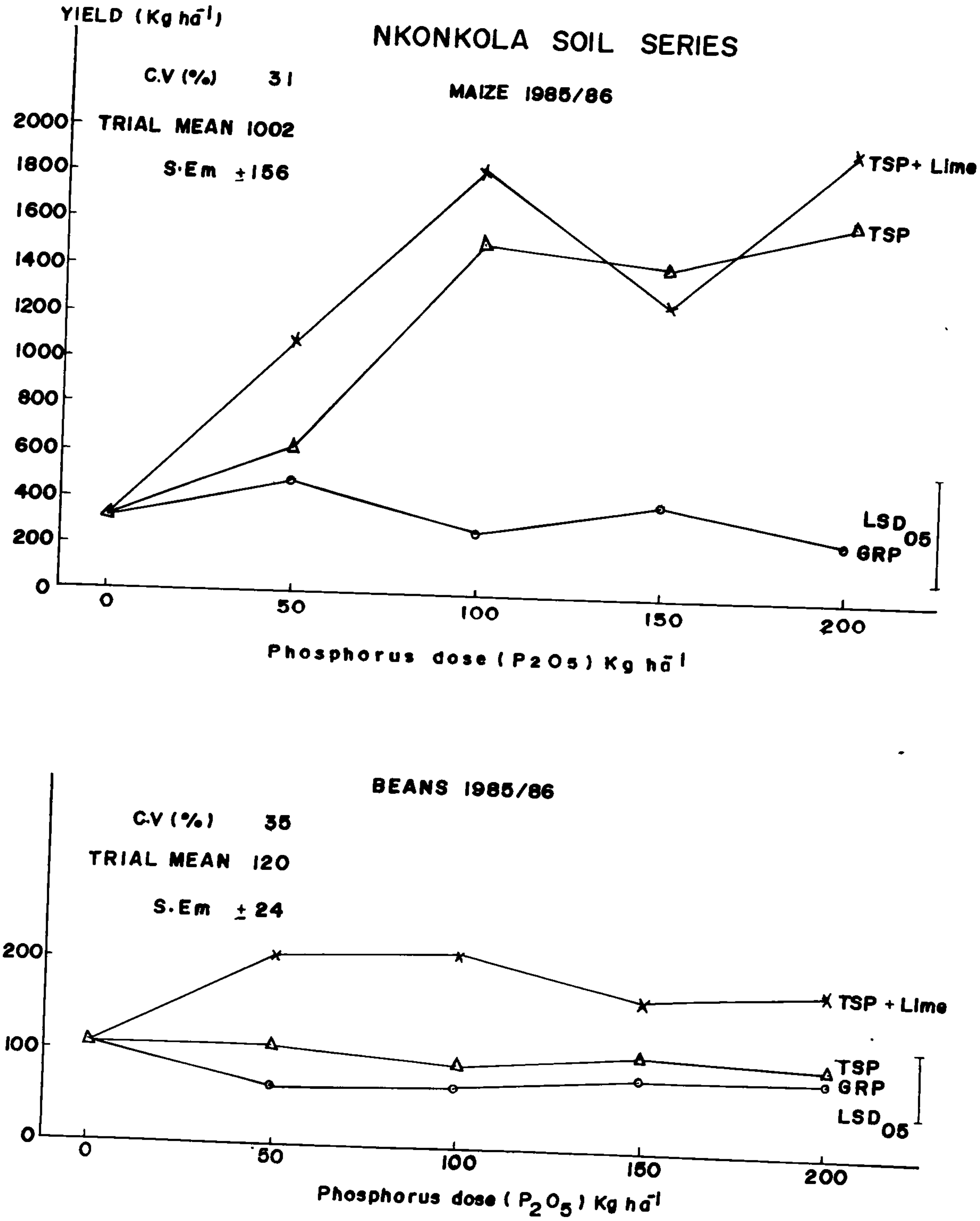


Figure 6 - Comparison of response of maize and beans to P applied through GRP with that through TSP with and without lime.

(Source: SPRP Annual Report 1986)

and that these materials are not an effective source of P for the whole range of annual short duration crops tested.

The poor performance of Chilembwe and Mumbwa PRs could be attributed to their very low citrate soluble phosphorus content (1.3% and 1.0% P_2O_5 respectively) and to their igneous parent material (Mapiki and Singh, 1986; Munyinda, 1987).

6.2 Partially acidulated phosphate rock (PAPR)

Partial and/or complete acidulation of phosphate rocks (PR) represents an alternative means of producing agronomically effective P fertilizers from indigenous PR resources which may otherwise be unsuited for use as a fertilizer. Acidulation and beneficiation of indigenous phosphate rock with indigenously available sulphuric acid may be a feasible process in Zambia as the country has large quantities of sulphuric acid, a by-product from the copper mining industry.

According to Chien & Hammond (1988), the main advantages of partially acidulated phosphate rocks (PAPR) are:

1). In agronomic terms, unlike superphosphates, PAPR can provide a portion of the phosphorus in a readily plant-available form and the remainder in a form that should enhance residual value;

2). The PAPR increases the concentrations of phosphorus above that of the unacidulated PR;

3). When sulphuric acid is used in the acidulation process, sulphur (S) is included in quantities appropriate for many nutritional demands and especially so on sulphur deficient soils;

4). The quantity of acid required is reduced and therefore the cost of raw materials, such as sulphuric acid, for PAPR production will be less than that when producing TSP or SSP;

5). Phosphate rocks that are unsuited chemically to produce superphosphates can be used for production of PAPR;

6). PAPR products have better physical and chemical properties than superphosphates for bulk blending with urea.

6.2.1 Production and characteristics of PAPR

Commonly, PAPRs have been manufactured by reacting with a phosphate rock, less than the stoichiometric amount of sulphuric or phosphoric acid required to produce SSP or TSP respectively (Harrison & Hedley, 1987). The commercial production of sulphuric acid-based PAPR-50 (SAB-PAPR-50) and single superphosphate (SSP) is that of run-of-pile (ROP) process. In some cases, according to

Chien and Hammond (1988), both the products may be manufactured in the same plant. The steps for production of conventional SSP are acidulation, denning (15-60 minutes), curing for a suitable length of time (a few weeks), granulating and drying before bagging. A continuous process using a single step for acidulation and granulation in the drum or pug mill-type granulator has been recently developed by IFDC for the production of **PAPR**. The liquid added during the granulation acts as the acidulation medium and prevents precipitation of part of the gypsum on the surface of the unreacted PR, thereby allowing the reaction to proceed towards complete utilization of the acid. In this process a closely sized, durable and nondusty granular (-3.35 + 1.18mm or-6 + 14mesh) product resembling granular SSP or TSP is produced in a single step without curing. After beneficiation the PAPR so produced contains 20.5% total and 20.0% citrate soluble P_2O_5.

6.2.2 Agronomic evaluation

SAB-PAPR-50 and Mumbwa PR were tested for their agronomic effectiveness with TSP as standard P source on Mufulira and Konkola soil series. Test crops were maize (Zea mays), fingermillet (Elysine coricana), groundnuts (Arachis hypogaea), and beans (Phaseolus vulgaris).

On Konkola soil series with fingermillet PAPR significantly ($p = 0.05$) outyielded Mumbwa PR at all P rates and TSP at P rates up to 20kg P ha^{-1} (Fig.7). On **Mufulira** soil series maize was monocropped for two seasons between 1987 and 1989. PAPR-50 was generally as agronomically effective as standard TSP. The relative agronomic effectiveness of PAPR was generally 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 there were no significant yield differences between PAPR-50 and standard TSP. The response to applied P through PAPR was linear with yields increasing with rates (Fig.8). On another site on **Mufulira soil** series fingermillet was rotated with ground nuts and beans in the third cropping season. Fingermillet respond positively to all forms of applied P. With groundnuts, there was no significant crop response to any of the P forms applied. Beans, however, was found to be responsive to applied P (1) once the PR was partially acidulated and (2) when soluble TSP was employed. There was a significant linear ($p = 0.05$) response to applied P through PAPR-50 and a highly significant ($p = 0.01$) crop response to P applied through standard TSP with yields increasing with P rates (Fig.9).

Konkola Soil Series

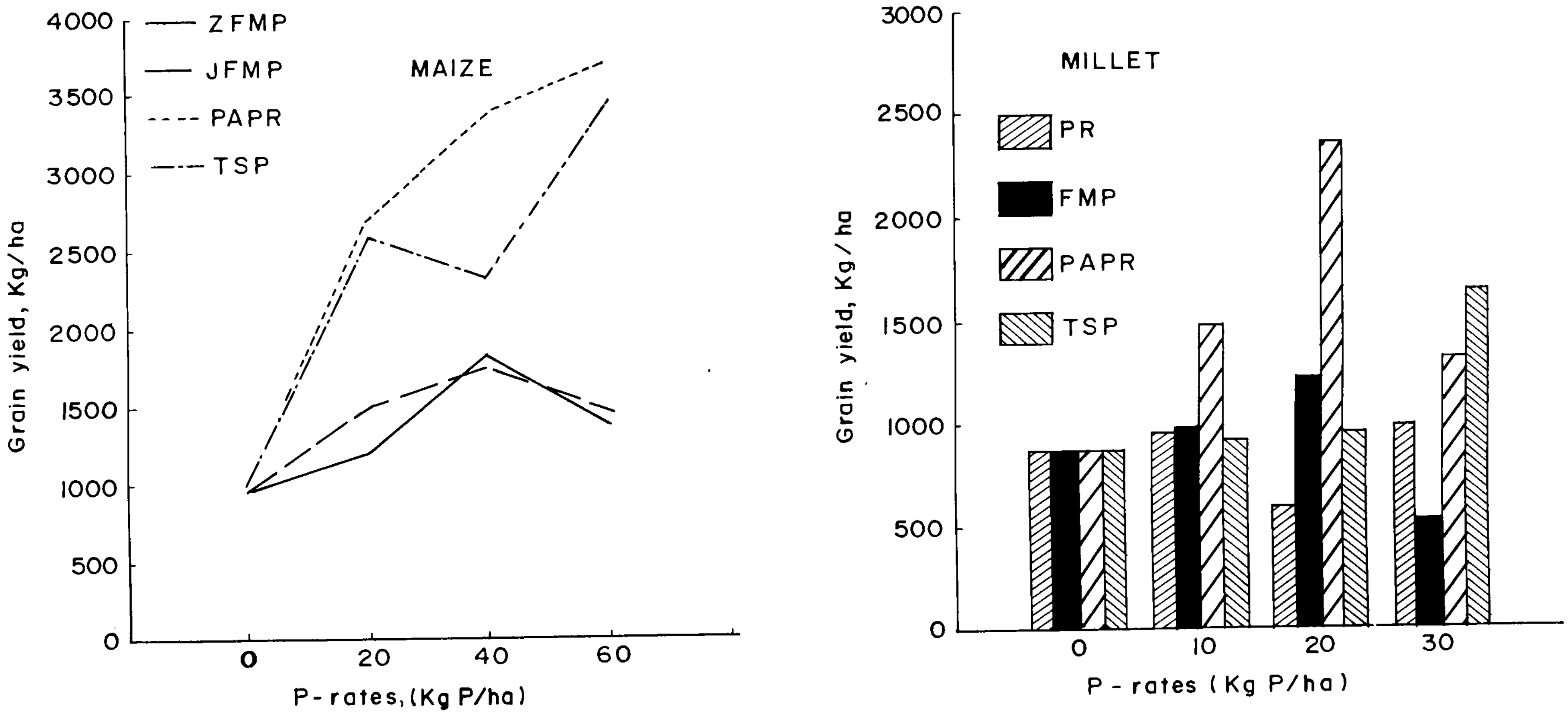


Fig. 7 Effect of PR,FMP,and PAPR on maize & millet yields.

(Source : SPRP Annual Report 1988)

Mufulira soil series

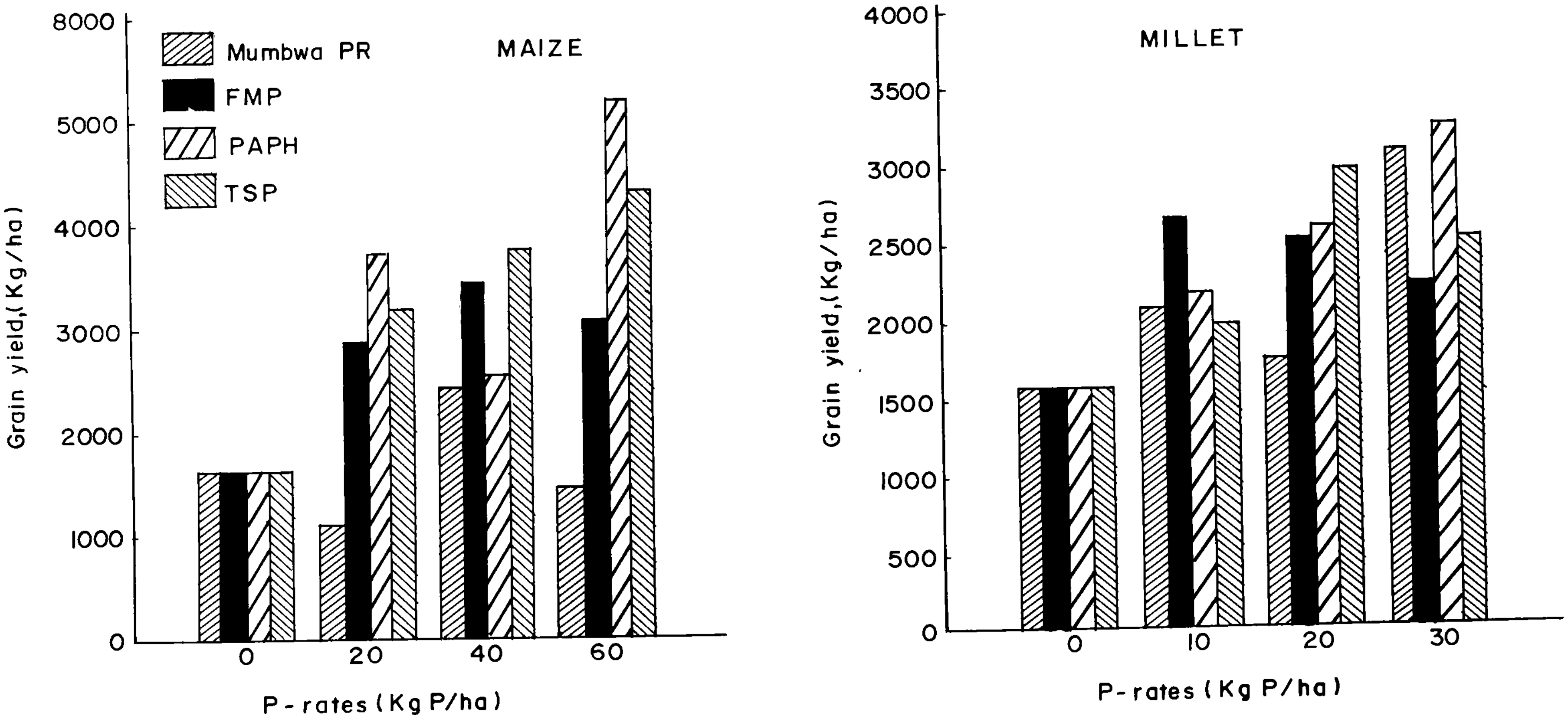


Fig. 8 Effect of PR,FMP, and PAPR on maize & millet yields.
(Source: SPRP Annual Report 1988)

6.3 Fused magnesium phosphate (FMP)

Fused magnesium phosphate (FMP) is a thermal phosphate produced under very high temperatures. Phosphate rock together with serpentine (a magnesium based rock) are subjected to extreme heat (1200^{o}C) to produce molten glass of these two products. Upon cooling the glass is broken and ground to fine grains. In Zambia there are huge deposits of phosphate rock as mentioned earlier. The serpentine deposit is located 400km north of Lusaka.

6.3.1 Characteristics of FMP

FMP has major part of its total P soluble in weak acids, e.g. in 2% citric acid. In addition to 9.5% total and 9.0 citrate soluble P, the other effective components of FMP are magnesium (8-11% MgO), calcium (28-35% CaO) and silica (18-24% SiO_2) and thus it is also an effective source of these elements which are deficient in most soils of Northern Zambia. Because it is fine grained glass it is very unpleasant during handling especially with bare hands. FMP holds promise if blended with K fertilizers and then compounding it with N fertilizers.

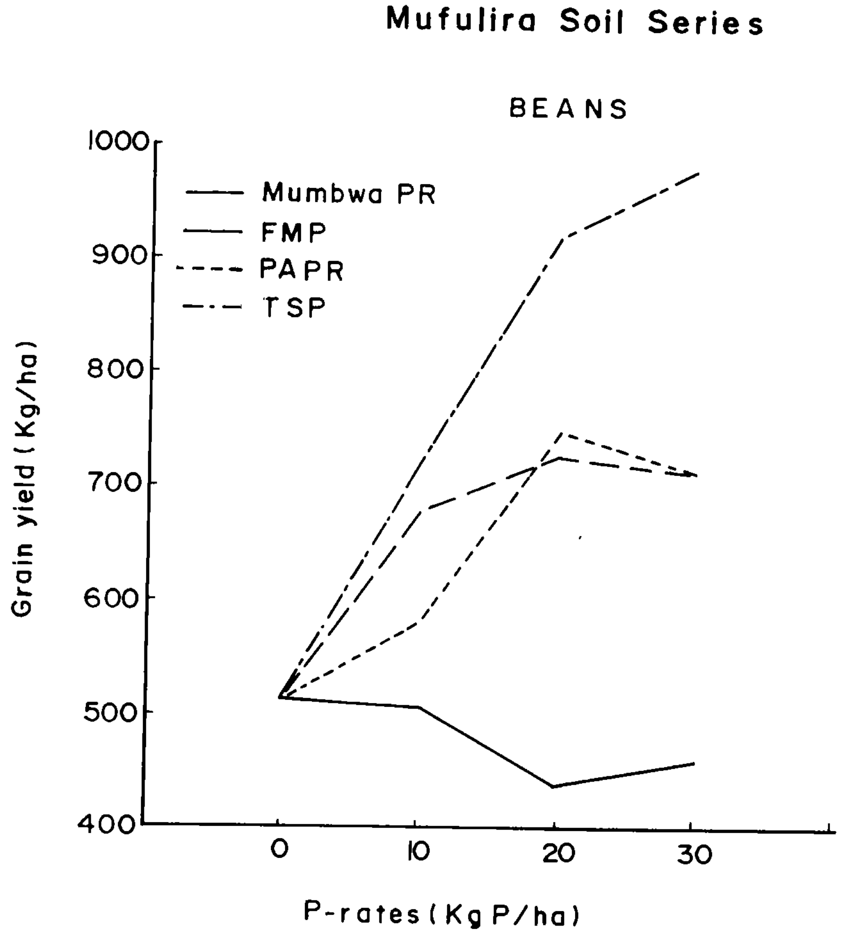


Fig. 9 Effect of PR, FMP, & PAPR on bean yield
(Source: SPRP 1990)

6.3.2 Agronomic evaluation of FMP

A series of field experiments were conducted between 1984 and 1986 on three soil series belonging to Misamfu and Mufulira soil series at Misamfu Research Station in Kasama, on Konkola soil series 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.

At Misamfu the test crops were maize and groundnuts grown in rotation on both soil series. On Misamfu soil series, there was no significant ($p = 0.05$) response to applied P in maize in all the cropping seasons. Comparatively, groundnuts were more responsive to P than maize and a response was recorded from the first season itself. While TSP gave responses only at 50 kg P_2O_5 ha^{-1} and above, FMP gave responses at 100 and 200kg P_2O_5 ha^{-1} (Fig.10). On Mufulira soil series, significant ($p = 0.05$) responses of groundnuts to applied P through TSP or FMP were obtained at 100kg P_2O_5 ha^{-1}. With maize, significant ($p = 0.05$) responses were recorded for both the P sources at 50kg P_2O_5 ha^{-1} (Fig.11). For both the test crops grown on Mufulira soil series, it is evident that P fertilization and perhaps not liming was important and that FMP was as effective source of P as TSP.

On Konkola soil series, a beans/maize rotation was used during direct applications of FMP and a maize-groundnut rotation for

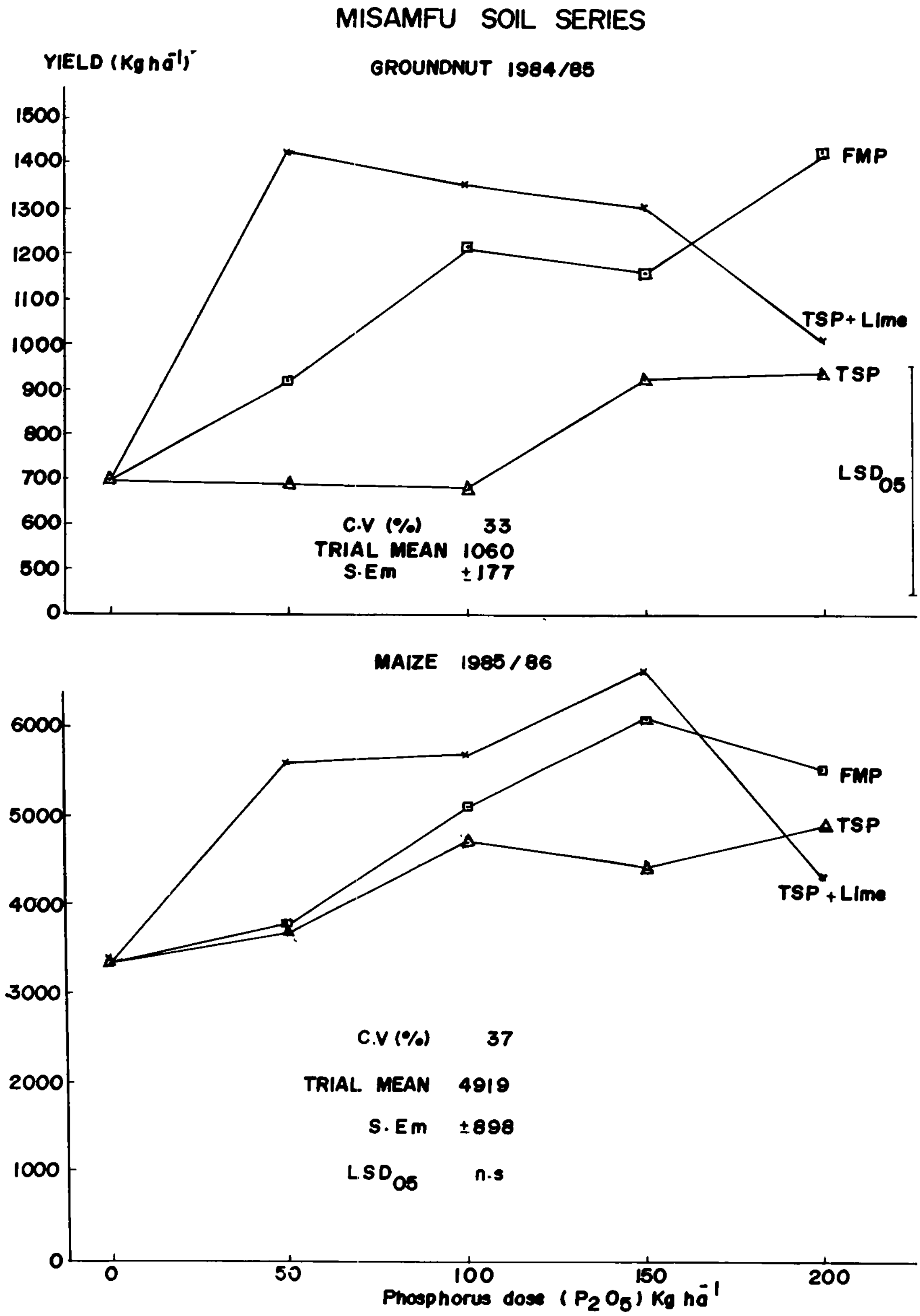


Figure 10 –Comparison of reponse of groundnut and maize to P applied through FMP with that through TSP with and without lime.

(Source: SPRP Annual Report 1986)

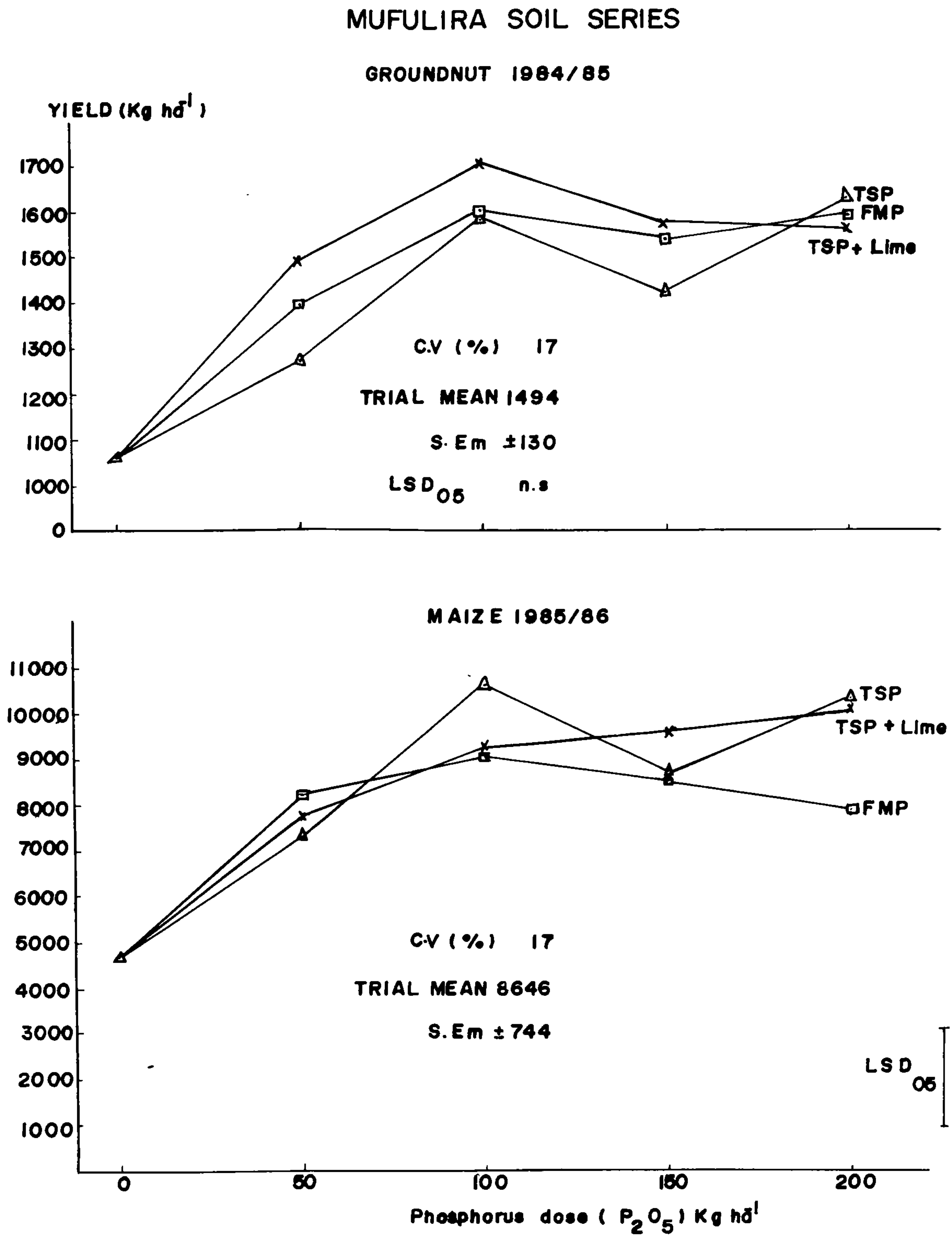


Figure 11 —Comparison of response of maize and groundnut to P applied through FMP with that through TSP with and without lime.
(Source: SPRP Annual Report, 1986)

residual FMP evaluations. Results for the maize-groundnut rotation only are presented. During direct application, liming was found not to be important. Significant ($p = 0.05$) maize responses were obtained with only 50kg P_2O_5 ha^{-1} when applied through FMP, whereas with beans both lime and P were important with significant ($p = 0.05$) yield responses at 100 and 150kg P_2O_5 ha^{-1} TSP plus lime and FMP respectively (Fig.12). Maize responded significantly ($p = 0.05$) to the residual effects of the different P sources. The yields increased steadily with increasing rate of P application up to 100 and 150kg P_2O_5 ha^{-1} in case of TSP and FMP respectively. TSP plus lime treatment was however superior to either FMP or TSP at the same or higher rates. Groundnuts responded significantly ($p = 0.05$) to residual P from any of the sources (Fig.13) with yields generally higher in P treated plots than in the control.

On Katito soil series, FMP was tested with SSP with wheat as the test crop. There was a significant ($p = 0.05$) linear response 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 Report, 1987).

These results suggest that FMP is as effective a source of plant available P as TSP. Often FMP gave higher yields in all test crops compared to TSP without lime. This suggests that FMP in addition to phosphorus also possesses some liming value.

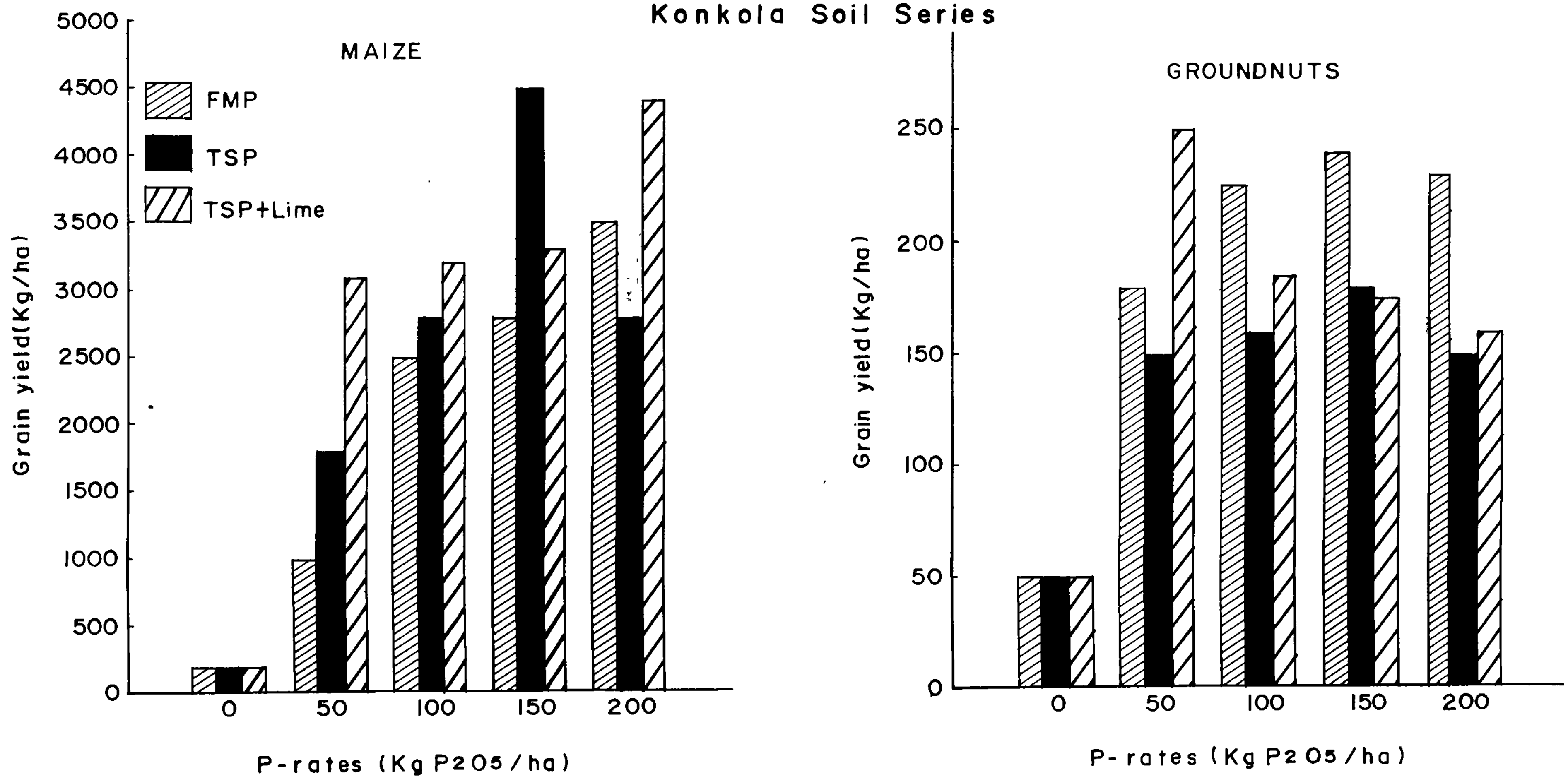
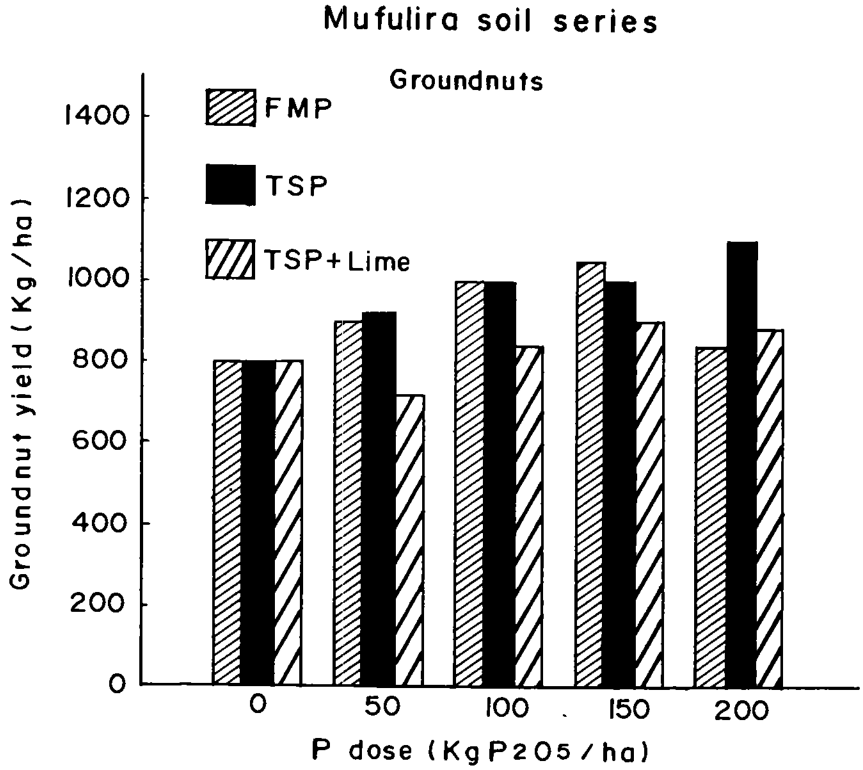


Fig.12 Effect of FMP on maize and groundnut yields.

(Source SPRP Annual Report 1986)



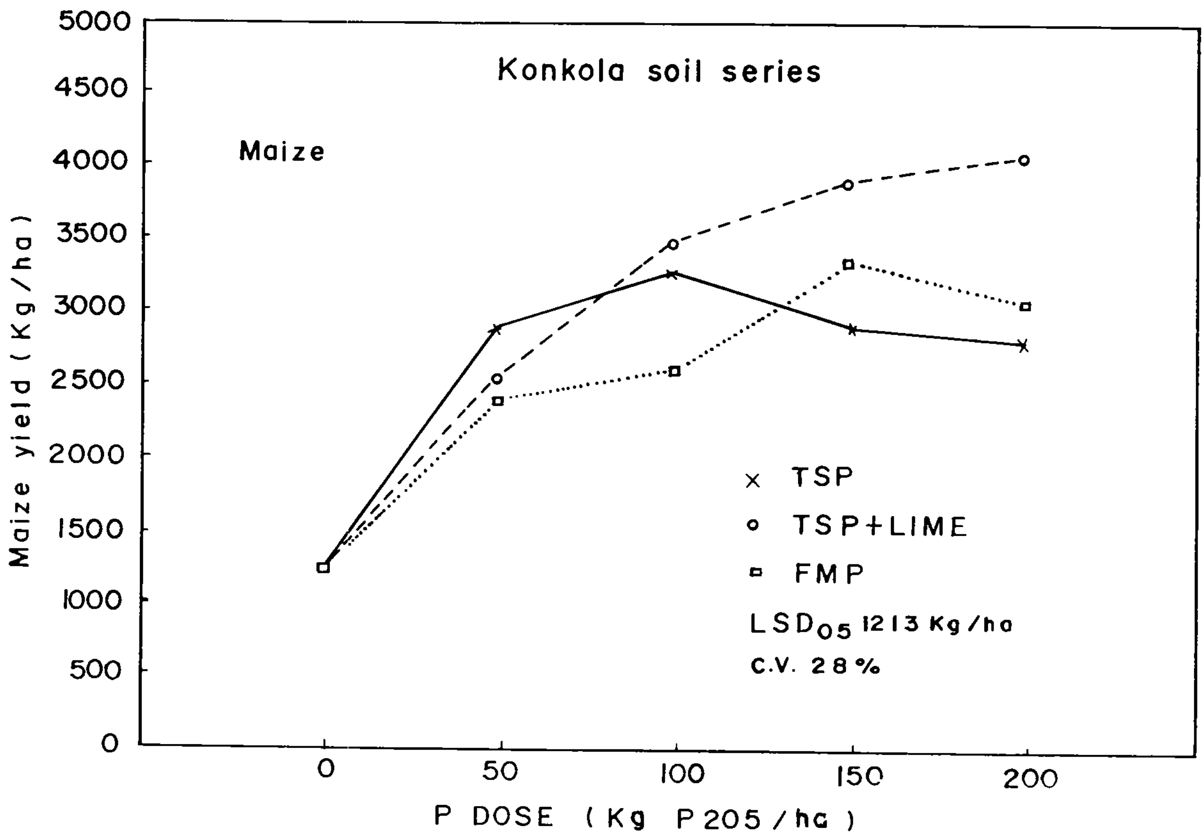


Fig. 13 Residual effect of FMP and TSP on groundnut and Maize yields.
(Source: SPRP Annual Report 1987)

7. RELATIVE AGRONOMIC EFFECTIVENESS OF THE TESTED P SOURCES

To compare the relative agronomic effectiveness (RAE) of the different PR sources and TSP or SSP on different soils,RAE was calculated. The RAE was defined as the crop yield response ratio of studied P source minus that of the check relative to the standard P source minus that of the check expressed in percent, i.e.,

$$RAE\ (\%) = \frac{\text{Yield of P source} - \text{Yield of Check}}{\text{Yield of P Standard} - \text{Yield of Check}} \times 100$$

This expression is similar to that proposed by Hammond L.L., et al.(1989); Leon et al. (1986); Munyinda (1987); and Sanchez (1982) to compare the relative agronomic effectiveness of different sources of P.

7.1. Chilembwe and Mumbwa PR

Chilembwe PR showed potential to replace TSP in Misamfu soil series with beans being 55% as efficient as TSP. It was however, ineffective on Konkola soil series with the same test crop. When assessed on Katito soil series with SSP and wheat as a test crop, Chilembwe PR was again inferior (RAE values of 6 and 9%) and hardly any crop response was observed (Table.6). Similarly, Mumbwa PR was also found to be generally ineffective and it only showed some potential on Mufulira soil series for one season when its efficiency was 39% at 40kg P ha^{-1} with maize (Table.4).

Table 4. Relative agronomic effectiveness of different P-sources on Mufulira Soil Series.

	Maize 1987/88			Maize 1988/89				Beans 1989/90			
	Rate of application (kg P ha^{-1})										
	20	40	60	20	40	60	Mean	10	20	30	Mean
	-relative agronomic effectiveness (%)-										
TSP	100	100	100	100	100	100	100	100	100	100	100
PAPR-50	134	43	168	60	78	85	95	33	59	43	45
FMP	80	85	54	125	74	84	84	79	53	43	58
MPR *	-	39	-	-	-	-	7	-	-	-	-

	Maize 1985/86					Groundnuts 1984/85				
	Rate of application (kg P_2O_5 ha^{-1})									
	50	100	150	200	Mean	50	100	150	200	Mean
	-relative agronomic effectiveness (%)-									
TSP	100	100	100	100	100	100	100	100	100	100
TSP+Lime	112	75	126	96	102	191	133	147	83	138
FMP	138	71	97	61	92	148	112	139	92	123

*MPR - Mumbwa PR.

7.2. Chilembwe PAPR-50

The pot study revealed that partially acidulated Chilembwe PR increased its efficiency in Konkola and Misamfu soil series being 97% and 72% as effective as TSP respectively. Field experiments with maize on Mufulira and Konkola soil series showed that PAPR was agronomically superior to PR and that its mean relative agronomic effectiveness was 95 and 131% respectively of that of standard TSP. It was, however, less effective with beans being only 45% as effective as TSP but these results are only for one year. These results suggest that PAPR performed better in the soil with relatively high P retention capacity (e.g. Konkola soil series) and that it was even better than TSP. Similar observations were made by Chien and Hammond (1989) who found PAPR more effective than TSP in soils with high P-fixing capacities.

7.3. Japanese FMP and Chilembwe FMP

On Mufulira soil series with maize as the test crop. The relative agronomic effectiveness of FMP of Japanese origin was found to be 84 and 92% as effective as, TSP whereas TSP plus lime was 2% more effective than TSP alone. On Konkola soil series with the same crop, this form of FMP behaved in different patterns. While its efficiency in 1984/85 season was only 80% to that of TSP, in the following year the efficiency surpassed that of standard TSP by 3% and in the third year it dropped to 37%. On Katito soil series it was 97% as efficient as SSP. This leads to the conclusion that FMP is agronomically as suitable as soluble TSP

Table 5. Agronomic effectiveness of different P sources on Konkola Soil Series.

	Maize crop 1984/85					Maize Crop 1985/86				
	Rate of application (kg P_2O_5 ha^{-1})									
	50	100	150	200	Mean	50	100	150	200	Mean
	-relative agronomic effectiveness (%)-									
TSP	100	100	100	100	100	100	100	100	100	100
TSP+Lime	189	128	81	152	137	88	112	175	200	144
FMP	56	85	63	115	80	88	68	131	127	103

Table 6. Relative agronomic effectiveness of different P-sources on Konkola and Katito Soil Series

	Konkola Maize 1987/88					Katito Wheat 1986/87				
	Rate of application (kg P ha^{-1})									
	20	40	60	Mean		22	44	88	176	Mean
	-relative agronomic effectiveness (%)-									
TSP	100	100	100	100	SSP	100	100	100	100	100
ZFMP	15	63	17	32	FMP	72	178	88	48	97
JFMP	33	58	20	37	CPR *	-	-	6	9	4

* CPR - Chilembwe PR
ZFMP - Chilembwe FMP
JFMP - Japanese FMP

and/or SSP. Agronomic effectiveness of Chilembwe FMP was similar to that of FMP of Japanese origin on maize yield (Table.6) leading us to believe that the quality of phosphate rock from Chilembwe was equally as good as the Japanese for the manufacture of thermal phosphates like FMP.

8. FUTURE PROSPECTS AND RESEARCH NEEDS

8.1 Potentials and reserves

Of the five proven phosphate rock reserves in Zambia, Chilembwe and Mumbwa hold promise for their exploitation in producing PAPR or SSP for agricultural use. Proven reserves of Chilembwe PR (15% P_2O_5 amount to 1.64 million tonnes giving about 246 000 tonnes of P_2O_5 when beneficiated to produce SSP or PAPR. The life span for this deposit is estimated to be 30 years at an annual consumption rate of 8 000 tonnes of P205 in the high rainfall areas. The value of 8.000 tonnes of P205 is arrived at by taking the P205 consumption in 1987 for the whole country as basis and assuming that about one third of the whole consumption took place in the high rainfall areas. The total consumption of P205 in 1987 was calculated to be about 24.000 tonnes (calculated on the basis of fertilizer consumption data from NAM BOARD, 1988). With the exploitation of the Mumbwa deposit, the reserves may extend beyond 30 years.

With sulphuric acid in abundance from the copper mining industry, all raw materials in the production of PAPR and/or SSP could be locally available, saving scarce foreign currency which is used at present for the importation of fertilizers.

8.2 Research Needs

Evaluation of product alternatives of PR, such as PAPR and SSP should be expanded to more experimental sites on different soils and in different agroecological zones. Presently research on PAPR is confined mainly to Northern Province. In future it is intended to carry out such trials across the whole high rainfall area encompassing Region III.

Mumbwa PR has higher total phosphorus content (30%) than Chilembwe (15%) and this could also be acidulated to produce PAPR and tested for agronomic effectiveness.

From research carried out so far, PAPR holds promise and validation through tests on farmers' fields should run concurrently with on-station evaluation. With the acquisition of more PAPR, this programme could start in the next cropping season.

More research on phosphorus behaviour in the soil should be carried out. P-retention and release, and the role of organic matter in the soil for P-availability should be closely studied.

The residual effect of PR has not been positive and there is need to investigate this with PAPR as it is known to be a slow-release fertilizer.

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