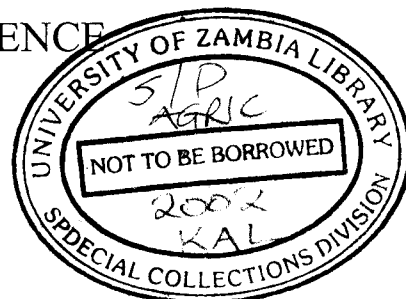
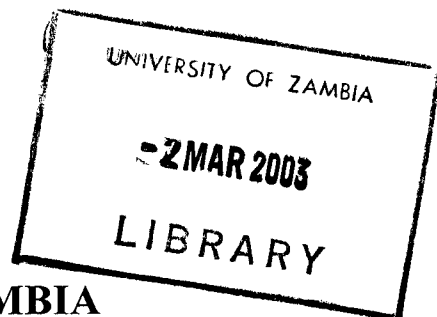




**THE UNIVERSITY OF ZAMBIA
SCHOOL OF AGRICULTURAL SCIENCES**

DEPARTMENT OF CROP SCIENCE



**RELATION OF AMOUNTS AND FORMS OF P TO MAIZE (*zea mays*)
YIELDS FOLLOWING PAPER APPLICATION.**

By

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**A Thesis submitted to the School of
Agricultural Sciences in Partial Fulfillment of the Requirements for
the Degree of Bachelor of Agricultural Sciences**

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Abstract

The study was part of an on going experiment on the evaluation of PAPR on a number of crops including maize. The part of this study was to determine the amounts and forms of P related to maize yield response.

The trials were carried out on five benchmarks soil types in Central, Lusaka and Southern Provinces of Zambia. During the first cropping season (2000/2001), On-Farm and On-Station trials were conducted in agro-ecological Regions I and II. There were three On-Farm trials (GART in Chisamba, Chibwe in Kabwe and Mwanachingwala in Magoye) and three On-Station trials (Kafuku Farm Institute in Mkushi, UNZA Farm and Magoye CDT). PAPR was compared with MAP as a source of P for maize production. Treatment rates were 0, 60 and 120 kg P₂O₅ ha⁻¹ and 0, 40, 80, 120, 160 and 200 kg P₂O₅ ha⁻¹ for On-Farm and On-Station trials respectively. Absolute Zeros were added in the second year to evaluate the natural soil fertility compared to the added nutrients.

The available forms and amounts of P were determined by Bray I and the Pi soil tests from the first season's soil samples. Results of the soil tests from 0 – 15 cm and 15 – 30 cm were regressed on maize yield. For GART, only P by Bray 1, in the 0 – 15 cm (surface layer) was significantly (P 0.05) related to the maize yield. At Mwanachingwala and UNZA Farm, maize yield was responding to additional P in the 15-30 cm soil horizon The increase in maize yield response verified the low initial soil P at the above sites. At Kafuku Farm Institute, the response was to higher rates of fresh and residual application of P which maintained a higher soil solution P concentration resulting in significant increase in yield response. At all sites except Kabwe, there was response to both fresh and residual application of both sources of P. The fresh application of PAPR was more effective than MAP at Mwanachingwala. The residual effect of PAPR and MAP was similar at all sites except UNZA Farm where the residual effect was more for PAPR than MAP.

This study indicates that the available forms of P at the experimental sites for maize uptake were only $\text{H}_2\text{PO}_4^{-1}$, HPO_4^{-2} . This is deduced from the soil pH and Bray 1 determination and verified by the Pi test.

Other nutrients other than P (N,K,S) were limiting for all sites and the extent varied from site to site. The effect of lime application was dependent upon site. Liming increased maize yields where exchangeable aluminum was high and at sites where Ca was deficient. Depression of maize yields was observed where there was a probable imbalance of Ca/Mg cations for normal plant growth.

Dedication

To my Father, Mr. Jack Francis Kalipenta.

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I would like to sincerely thank my supervisor Dr. K. Munyinda for actually putting himself in my position all the times and providing me with all the help and encouragement he could possibly give.

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CHAPTER ONE

• Introduction

Phosphorus is taken up from soil by plants and unless the soil contains adequate phosphorus or it is supplied to the soil from external sources, plant growth will be restricted. Phosphorus is one of the three major nutrients required for plant growth. It is important for shoot and root growth, blossoming and flower production. Deficiencies in phosphorus ultimately affect the yield of the crop. Phosphorus deficiency arises not only from the inherent low levels of the nutrient in the soil, but also from the high capacity of the soils to render insoluble any applied soluble phosphate fertilizer through its reaction with soil components such as clay and sesquioxides (hydrous oxides of iron and aluminum (Lungu and Munyinda, 2001).

Phosphorus deficiency is widely considered the main biophysical constraint to food production in large areas of farmland in sub-humid and semiarid Africa phosphorus dynamics in soils are complex, because they involve both chemical and biological processes and the long-term effects of sorption (fixation) and desorption (release) processes. The low concentration, low solubility and also the high capacity of the soils to render insoluble any applied soluble phosphate fertilizer frequently make phosphorus a limiting growth factor.

There can be long lasting benefits from residual phosphorus, the duration and magnitude of which depend largely on the rate of initial applications, crop removal and the buffering capacity of soil for phosphorus. The performance of initial applications of phosphorus cannot be fully assessed from one or two consecutive crops. On both acidic and basic soils, substantial benefits from residual phosphorus can persist for as long as 5 to 10 years or more. The duration of response will, of course, be influenced by the amount of residual phosphorus.

Zambia is spending a lot of foreign exchange on importation of raw materials required for the production of phosphate fertilizers. As a result, commercially produced water-soluble phosphate is very expensive for the ordinary peasant farmer. If crop yields are going to be improved, it is necessary to look at alternative cheaper

source of phosphorus where phosphorus appears to be a major limiting nutrient to obtain good yields.

Phosphate Rock (P.R) could be an alternative to expensive fertilizers in supplying phosphorus to the crop. Zambia has about five phosphate rock deposits. These are found in Kaluwe, Mumbwa, Rufunsa, Chilembwe and Nkombwa. It therefore has the potential to partly substitute some of the imported expensive phosphate fertilizers with cheaper local products. One of the potential products is Partially Acidulated Phosphate Rock (PAPR). This is produced by treating ground phosphate rock with less acid than is required to completely dissolve all the phosphorus in the phosphate rock. Through this process of partial acidulation of the rock, phosphorus is made more available to the plants than it normally is when the phosphate rock is ground and applied directly to the field as ground phosphate rock. It is also less expensive to prepare than the imported water soluble phosphate fertilizers. Moreover, most of the required raw materials are locally available i.e. phosphate rock and sulphuric acid.

At low pH values, phosphates are rendered less available because of the reaction of aluminium, thus decreasing the level of plant available phosphorus. If the soil pH is greatly increased by the addition of excessive amount of lime, phosphate availability will again be decreased because of precipitation as calcium or magnesium phosphates. A liming program should be planned so that the pH can be kept between 5.5 and 6.8 to 7.0 if maximum benefit is to be derived from the applied phosphate. Most farmers rely on soil test programs to rapidly provide them with a single number or index that shows the likelihood of an economic return from fertilizer phosphorus investment (Phiri and Damaseke, 1999). They assume that soil test values are accurate and have been derived from field calibration studies relating soil text phosphorus to crop yield response. Farmers also use phosphorus soil testing to monitor the quantity of available phosphorus present overtime for evaluating efficiency of their fertility management (Sims, 1993).

An ideal soil test should predict the nutrient response of a wide variety of crops but, at the same time, be independent of the chemical and mineralogical properties of the soil. In all of the soil tests in use except for the onion exchange resin and water

extraction methods, phosphorus is removed by using extracting solutions. These solutions not only dissolve some phosphorus available for plant use but may also dissolve some phosphorus that is not available. Besides, these methods were developed to measure phosphorus from soil having specific characteristics. Thus a new approach to testing for soil phosphorus is needed i.e. The Pi test.

Problem Statement

Most of the soils are low in P and the cost of P application is high in Zambia limiting crop production.

The objectives of this study were:

- (i) To relate soil P to maize yield
- (ii) To determine the forms and amounts of phosphorus for crop Production.
- (iii) To evaluate the residual phosphorus and its effects on Crop Production.

CHAPTER TWO

- **Literature review**

Many soils are acutely deficient in phosphorus in sub-humid and semi arid Africa. Even though previously applied P may be less effective than freshly applied P, it nevertheless has value (Barrow, 1980). The duration of crop yield responses to P applications depends on the amount of P applied, the soil's P sorption, and cropping intensity. The larger the P application rate, the longer the residual effect. Low P-sorbing soils have shorter residual effects than high P- sorbing soils.

One index of measuring the residual value is the period over which an application remains adequate. It has been concluded that an application of P has a marked residual value (Kamprath, 1967) in later years. However, it is more informative to measure the current availability of a previous application. There is no way to measure an absolute value of availability (Black and Scott, 1956). All that can be done is to measure the availability relative to that of another fertilizer.

The current effect of a fertilizer may be compared with the original effect after adjustment for seasonal differences (Amdt and McIntyre, 1963). The same author compared the effectiveness of P fertilizer dressing rather than its availability – removal in agricultural produce. This will reduce the future effectiveness of the fertilizer dose, though it will not, of itself, reduce the availability coefficient of the P remaining.

If effectiveness is to be measured, the fertilizer must have a measurable effect – there must be a response. The response measured maybe in yield or in up take of P. Since the purpose of applying fertilizer is usually to increase yield, this is a better measure. It is implied in the measurement of relative effectiveness that freshly applied fertilizer can duplicate the effects of the previously applied fertilizer. It has been found that larger yields can be obtained from residues of previous fertilizer than from freshly applied (Mattingly, 1971). The ultimate measure of the residual value of a fertilizer is it's ability to help grow a desired product.

It is important to look at the soil phosphorus capital when looking at residual effects of phosphorus application. The stock of soil P that gradually supplies plant- available P to

crops for about 5 to 10 years is referred to as P capital (Sanchez and Palm, 1996). The goal of replenishing soil P is to increase capital P to a size that results in service flows sufficient for crop production without P Limitations for several years (Sanchez et al, 1997). The P available to crops within one season is referred to as liquid capital P (Baanante, 1998) and includes service flows, the flux of P from capital P, as well as a portion of the P added in the cropping season as mineral fertilizers i.e. inorganic fertilizers and organic materials.

Numerous studies in Africa have shown that P fertilizers including ground PR, modified PR products, an soluble sources, such as triple super phosphate (TSP) and single super phosphate (SSP) – can significantly increase crop yields

Relatively small seasonal applications of soluble P fertilizer can mitigate P deficiency in soils with low to moderate P- Sorption capacity; but larger rates of soluble P are required for soils with higher P- sorption capacity.

Partial acidulation of PR is an alternative use for indigenous PR that is too low in reactivity for direct application (Bolan et al., 1990; Rajan and Marwaha, 1993). The production of partially acidulated PR (PAPR) uses only a portion of the acid required for production of SSP and hence has a lower cost than SSP (Schultz, 1986). PAPR has been shown to be effective on sandy soils with low P Sorption in West Africa (Chien and Menon, 1995 a). The water-soluble P from PAPR presumably promotes early root growth following application of PAPR, thereby enabling more effective use of P from PR (Hammond et. al., 1986 b).

Results from agronomic trials in Zambia have shown the internal efficiency of P obtained from PAPR was found to be as effective as that of SSP. Published results appear to be consistent with the idea that the effectiveness of all soluble P fertilizers decreases with time in a similar manner so that high initial effectiveness is followed by a markedly decreased effectiveness.

Liming acid soils to pH 5.5 or 6.0 eliminates Al and Mn toxicity and supplies Ca (Sanchez and Uehara). These effects generally result in increases in plant growth and P uptake. When the changes in P- fixation capacity are measured, the effect of liming is found to

depend on soil properties. Liming has little or no influence in decreasing P fixation in soils with high pH values (ranging from 5.0 to 6.0) (Barrow, 1980). Liming to pH values near or above neutrality may increase rather than decrease P fixation because of the formulation of relatively insoluble phosphorus.

The supply of inorganic phosphorus to plants is usually estimated by extractive tests that measure the inorganic phosphorus in solution and an amount of labile inorganic phosphorus. Chemical extractants, however, do not consider the Kinetics of P sorption and desorption, which can strongly influence the supply of P to plants. Phosphorus sinks; such as resins and Fe- oxide impregnated Paper (Sharpley et al., 1994, Menon and Chien, 1995; Menon et. al; 1997) generally estimates P availability to plant roots more closely than do chemical extractants.

In order to understand the mechanism of extraction of P from the soil test, it is necessary to understand the P fractions in the soil. P in the soil is found in three fractions. The first fraction is the phosphate dissolved in soil solution. Plants take up P from this fraction. The second fraction is the labile phosphate, which is held on surfaces of clay minerals and is in rapid equilibrium with soil solution phosphate. The third fraction is the non-labile phosphate that is released only very slowly into the labile pool (Kirkbly and Mengel, 1987).

An ideal soil test should predict the nutrient response of a wide variety of crops but at the same time, be independent of the chemical and mineralogical properties of the soil (Menon, Chien and Hammond, 1989).

CHAPTER THREE

• **Materials and methods**

The study is part of an on-going experiment on the evaluation of Partially Acidulated Phosphate Rock (PAPR) on a number of crops including maize. The part of this study was to determine the amount and forms of soil P related to maize yield response and residual P.

The trials were carried out on five benchmark soil types in Central, Lusaka and Southern Provinces of Zambia. The benchmark soil types are indicated in Table 1 below. During the first year cropping season (2000/2001, On-Farm and On-Station trials were conducted in agro-ecological region II and I. There were three On-Farm trials (GART in Chisamba, Chibwe in Kabwe and Mwanachingwala in Mazabuka) and four On-Station trials (Mukonchi in Mkushi, UNZA Farm, Lusitu and Magoye, CDT).

WFB: FAO-ISRIC-ISSS. 1998 world Reference Base for soil Resources. World Soil Resources Report No.84. FAO, Rome.

The test crops included a cereal (maize, Sorghum), legume (Soybeans, Groundnuts and Cowpeas) and oil crop (Sunflower). The choice of cereal, legume and Sunflower depended on the importance and suitability of the crop in the locality. This study focused only on P evaluation on maize. PAPR was compared with MAP as sources of phosphate. PAPR was produced from the pilot plant at the School of Mines of the University of Zambia.

Table1: Soil Classification and surface (0 – 15cm) characteristics of the soil used in the study.

Trial Site	Region	Annual Rainfall (mm)	Soil Reaction pH	Available P ₂ O ₅ , Mg Kg ⁻¹	Soil Classification WRB/Soil Taxonomy
1.	II	800 – 1000	5.8	17.8	Haplic Lixisol/Typic Kandrust
2.	II	800 – 1000	4.7	24.0	Haplic Lixisols/Typic Kandustalfs
3.	II	800 – 1000	4.4	5.0	Haplic Lixisols/Kandic Paleustalfs
4.	II	800 – 1000	5.4	6.9	Haplic Lixisols/Typic Kandustalfs
5.	II	800 – 1000	4.0	6.0	Haplic Lixisols/Kandic Paleustalfs
6.	II	800 – 1000	4.3	3.0	Haplic Lixisols/Kandic Paleustalfs
7.	I	< 800	4.4	12.0	Chromic Luvisols/Rhodix Paleustalfs

The amount of acid added was 50% of the quantity required to completely react the phosphate rock to soluble super phosphate (Nkonde, Simukanga and Witika, 1991). The Chemical composition of PAPR and MAP is shown in Table 2 below. Fertilizer rates were 0, 60 and 120 P₂O₅ kg ha⁻¹ and 0, 40, 80, 120, 160 and 200 kg P₂O₅ ha⁻¹ for On-Farm and On-

Station respectively. All treatments received adequate amounts of K and S as recommended. In the first year, for On-Farm trials, where P was applied at 60 and 120 P₂O₅ kg ha⁻¹, the amount of N was applied at 120 and 200 kg N ha⁻¹ respectively. For On-Station, nitrogen was applied at 200 kg N ha⁻¹ for all treatments. In the second year for On-Station, N was applied as in the first year. For On-Farm, N was applied at 120 kg N ha⁻¹ for all treatments.

Table 2: Chemical Composition (%) and Phosphate Sources used in the study

P Source	Total P ₂ O ₅	Available P ₂ O ₅	¹ Fe ₂ O ₃	S	CaO	Mgo
MAP	50.0	-	-	-	-	-
CGPR	16.0	1.3	6.4	-	29.8	-
50% PAPR	-	9.47	-	7.0	-	-

¹ Water soluble plus neutral ammonium citrate soluble P as a percentage of the total sample.

CGPR = Chilembwe Ground Phosphate Rock

MAP = Mono-ammonium Phosphate (also contains 11% N and 0.075% Zn).

Crop management was carried out according to the conventional agronomic practices for the crops. At harvest, the yield data were obtained. Soil samples were taken from 0 – 15cm and 15 – 30cm depths from only two replicates of the experiment after harvest. Soil analysis was conducted for soil pH (C_aCl₂), available P using Bray I and Pi tests.

3.1 Bray I

The Bray I method uses a combination of NH₄F and HCl and is known to be a reliable method to determine an index of available phosphorus in acid tropical soils. Bray I extracts Iron Phosphate and Aluminum (Bray and Kurtz, 1945). The soil was crushed and passed through a 2 mm sieve. Two and one-half g of the soil sample was weighed into 15 ml polythene shaking bottles. Twenty-five (25) ml of the Bray I extracting solution (0.03N NH₄F and 0.025 N) was added to each bottle. The bottles were stoppered and shaken on a mechanical shaker for 1 minute. The suspension was filtered through Whatman No. 542 filter paper. Five(s) ml of the filtered sample was transferred into 100 ml bottles and eight (8) ml of a mixture of ascorbic acid and an ammonium molybdate reagent was added to the sample in the beaker. 30 ml-distilled water was added to the sample after 30 minutes, the concentration of P in the sample was measured at 880 nm by a Spectrophotometer.

3.2 Pi Test

The Pi soil test uses iron hydroxide impregnated filter paper strips which were prepared by submerging filter paper (Whatman No. 541) in 10% FeCl₃ solution. The papers were drip

dried and exposed to ammonia vapour to convert the iron chloride to iron hydroxide. After complete conversion to hydroxide as indicated by the uniform intense brown colour, the papers were cut into strips of 10 cm long and 2 cm wide having a total area of 20cm². The paper strips were then placed inside a nylon sheaths and placed in bottles containing 1 g soil and 40 ml of CaCl₂ (0.01 m). The bottles were shaken for 16 hours after which the paper strips were removed and washed with distilled water to remove soil particles sticking to them. After the paper strips had dried, they were transferred to shaking bottles containing 40ml of 0.02N Sulphuric acid and shaken for 1 hour. The solution was filtered and the filtrate analysed for available P.

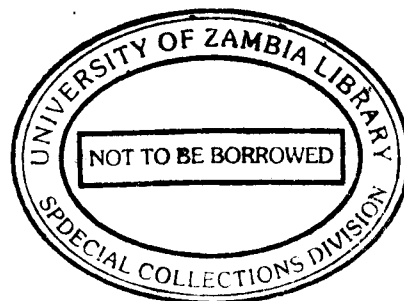
The rate and amount of phosphate absorption by the Pi paper depend on the forms and quantities of the phosphate present in the soil samples i.e. the fractions of P dissolved in the soil solution. Because the desorption of phosphate from the soil particles to the Pi paper is a diffusion controlled process, the Pi extraction stimulates the natural process in which a plant's roots absorb the phosphate ions from the soil solution and under field conditions. Therefore, the Pi test extracts the fractions of P and quantities of P in soil solution of that particular soil type i.e. fractions of P, which are readily available to the plant. These inorganic fractions occur in numerous combinations with aluminum, iron, calcium, fluorine and other elements. (Menon, Chien and Hammond, 1989).

During the second season, the planting furrows from the first season were maintained. To evaluate the residual effects, no P was applied for high treatment rates of 120 kg P₂O₅ ha⁻¹ and 120,160 and 200 kg P₂O₅ ha⁻¹ for On-Farm and On- Station trials respectively for both sources of P. Absolute zero treatment plots were added to the experimental sites to evaluate the natural soil fertility of these sites. The treatments were split and lime added to some sites to evaluate its effect on crop growth.

3.3 Statistical Analysis

MSTAT Statistical package was used to analyze data. Analysis of variance (ANOVA) was done. Separation of means was done using Duncan's multiple range tests and Regression analysis.

CHAPTER FOUR



RESULTS AND DISCUSSION

The results are reported according to experimental sites.

4.1 Mwanachingwala

At Mwanachingwala On-Farm site, the regression coefficient for available P extracted by Bray1 was significantly related to the maize yield in the sub-soil layer 15-30 cm (Table 3, Appendix 1).

Table 3: Regression Coefficients – Mwanachingwala

Method of Analysis and Soil Depth	Regression Coefficient	Standard Error	Prob.
1	7.8465 e + 001	6.038 e + 001	0.226 ns
2	4.1223 e + 002	1.7704 e + 002	0.045 **
3	1.5465 e + 002	1.2509 e + 002	0.248 ns
4	3.2387 e + 002	1.7969 e + 002	0.105 ns

Key

- Bray I (0 – 15cm) = 1
- Bray I (15 – 30cm) = 2
- Pi (0 – 15) = 3
- Pi (15 – 30) = 4
- Ns = non-significant
- ** = Significant

Intercept = 2.072.723160
 Multiple R = 0.859
 Coefficient of determination (R- square) = 0.737

This was because the soil P was inadequate and the maize crop was responding to additional soil P in this soil horizon. Soil available P revealed that in case of PAPR application, P migrated from 0-15 cm to 15-30 cm soil profile (Figure3, Table 3). The forms of P in this soil layer were $H_2PO_4^{-1}$ and HPO_4^{-2} . This is supported by the fact that available P in acidic soils below 7.2 is only $H_2PO_4^{-1}$ and HPO_4^{-2} (Tisdale, Nelson and Beaton). There was no available form of P (PO_4^{-3}) as the Pi test which was included in the regression was not significant (Appendix 1). The Pi test only measures phosphorus in the soil solution available to the plant.

An absolute zero treatment was included in the second year to evaluate the natural fertility compared to the added nutrients. Lime was also applied to test sites where soils were acidic

(Table 3) to neutralize soil acidity and eliminate aluminium toxicity. Lime was applied according to exchangeable aluminium.

The maize yield in the PO control treatment where P was not applied was higher than in the absolute zero. This was because the maize crop was responding to added nutrients other than P (N, K, S). At this site, the soil P was inadequate for maize production in the first crop season (2000/2001). This is corroborated by the response of maize in the second year to fresh and residual application of P. The response to fresh application was more for PAPR than MAP (Figure 1). The response of maize yield to

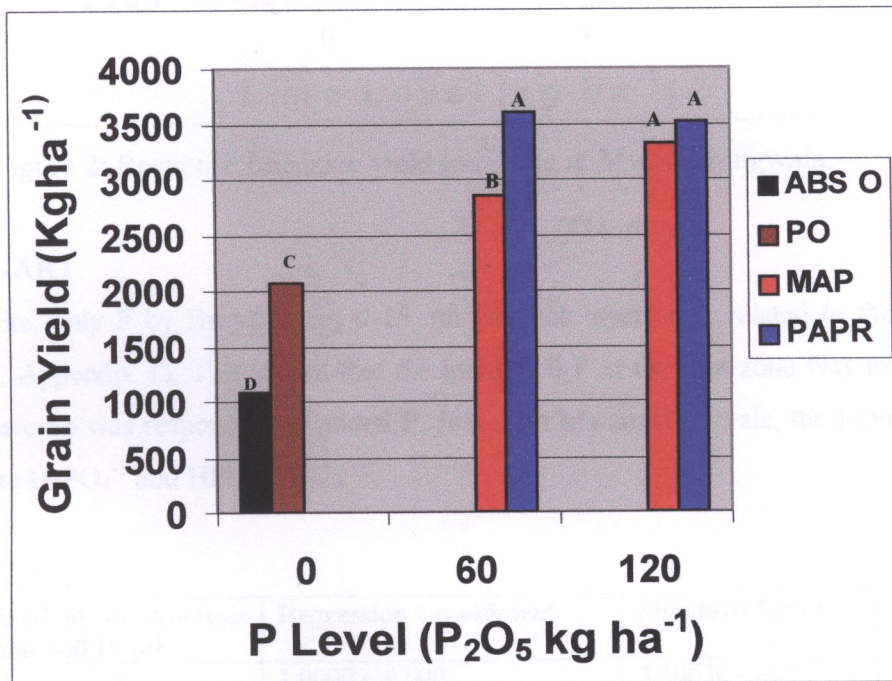


Figure 1: Response of Maize yield to source and level of P at Mwanachingwala in the second season (2001/2002).

the residual yield application of both PAPR and MAP was similar. The effect of residual P at 120 kg P₂O₅ ha⁻¹ was similar to fresh application of PAPR at 60 kg P₂O₅ ha⁻¹.

Liming depressed maize yields for all treatments as a result of a probable Ca/Mg imbalance for normal plant growth (Figure 2).

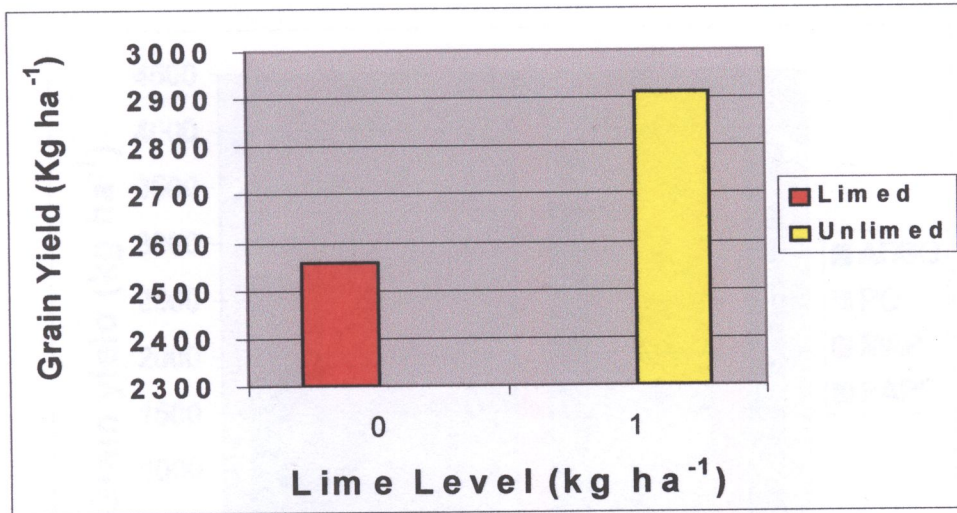


Figure 2: Response of Maize yield to liming at Mwanachingwala.

4.2 GART

At this site, only P by Bray1 in the 0-15 cm (surface layer) was related to the maize yield (Table 4, Appendix 1). This shows that the initial soil P in the root zone was inadequate and the maize crop was responding to added P. Just as at Mwanachingwala, the forms of P in this layer were $H_2PO_4^{-1}$ and HPO_4^{-2} .

Table 4.

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	1.0000 e + 000	3.3063e - 001	0.014 **

Intercept = 5391.799997

Mutiple Range = 0.730

Coefficient of Determination (R - Square) = 0.533

The yield of maize from the absolute zero treatment was similar to the PO control treatment (Figure 3, Appendix 2). This implies that other nutrients apart from P were not limiting. In the second cropping season, the soil P at this site was still inadequate for P applied the previous season as shown by response to application of P. The residual P from the higher rate ($120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) was effective (Figure 3).

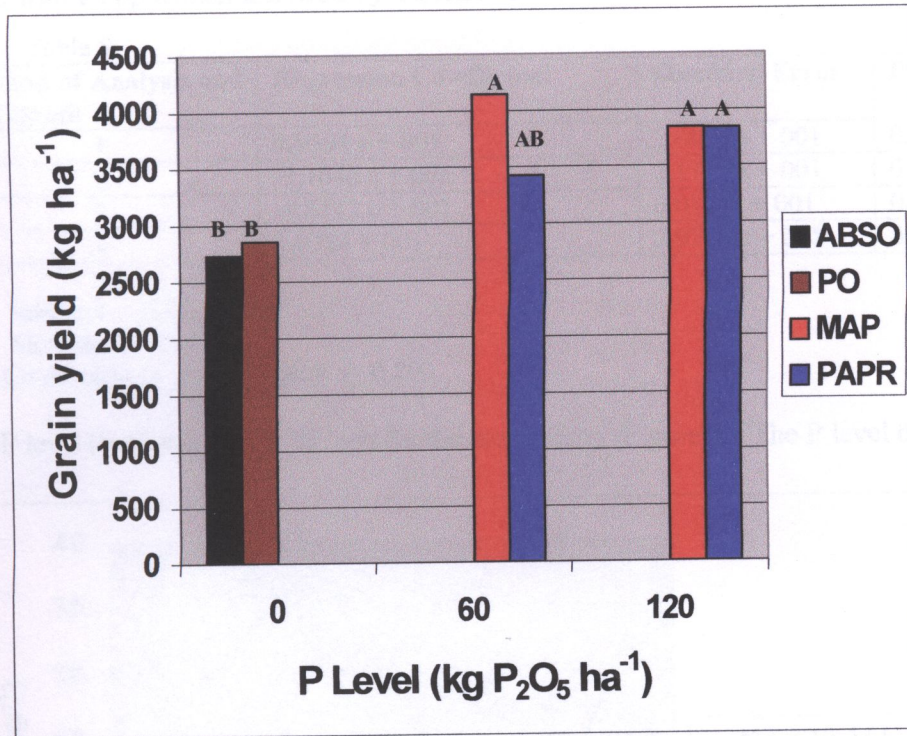


Figure 3: Response of Maize yield to source and level of P at GART

At GART, there was higher exchangeable aluminum than at Mwanachingwala and Kabwe. This level of aluminum saturation depresses maize yields even for an acid tolerant variety

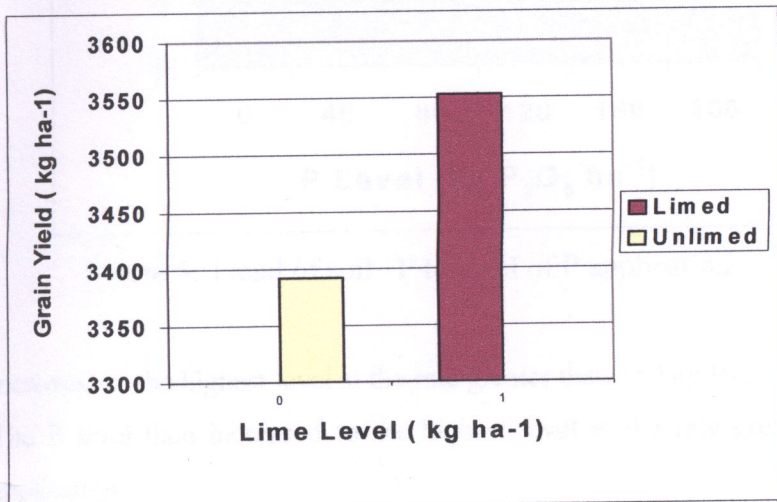


Figure 4: Response of Maize yield to application of lime at GART.

such as MM603-New. A higher level of lime application was required to eliminate aluminum toxicity. This increased maize yields by 5 % after lime application (Figure 4).

4.3 Kafuku Farm Institute (Armstrong)

At this site, the individual

regression coefficients were not significant. The combined regression coefficient, however, was significant (Table 5, Appendix 1). The initial P level was high and adequate and increased with P application followed by a decline to a minimum at 120 kg P₂O₅ ha⁻¹.

Table 5.

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	4.9504 e + 001	2.6664 e + 001	0.077 ns
2	-3.1646 e + 001	2.1780 e + 001	0.161 ns
3	-8.5112 e + 001	6.012 e + 001	0.172 ns
4	1.0784 + 001	2.9786 e + 001	0.172 ns

Intercept = 3635.109365

Multiple R = 0.044**

Co-efficient of determination = 0.200

But this P level (0-15 cm) was still high for the maize crop (Figure 5). The P level then

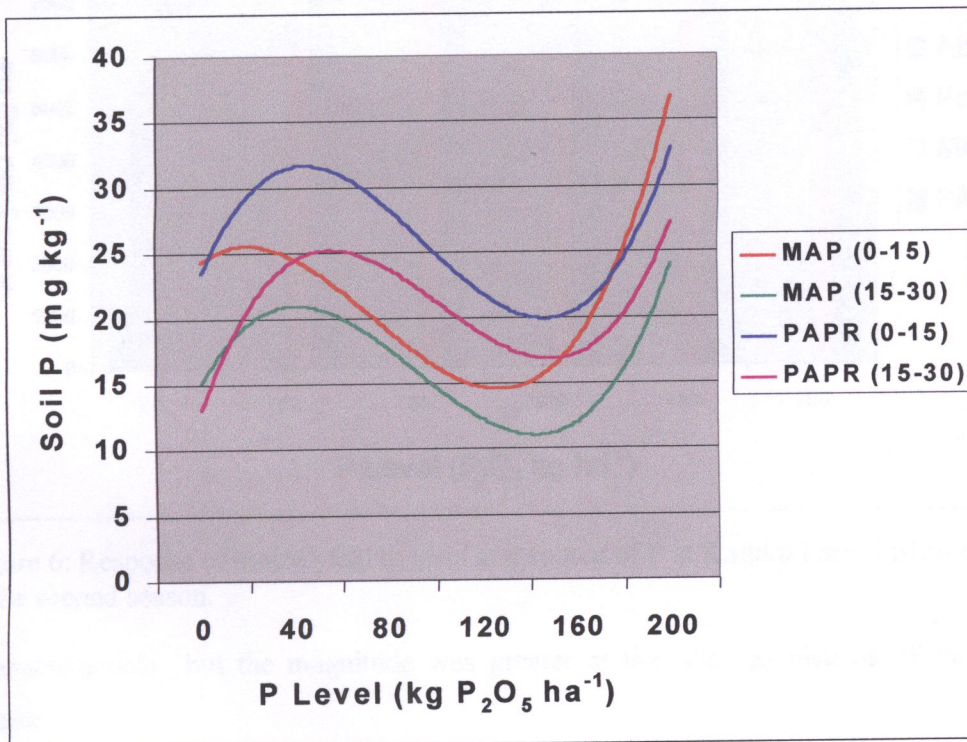


Figure 5: Trend of soil P to level of P application.

increased to the highest level at the rate greater than 160 kg P₂O₅ ha⁻¹ P application.

The P level then increased to the highest level at the rate greater than 160 kg P₂O₅ ha⁻¹ P application.

The effect of P at higher rates of fresh and residual application maintained a higher soil solution concentration of P resulting in a significant increase in yield response at 80 kg P₂O₅ ha⁻¹ for fresh and 160 kg P₂O₅ ha⁻¹ for residual application. At still a higher rate of 200 kg P₂O₅ ha⁻¹ there was a depression in maize yield (Figure 6).

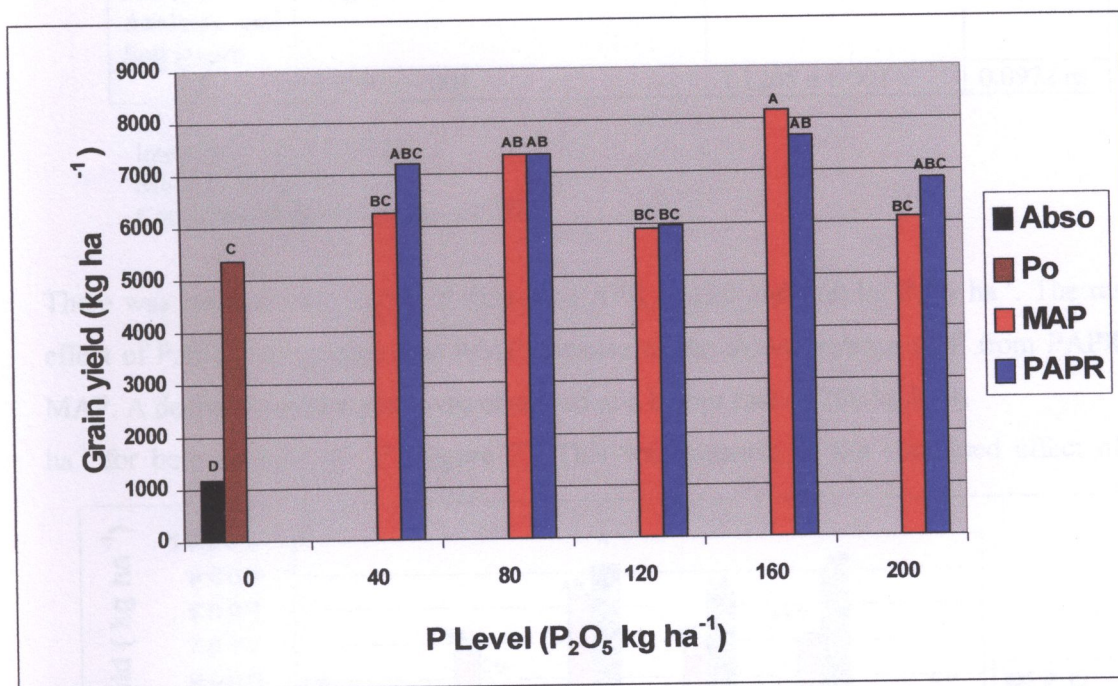


Figure 6: Response of maize yield to level and source of P at Kafuku Farm Institute in the second season.

as at Mwanachingwala but the magnitude was greater at this site as high as 78 %. This was because this site was more deficient in other nutrients than at Mwanachingwala.

In the second year, the soil P was still high as observed by the high maize yield of 5000 kg ha⁻¹ in the PO control treatment.

4.4 UNZA Farm

At Unza Farm site, as at Mwanachingwala, the P extracted by Bray1 was related to the maize yield in the sub-soil layer (15-30 cm) (Table 6). The maize was only responding to additional P in this soil horizon. There was response to both fresh and residual application of both sources of P. The response to fresh application was only at 80 kg P₂O₅ ha⁻¹. This suggests that there was high P fixation in this soil.

Table 6.

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
2	3.9792e - 001	1.1265 e + 001	0.0972 ns

Intercept = 5840.337028

Multiple R = 0.004**

Coefficient of determination = 0.000

There was residual response of P only for PAPR at 120 and 160 kg P₂O₅ ha⁻¹. The residual effect of PAPR was greater than MAP because of the slower release of P from PAPR than MAP. A decline of stover yield was observed at a higher rate of 200 kg P₂O₅ ha⁻¹ for both sources of P (Figure 7). This was because of the combined effect of high

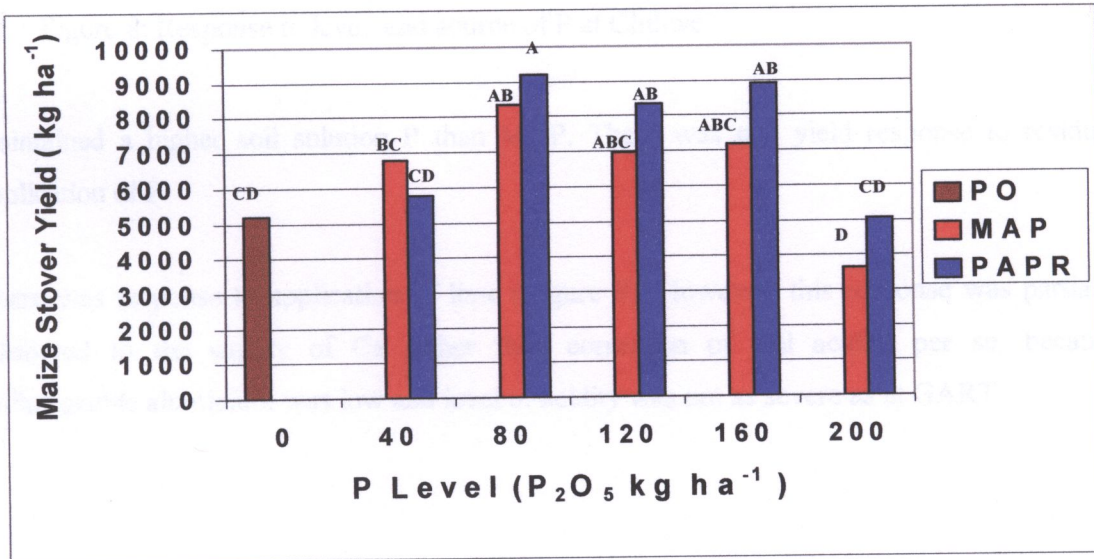


Figure 7: Response of Maize stover yield to source and level of P at UNZA Farm.

concentration of added nutrients and the moisture stress due to the draught experienced this year.

4.5 Chibwe

The initial soil P values were high at this site. The effect of P was observed for fresh application only for PAPR at 60 kg P₂O₅ ha⁻¹ (Figure 8). As at other sites, the PAPR

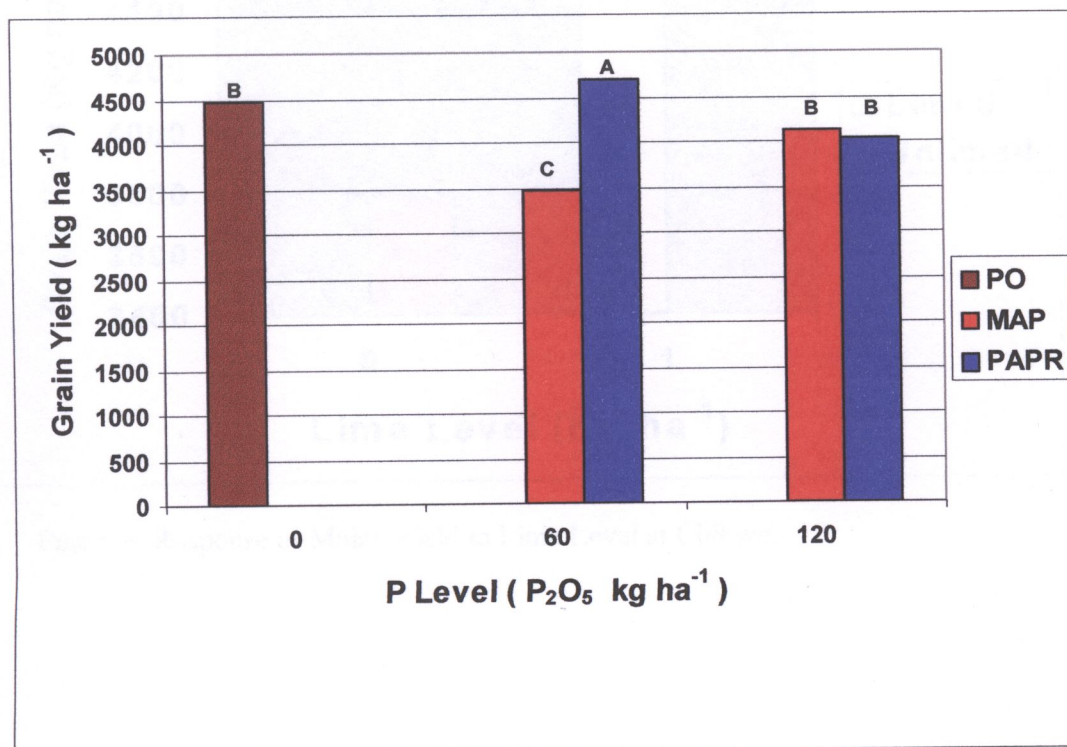


Figure 8: Response to level and source of P at Chibwe.

maintained a higher soil solution P than MAP. There was no yield response to residual application of P.

There was response to application of lime (Figure 9). However, this response was partially attributed to the supply of Ca rather than correction of soil acidity per se. because exchangeable aluminium was low and level of acidity was not as severe as at GART.

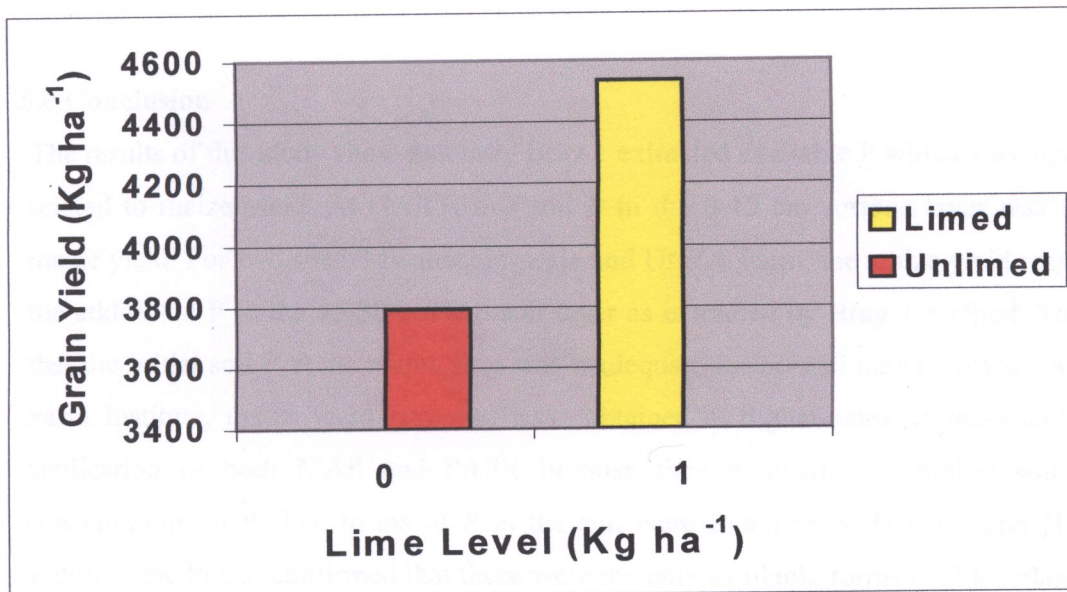


Figure 9: Response of Maize Yield to Lime Level at Chibwe.

CHAPTER FIVE

5.0 Conclusion

The results of this study show that only Bray 1 extracted available P which was significantly related to maize yield. At GART, this soil P in the 0-15 cm surface layer was related to maize yield. For two sites, Mwanachingwala and UNZA Farm, the maize yield responded to the additional P in the 15-30 cm sub-soil layer as extracted by Bray 1 method. This shows that the initial soil P at the above sites was inadequate for normal maize growth. At Kafuku Farm Institute, maize yield response was obtained at higher rates of fresh and residual application of both MAP and PAPR because they maintained a higher soil solution concentration of P. The forms of P in the soil were found to be $\text{H}_2\text{PO}_4^{-1}$ and HPO_4^{-2} . In addition, the Pi test confirmed that these were the only available forms of P for plant uptake. The study also confirms that Bray 1 extraction method works well in acid soils where Al and Fe phosphates are predominant because these forms of P were related to maize yields.

At all sites except Kabwe, there was response to both fresh and residual application of both sources of P. The fresh application of PAPR was more effective than MAP at Mwanachingwala. At all sites except at UNZA Farm, the residual effect was similar for both PAPR and MAP. At UNZA Farm, the residual was greater for PAPR than MAP. At all sites, other nutrients other P were limiting but the extent differed from site to site. The response to lime application was dependent upon site. The maize yield increased with lime where exchangeable aluminum was high and at all sites where there was Ca deficiency. There was a depression in yield where lime caused a probable imbalance of Ca/Mg cations for normal plant growth.

6.0 Recommendations

On the basis of the findings of this study, it is suggested that: -

- (i) The experiment continues to evaluate the duration of the residual effect.
- (ii) Sequential P fractionation must be carried out to determine the fractions of P which will supply residual P for a duration of 3 to 5 years.
- (iii) The contribution of each of the three elements (N,K,S) to the maize response where they were limiting must be determined.

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Appendix 1

ANALYSIS OF VARIANCE TABLE – CHIBWE

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	1	2624093.735	2624093.735	3.6110	0.1302
2	Factor A	4	3518906.783	879726.696	1.2106	0.4288
-3	Error	4	2906759.852	726689.963		
4	Factor B	1	2754462.572	2754462.572	10.5004	0.0229
6	AB	4	132937.882	33234.470	0.1267	
7	Error	5	1311602	262320.401		
TOTAL		19	13248762.830			

Co-efficient of variation: 12.30%

MEAN SEPARATION

Original Order

Mean 1 = 4467 B
 Mean 2 = 3472 C
 Mean 3 = 4139 B
 Mean 4 = 4706 A
 Mean 5 = 4039 B

Ranked Order

Mean 4 = 4706 A
 Mean 1 = 4467 B
 Mean 3 = 4139 B
 Mean 5 = 4039 B
 Mean 2 = 3472 C

Analysis of Covariance Table – Mwanachingwala

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	Prob.
1	Replication	1	140657.659	140657.659	2.00 818	0.1797
2	Factor A	5	18984681.5 71	379636.314	56.1954	0.0000
4	Factor B	1	731165.754	731165.754	10.8214	0.0082
6	AB	5	990301.433	198060.287	2.9313	0.0695
		1	7018.932	7018.932.932	0.1244	
7	Error	10	564335.803	56433.580		

Coefficient of variation: 8.69%

SEPARATION OF MEANS

ORIGINAL ORDER

RANKED ORDER

LIME

Mean 1 = 1081 D
1 = 2558.484
Mean 2 = 2055 C
2 = 2910.454
Mean 3 = 2847 B
Mean 4 = 3321 A
Mean 5 = 3598 A
Mean 6 = 3505 A

Mean 5 = 3598 A
Mean 6 = 3505 A
Mean 4 = 3321 A
Mean 3 = 2847 B
Mean 2 = 2055 C
Mean 2 = 2055 C

ANALYSIS OF VARIANCE – ARMSTRONG

Source	Degrees of Freedom	Sum of Squares	Mean Square	F. Value	Prob.
REP.	3	17339393.31	5779797.770	4.58	0.0087
P	11	145407029.04	13218820.876	10.47	0.000
Error	33	41647707.97	1262051.757		
Non-additivity	1	601399.44	601399.443	0.47	
Residual	32	41046308.53	1282697.141		
TOTAL	47	2043941			

Grand mean = 6275.347 Grand sum = 301216.672 Total Count = 48
Coefficient of Variation = 17.90%

SEPARTATION

Original Order

Mean 1 = 1152 D
 Mean 2 = 5351 C
 Mean 3 = 6269 BC
 Mean 4 = 7359 AB
 Mean 5 = 5907 BC
 Mean 6 = 8161 A
 Mean 7 = 6082 BC
 Mean 8 = 7192 ABC
 Mean 9 = 7341 AB
 Mean 10 = 5974 BC
 Mean 11 = 7677 AB
 Mean 12 = 6839 ABC

Ranked Order

Mean 6 = 8161 A
 Mean 11 = 7677 AB
 Mean 4 = 7359 AB
 Mean 9 = 7341 AB
 Mean 8 = 7192 ABC
 Mean 12 = 6839 ABC
 Mean 3 = 6269 BC
 Mean 7 = 6082 BC
 Mean 10 = 5974 BC
 Mean 5 = 5907 BC
 Mean 2 = 5351 C
 Mean 1 = 1152 D

ANALYSIS OF VARIANCE TABLE – UNZA FARM

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	Prob.
REP	3	78653838.60	26217943.534	2.45	
P	10	126757414.16	12675741.42	9.08	0.0410
Error	30	65029777.62	13523051.42		
Non-additivity	1	493426.24	493426.24	0.12	
Residual	29	64536351.38			
TOTAL	43	270441022.38			

Grand mean = 6858.657

Grand Sum = 301780.9007

Total Count 44

Coefficient of Variation = 21.47%

Original Order

Mean 1 = 5208 CD
 Mean 2 = 6771 BC
 Mean 3 = 8335 AB
 Mean 4 = 6979 ABC
 Mean 5 = 7187 ABC
 Mean 6 = 3660 D
 Mean 7 = 5777 CD
 Mean 8 = 9217 A
 Mean 9 = 8350 AB
 Mean 10 = 8910 AB
 Mean 11 = 5052 CD

Ranked Order

Mean 8 = 9217 A
 Mean 10 = 8910 AB
 Mean 9 = 8350 AB
 Mean 3 = 8335 AB
 Mean 5 = 7187 ABC
 Mean 4 = 6979 ABC
 Mean 2 = 6771 BC
 Mean 7 = 5777 CD
 Mean 1 = 5208 CD
 Mean 11 = 5052 CD
 Mean 6 = 3660 D

ANALYSIS OF VARIANCE- GART

K Source	Source	Degrees of Freedom	Sum of Squares	Mean Square	F – Value	Prob.
1	REP	1	356015.001	356015.001	1.5322	0.2707
2	Factor A	5	6640899.192	1328179.838	5.7163	0.0393
-3	Error	5	1161742.579	232348516		
4	Factor B	1	155465.081	155465.081	2.1972	0.1888
6	AB	5	555350.438	111070.088	1.5698	0.2977
-7		6	424527.911	70754.652		
	TOTAL	23	9294000.202			

Coefficient of Variation = 7.66%

MEAN SEPARATION

Original Order

Mean 1 = 2733 B
 Mean 2 = 2853 B
 Mean 3 = 4145 A
 Mean 4 = 3846 A
 Mean 5 = 3422 AB
 Mean 6 = 3039 A

Ranked Order

Mean 3 = 4145 A
 Mean 4 = 3846 A
 Mean 6 = 3039 A
 Mean 5 = 3422 AB
 Mean 2 = 2853 B
 Mean 1 = 2733 B

Appendix 2

Regression Coefficients – Mwanachingwala

Method of Analysis and Soil Depth	Regression Coefficient	Standard Error	Prob.
1	7.8465 e + 001	6.038 e + 001	0.226 ns
2	4.1223 e + 002	1.7704 e + 002	0.045 **
3	1.5465 e + 002	1.2509 e + 002	0.248 ns
4	3.2387 e + 002	1.7969 e + 002	0.105 ns

Intercept = 2.072.723160

Multiple R = 0.859

Coefficient of determination (R- square) = 0.737

Key

Bray I (0 – 15cm) = 1

Bray I (15 – 30cm) = 2

Pi (0 – 15) = 3

Pi (15 – 30) = 4

Ns = non-significant

** = Significant

Method of Analysis and Soil Depth	Regression Coefficient	Standard Error	Prob.
1	5.7871 e + 001	5.4032 e + 001	0.312 ns
2	4.3126 e + 002	2.2826e + 002	0.091 ns

Intercept = 1850.669920

Multiple R = 0.616

Coefficient of determination

= 0.380

Method of Analysis and Soil Depth	Regression Coefficient	Standard Error	Prob.
1	4.5273 e + 001	6.1631 e + 001	0.481ns

Intercept = 4079.659254

Multiple R = 0.251

Coefficient of determination =

4079.659254

Method of Analysis and Soil Depth	Regression Coefficient	Standard Error	Prob.
2	4.0109e + 002	2.2859 e + 002	0.113 ns

Intercept= 2536.621731

Multiple R = 0.525

Coefficient of determination = 0.279

Method of Analysis	Regression Coefficient	Standard Error	Prob.
3	2.2362 e + 002	1.3508 e + 002	0.132 ns

4	2.2820 e + 002	1.8620 e + 002	0.252 ns
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Intercept = 776.543564

Multiple R = 0.603

Co-efficient of determination = 0.363

Method of Analysis	Regression Coefficient	Standard Error	Prob.
3	2.12729 e + 002	1.3895 e + 002	0.160 ns

Intercept = 2590.908298

Multiple R= 0.476

Coefficient of determination = 0.227

Method of Analysis	Regression Coefficient	Standard Error	Prob.
4	2.00802 + 002	2.0511e + 002	0.337 ns

Intercept = 2935.350650

Multiple R = 0.338

Coefficient of determination = 0.114

REGRESSION COEFFICIENT – GART

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
2	5.7100 e + 001	5.8435 e + 001	0.354 ns

Intercept = 5014.941608

Multiple Range = 0.812

Coefficient of Determination (R-square) = 0.659

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	1.000 e + 000	4.1955 e – 001	0.041
2	4.4140 e + 001	4.3433 e + 001	0.336
3	5.6037 e + 001	3.1265 e + 001	0.107

Intercept = 4552.431047

Multiple range = 0.800

Coefficient of Determination (R – Square) = 0.640

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
3	6.7901 e - 001	4.6197 e + 001	0.176 ns
4	-7.7229 e + 000	2.4423 e + 001	0.759 ns

Intercept= 4810.790029

Multiple Range = 0.498

Coefficient of Determination (R-Square) = 0.248

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	1.000 e + 000	5.9992 e – 001	0.058 ns
2	5.7100 e + 001	3.2654 e - 001	0.267 ns

Intercept = 5014.941613

Multiple R= 0.683

Coefficient of determination (R-square) = 0.467

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	1.0000 e + 000	3/3063 e - 001	0.014 **

Intercept = 5391.799997
Multiple Range = 0.730
Coefficient of Determination (R – Square) = 0.533

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
2	5.7100 e + 001	5.8435 e + 001	0.354 ns

Intercept = 5014.941608
Multiple R = 0.327
Coefficient of Determination (R-square)= 0.107

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
4	8.4319 e + 000	2.3338 e + 001	0.726 ns

Intercept = 5301.114828
Multiple R = 0.127
Coefficient of Determination(R-Square) = 0.016

REGRSSION COEFFICIENTS – UNZA FARM

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	-1.5717e +001	1.9899e +001	0.438 ns
2	-1.8186e +001	1.9058e +001	0.351 ns
3	8.8060e +001	7.4734e +001	0.252 ns
4	1.7630e +002	1.2183e + 001	0.163 ns

5376.174816Intercept = 4905.313281
Multiple R = 0..503
Coefficient of determination = 0.253

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	8.2836 e + 000	7.2754 e + 000	0.268 ns
2	4.0769 e - 001	1. 1183 e + 001	0.971 ns

Intercept = 5519.754314
Multiple R = 0..253
Coefficient of determination = 0.064

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	8.2834 e + 000	2.5271 e - 001	0.250 ns

Intercept = 5529.522719
 Mutiple R = 0..253
 Coefficient of determination = 0.064

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
2	3.9792e - 001	1.1265 e + 001	0.0972 ns

Intercept = 5840.337028
 Multiple R = 0.004**
 Coefficient of determination = 0.000

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
3	4.0024 e + 001	2.5439 e + 001	0.131 ns
4	7.2125 e + 001	6.9150 e + 00	0.309 ns

Intercept = 4994.582026
 Multiple R = 0.407
 Coefficient of determination = 0.116

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
3	4.1626 e + 001	3.4350 e - 001	0.117 ns

Intercept = 541.8941188
 Multiple R = 0.344
 Coefficient of Determination = 0.118

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
4	7.8692 e + 001	7.1524 e + 001	0.284 ns

Intercept = 5376.174816
 Multiple R = 0.239
 Coefficient of determination = 0.057

REGRESSION COEFFICIENTS MUKONCHI

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	4.9504 e + 001	2.6664 e + 001	0.077 ns
2	-3.1646 e + 001	2.1780 e + 001	0.161 ns
3	-8.5112 e + 001	6.012 e + 001	0.172 ns
4	1.0784 + 001	2.9786 e + 001	0.172 ns

Intercept = 3635.109365
 Multiple R = 0.044**
 Coefficient of determination = 0.200

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	1.9744 e + 001	1.6084 e + 001	0.233
2	-2.5059 e + 001	1.8765 e + 001	0.196

Intercept = 3658.068327

Multiple R = 0.317

Coefficient of Determination (R-Square) = 0.101

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
1	7.8983 e + 000	1.3677 e + 001	0.570

Intercept = 3508.587498

Multiple R = 0.617

Co-efficient of Determination (R-Square) = 0.031

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
2	-1.2354 e + 001	1.5850 e	0.444 ns

Intercept = 3930.723507.

Multiple R = 0.172

Coefficient of determination = 0.029

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
3	-5.6475 e + 000	3.6455 e + 001	0.878 ns
4	-2.4146 e + 000	2.6420 e + 001	0.928 ns

Intercept = 3773.080861

Multiple R = 0.049

Coefficient of determination = 0.002

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
3	-6.6587 e + 000	3.3863 e + 001	0.846 ns

Intercept = 3763.233998

Multiple R = 0.44

Co-efficient of determination = 0.002

Method of Analysis and Soil Depth	Regression Co-efficient	Standard Error	Prob.
4	-3.6568 e + 000	2.4552 e + 001	0.883 ns

Intercept = 3736.315182

Multiple R = 0.033

Coefficient of determination = 0.001