

**EFFECT OF LIME ON PLANT-EXTRACTABLE PHOSPHORUS IN ACIDIC  
SOIL**



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## **DEDICATION**

This report is dedicated to my ever caring God, parents Mr/Mrs Mwenya and my brother George.

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I would like to acknowledge and expressed my gratitude to my supervisor, Mr. H Chalwe for his great support, guidance and the time he dedicated to help me for the great success and completion of my project. I also wish to thank Mr. V. Shitumanuma for supporting me with experimental materials and also the Chief Technician, Mr. G Musukwa for a full guidance, advice and assistance during experimental work. Last of all am grateful to my course mates.

## ABSTRACT

Zambia like many other tropical countries is dominated by soils that are very deficient in phosphorus. Currently all phosphate fertilizers that are imported from outside Zambia are relatively expensive for small scale farmers. An incubation study was conducted in laboratory to determine the effect of  $\text{CaCO}_3$ ,  $\text{Ca(OH)}_2$  and  $\text{CaO}$  on soil pH and Bray-1 extractable phosphorus in an acid soil. Five rates of lime equivalent to 1, 2, 3, 4 and 5 ton  $\text{CaCO}_3/\text{ha}$ , were applied as treatments in 500g of a strongly acid soil. Each lime treatment was replicated thrice. The soil was incubated at field capacity for 8 weeks during which it was analysed for available phosphorus using Bray 1 solution. Soil pH was monitored using 0.01M  $\text{CaCl}_2$ . The application of lime significantly increased soil pH and available P. The highest mean amount of P was 8.3 mg P/kg and was generated by  $\text{CaO}$  and the lowest was 7.1 mg P/kg generated by  $\text{CaCO}_3$ . The period of incubation also had a significant effect on available P, but not pH. At week 8, the mean available P was 9.529 mg/kg as the highest at the lowest pH of 5.4. At 3 weeks, the mean available phosphorus was 6.235mg/kg as the lowest and its lowest pH of 5.5. Although there were differences in the amounts of extractable P, there was a weak positive correlation of 0.24 between P and pH at 99% confidence level.

## CHAPTER ONE

### 1.0 INTRODUCTION

Soil pH is an important indicator of the relative acidity or alkalinity of a soil. The pH scale ranges from 0 to 14, and the soil is assigned a value from the pH scale to describe the acidity or alkalinity. Since pH 7 falls midway along the scale, pH values that are equal to 7 are said to be neutral. Values below 7 are acidic while those above 7 are alkaline (Harris et al., 2009).

By definition, the pH of a soil is the measurement of the relative concentration of hydrogen ions in the soil solution. The greater the concentration of hydrogen ions in the soil solution is, the lower the pH. In other words, the lower the pH value, the greater the acidity of the soil will be. This means that the concentration of hydrogen ions in the soil solution is directly proportionate to the hydrogen ions and in equilibrium with those retained on the soil's cation exchange complex. Therefore, the hydrogen ions retained by clay particles replenish, or buffer, the hydrogen ions in soil water (Hue et al., 1998).

Soil pH has been described as a single most important soil parameter that greatly influences the soil's physical, biological and chemical characteristics. For example, the availability of phosphorus and other nutrients is restricted by soil reaction. Although soil acidity does not directly affect phosphorus availability, it indicates how certain minerals such as iron, aluminum, and calcium, interact with phosphorus in the soil, and it is this interaction that affects phosphorus availability (Brady and Weil 2010).

The amount of soluble iron, aluminum, and calcium present in the soil are important because, each of these elements and their oxides and hydroxides are capable of reacting with soluble phosphorus to form insoluble compounds and thus, depriving plants of the soluble phosphorus that was initially present. In alkaline soils, iron and aluminum minerals are nearly insoluble, while soluble calcium is abundant and capable of fixing phosphate ions, usually  $\text{HPO}_4^{2-}$  to form insoluble calcium phosphates. However, in acid soil conditions, iron and aluminum concentrations are high because the minerals are soluble, while calcium concentrations are low because the mineral has been dissolved and leached out of the soil (Hue et al., 1998).



In highly acid soil solutions, active  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  react with  $\text{H}_2\text{PO}_4^-$  ions to form insoluble hydroxy phosphates. The  $\text{H}_2\text{PO}_4^-$  ions can also react with insoluble hydrous oxides. The other method of phosphorus fixation involves silicate minerals. This could be a surface reaction between  $\text{OH}^-$  groups and  $\text{H}_2\text{PO}_4^-$  ions or the  $\text{Fe}^{3+}$  and  $\text{Al}^{3+}$  ions from the silicate crystal form hydroxy phosphates with the phosphate ions. The latter mode of phosphorus fixation is influenced by clay mineralogy. Phosphorus can also participate in simple anion exchange reactions (Stevenson 1986, Brady 1990).

From above, it is clear that the availability of phosphorus is restricted in both acidic and alkaline environments. For most soils, maximum availability is in the slightly acid to neutral pH range. This implies that management of soil to optimize phosphorus availability should be such that the pH of the soil is raised to slightly acid to neutral range. In cases where lime is applied to raise soil pH, sufficient quantities should be applied to neutralize active aluminium and iron ions while over-liming should equally be avoided as this would solubilize calcium, which can remove phosphorus ions from solution through exchange reactions (Brady and Weil 2010). This study explores soil acidity management to maximize phosphorus availability.

## **1.1 STATEMENT OF THE PROBLEM**

In Zambia, soil acidity is widely spread and is one of the major factors negatively affecting crop productivity (Ragnar, 1987). The acid nature of most soils significantly contributes to phosphorous deficiency. The soil characteristics that influence P fixation include the amount and type of clay-fraction minerals, soil pH, soil organic matter content, soil temperature, time of reaction, exchangeable  $\text{Al}^{3+}$ , soil redox condition (Sanchez and Uehara 1980).

In strongly acidic conditions, phosphorus reacts with active iron and aluminium to form insoluble precipitates (Sarker et al., 2014). Precipitation is a slow reaction in which phosphate ions react with dissolved  $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$ , and  $\text{Mn}^{2+}$  in acid soils and  $\text{Ca}^{2+}$  in neutral to calcareous soils to form insoluble hydroxy phosphate precipitates (Sanchez and Uehara 1980). Thus, liming of soil to raise its pH should be at appropriate levels to avoid both under-liming and over-liming.

## **1.2 OBJECTIVES**

The main objective of this project is to study the management of soil acidity to optimize P availability

### **SPECIFIC OBJECTIVES**

1. To determine phosphorous availability at different rates of liming
2. To determine the correlation between soil pH and phosphorous availability
3. To determine the liming reactivity of  $\text{Ca}(\text{OH})_2$ ,  $\text{CaO}$  and  $\text{CaCO}_2$  to neutralize soil pH

### **1.3 HYPOTHESES**

1. Increasing the rate of lime application in acidic soils would increase the levels of plant-extractable phosphorus
2. There is a correlation between soil pH and the availability of phosphorous.
3. The effectiveness of a liming material to neutralize soil acidity is influenced by its reactivity

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

A study to investigate the effect of lime and lime/phosphorous combinations on soil pH and available phosphorus indicated a significant increase in plant-available phosphorous with increasing rates of lime application (Sumner, 1979). This can be attributed to the fact that lime significantly increased soil pH. The calcium ions in lime can displace  $\text{Al}^{3+}$ ,  $\text{Fe}^{2+}$  and  $\text{H}^{+}$  ions from the soil complex. The displaced acid cations react with the conjugate bases such as the bicarbonate and hydroxide ions from the lime used. Hence, some of the initially bound phosphate ions are released into the soil solution and are available for uptake by plants (Brady and Weil, 2010).

Lower P availability following P-fertilizer application alone is due to its fixation by Al and Fe ions in acid soils (Buresh, et al., 1997). Although lime increased available P, this effect was boosted by combining lime with P-fertilizer application. Nevertheless, combinations with higher quantities of lime and P-fertilizer resulted in increased levels of available phosphorus. Applying lime at the rate of 3 ton  $\text{CaCO}_3/\text{ha}$  reduced the availability of phosphorus. At high soil pH, precipitation of insoluble calcium phosphates can decrease phosphate availability (Oluwatoyinbo et al., 2005). This would suggest that the soil has been over- limed at high application rate.

In an incubation study to explore the effect of addition of organic materials on soil pH, exchangeable acidity, exchangeable Al, and P availability, it was shown that both farm yard manure (FYM) and *Tithonia diversifolia* (Tithonia) significantly increased available phosphorus. This effect was attributed to the effect of these materials on the other factors investigated. Both the FYM manure and Tithonia were used in combination with other forms of P-fertilizer. Farmyard manure and Tithonia diversifolia significantly increased the soil pH and reduced the exchangeable acidity and Al in the soil within a short term, but the inorganic P sources did not significantly affect these parameters (Hue et al., 1986).

The reduction in exchangeable acidity can partially be attributed to an initial increase in soil pH that was observed. An increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides, thus reducing the concentration of Al in soil solution (Ritchie, 1994).

## CHAPTER THREE

### 3.0 MATERIAL AND METHODS

#### 3.1 Soil sampling and preparation

The strongly acidic soil that was used in this study was collected from Kabangwe area of Chisamba District in Chief Mungule's area. Samples were collected randomly using auger holes and then sieved using a 2 mm sieve after air-drying. The soil samples were collected at the depth of 20 cm from the soil surface.

#### 3.2 Characterization of soils

The portion that passed through the 2mm sieve or the fine earth fraction was retained and used for various chemical and physical analysis described below.

##### 3.2.1 Determination of available phosphorus

The available P in the soil was extracted using the Bray-1 solution composed of 0.03M  $\text{NH}_4\text{F}$  and 0.025M HCl. About 3 g of air-dried soil was placed in a 100 ml plastic container, to which 21 ml of extracting solution was added. The mixture was then shaken for 1 minute on a mechanical shaker and then filtered through Whatman No. 42 filter paper under a funnel. A volume of 5 ml of the filtrate was pipetted into a 25 ml volumetric flask and 4 ml of reagent B which was composed of predetermined amounts of ascorbic acid, ammonium molybdate, Potassium Antimony Tartrate and sulfuric acid was added before making it up to the mark with distilled water. It was then shaken and left to stand for 15 minutes to allow the colour to develop. The P content in the solution was determined using a Jenway 6700 Visible Spectrophotometer at wavelength of 882 nm.

##### 3.2.2 Determination of particle size distribution

The particle size distribution was determined by the hydrometer method (Songolo and Pauwelyn, 1998). Fifty grams of air dry soil, was weighed into a dispersing cup and 50 ml of the dispersing agent, sodium hexametaphosphate (calgon) was added. The cup was then half filled with tap water and continuously stirred for 5 minutes. The suspension was transferred to the sedimentation cylinder using a stream of distilled water to quantitatively transfer the soil to the cylinder and then make the liquid up to 1 dm<sup>3</sup> mark. The temperature of the suspension was measured using an alcohol thermometer range -

20 to 100°C. A plunger was inserted and moved up and down to stir the suspension thoroughly. After 20 seconds a hydrometer was lowered into the soil suspension and the density reading was taken at 40 seconds to determine the silt and clay content. This was repeated three times to obtain an average value. The suspension was then left for 2 hours and then the density reading was taken for the clay content. The percentage of clay, silt and sand were calculated as outlined in the Practical Manual for Soil Science by Songolo and Pauwelyn, (1998). The soil texture was determined by plotting the percentages of sand, silt and clay on the USDA Texture Triangle.

### **3.2.3 Determination of soil organic matter**

The organic matter of the soil was determined using the Walkley and Black method as outline by Songolo and Pauwelyn (1998). 1 gram of air dry soil was weighed into a 250 ml conical flask and 10 ml of 1N  $K_2Cr_2O_7$  was added using a pipette, and then rapidly added 20 ml of concentrated  $H_2SO_4$ . The flask was then swirled gently until the soil and solution was mixed followed by a more vigorous swirling for about 1 minute. The suspension was then stored in the fume hood for 30 minutes, after which 150 ml of distilled water and 10 ml concentrated  $H_3PO_4$  was added.

Ten (10 ml) of diphenylamine indicator was added to the suspension before titrating with Iron (II) sulphate solution ( $FeSO_4$ ). The colour changed from an initial yellow brown to blue and then to green as the end point of the titration. The volume of  $FeSO_4$  added was recorded. The percentage of organic matter was calculated from the titration data.

### **3.2.4 Determination of soil pH**

The pH of the soil was determined in water using a pH meter (model PH 3110 SET 2). 10 g of soil was weighed into a 50 ml plastic container to which 25 ml of water was then added. The suspension was stirred gently for 30 minutes with a glass rod and allowed to settle for 18 hours before reading the pH of the supernatant. Calibration of a pH meter was done using buffer solutions at pH 4 and 7, respectively in the following steps: The glass electrode was immersed into a buffer solution followed by adjusting the indicator needle to the pH of buffer, starting with the buffer solution at pH 4 and then the one at pH of 7.

### **3.2.5 Determination of exchangeable bases**

Ten (10 g) air dry soil sample was placed in 100 ml plastic container to which 50 ml of  $\text{NH}_4\text{OAc}$  at pH 7.0 was then added followed by shaking on a mechanical shaker for 30 minutes. The suspension was then filtered through a Whatman paper No. 42 filter paper. The concentration of  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  were measured using spectrophotometry. From the filtrate,  $\text{K}^+$  and  $\text{Na}^+$  were determined by Flame Absorption Emission Spectrophotometry. For  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ , 5 ml of the filtrate, 5 ml of 500  $\text{mg/dm}^3$  strontium chloride and 15 ml of distilled water were mixed in a 50 ml plastic container and then their concentration determined by Atomic Absorption Spectrophotometry.

### **3.2.6 Determination of exchangeable acidity**

#### **3.2.6.1 Extraction of the exchangeable $\text{Al}^{3+}$ and $\text{H}^+$ using 1M KCl solution**

Ten (10 g) of air dry soil sample was weighed into a 250 ml conical flask and 100 ml of 1 M KCl was added to it. The flask was then covered with a parafilm and shaken for 1 hour. The suspension was then filtered through a Whatman paper No. 42 filter paper.

#### **3.2.6.2 Determination of the exchangeable $\text{Al}^{3+}$ and $\text{H}^+$**

From the extract, 25 ml was pipetted into a 250 ml conical flask and 100 ml of distilled water was added to it. 5 drops of phenolphthalein indicator were added to the solution and then titrated with a standard 0.01 M NaOH solution to a permanent pink end point. The amount of base used was equivalent to the exchangeable acidity in the aliquot. To the same flask, 10 ml of 1 M NaF solution was added. The solution was then titrated with 0.01 M HCl until the pink colour of the solution disappeared. The titration with 0.01 M HCl was to determine exchangeable  $\text{Al}^{3+}$ . Exchangeable  $\text{H}^+$  was determined by subtracting exchangeable  $\text{Al}^{3+}$  from exchangeable acidity.

### **3.2.7 Determination of Fe and Mn**

A 20 g air-dry soil sample was placed into a 100 ml plastic container. To it, 40 ml of DTPA-TLA extracting solution was added and the mixture shaken for 2 hours on the mechanical shaker. The suspension was then filtered through Whatman No. 42 filter paper. The filtrate was then analyzed for Fe and Mn using the Perkinelmer Analyst 400 Atomic Absorption Spectrometer.

### **3.3 Characterization of liming materials**

#### **3.3.1 *Determination of lime reactivity***

One (1) g of lime sample was added to 100 ml of 0.2 M acetic acid with pH of 3.0. After adding the lime to the acid and while stirring the mixture, pH measurements were taken at intervals of 1 minute for 15 minutes. Two replicates were run per sample.

#### **3.3.2 *Determination of neutralizing values of lime samples***

0.5 g of lime was dissolved in 25 ml of 1 N HCl by heating the mixture for 30 minutes. To the mixture, 100 ml of de-ionised water was added and then titrated with 1 N NaOH using 5 drops of phenolphthalein indicator. A blank titration was also run as a control.

### **3.4 Incubation procedure**

Three liming materials, namely calcium carbonate ( $\text{CaCO}_3$ ), calcium oxide (CaO) and calcium hydroxide ( $\text{Ca(OH)}_2$ ) were each mixed with 500 g of an acid soil in a plastic container. The rates of application were equivalent to: 1 ton/ha, 2 ton/ha, 3 ton/ha, 4 ton/ha and 5 ton/ha, and each treatment was replicated thrice. The soil and lime mixtures were thoroughly homogenized and then uniformly watered to field capacity. The treated soil was incubated for 8 weeks and analyzed for pH and available phosphorous at 1 week, 3 weeks, 6 weeks and the 8<sup>th</sup> week of the incubation period. The extraction solutions for the determination of pH and phosphorous were 0.01 M HCl and the Bray-1 solution, respectively. Moisture content was maintained by adding the lost amount during the incubation.

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

#### 4.1 Soil characterisation

**Table 1. General soil characteristics**

pH <sub>CaCl</sub>	Bulk density	Available P	O.M	H	Al	Ca	Mg	K	Na	EC/EC	Fe	Mn	Sand	Silt	Clay
	kg/m <sup>3</sup>	mg/kg	%	cmol(+)/kg soil							mg/kg		%		
4.20	1520	BDL*	2.16	2.12	0.504	0.255	0.075	0.302	0.239	3.50	10.3	25.6	59.1	27.5	13.4

\*BDL--below detection limit

Table 1 show that the soil was very strongly acid and the soil was deficient in plant extractable phosphorus. The phosphorus content of the soil was below the detection limit of the Jenway 6700 Visible Spectrophotometer at wavelength of 882 nm. The concentration of hydrogen ions was 2.12cmol/ kg. High concentration could be as a result of relatively high organic matter content. The organic matter could have contributed to the release of hydrogen ions especially from the functional groups during decomposition. The concentrations of iron and manganese were 10.3and 25.6 mg/kg. respectively. These ions participate in precipitation reactions with phosphate anions and can form insoluble compounds, which hinders the availability of phosphorus in the soil solution. The aluminium saturation in this soil was 14.4%, which shows that aluminium was not the main contributor to soil acidity. The texture class of the soil was sandy loam according to the USDA Texture Triangle.

#### 4.2 Characterization of liming materials

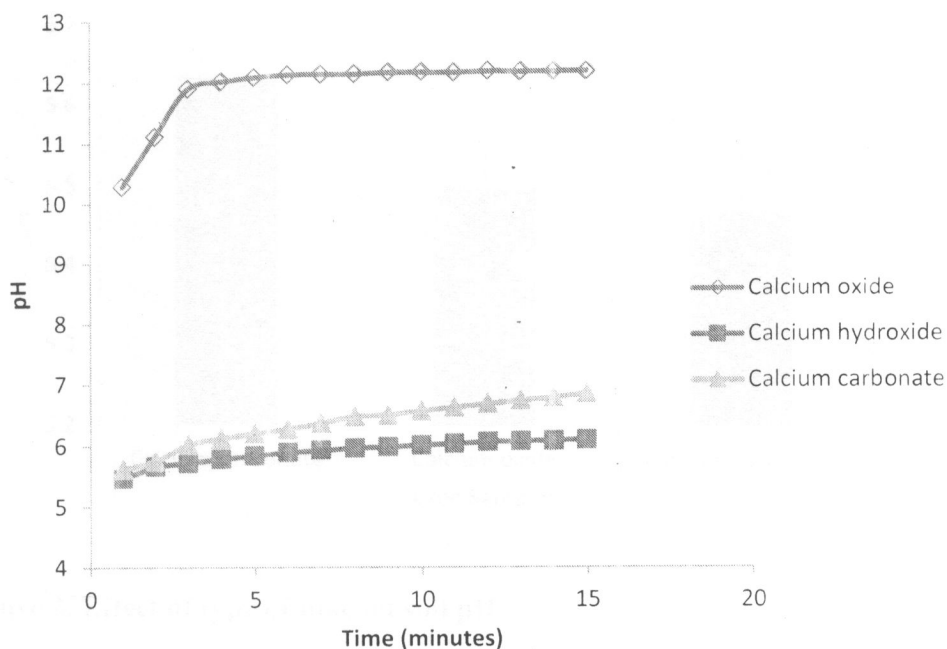
**Table 2. Neutralising values of liming materials**



Lime type	Calcium carbonate (CaCO <sub>3</sub> )	Calcium hydroxide (Ca(OH) <sub>2</sub> )	Calcium oxide (CaO)
Neutralising value	95%	117%	160%

Table 2 shows the neutralizing values or calcium carbonate equivalencies of the liming materials used in the study. By definition, the neutralizing value refers to the quantity of acid that a given mass of lime is able to neutralize in comparison with the same weight of pure calcium carbonate. As shown in Table 2, the neutralizing values of the liming materials were 95%, 117% and 160% for calcium carbonate, calcium hydroxide and calcium oxide, respectively. Different liming materials have a wide range of calcium carbonate equivalencies depending on their chemical composition. Typically the higher the calcium carbonate equivalence, the more effective the product at neutralizing soil acidity (Taworn, 2004).

Calcium oxide is very reactive compared to the other two liming materials because it had the highest neutralizing value. From the calculated neutralizing values, it was shown that calcium oxide is able to react and neutralize acid 1.7 times more effective than the same quantity of calcium carbonate. Calcium hydroxide is more reactive than calcium carbonate hence it is capable of neutralizing soil acidity of the soil by 1.2 times calcium carbonate equivalent. Therefore, the actual amount of lime added to the soil was determined based on the neutralizing values of the lime used.

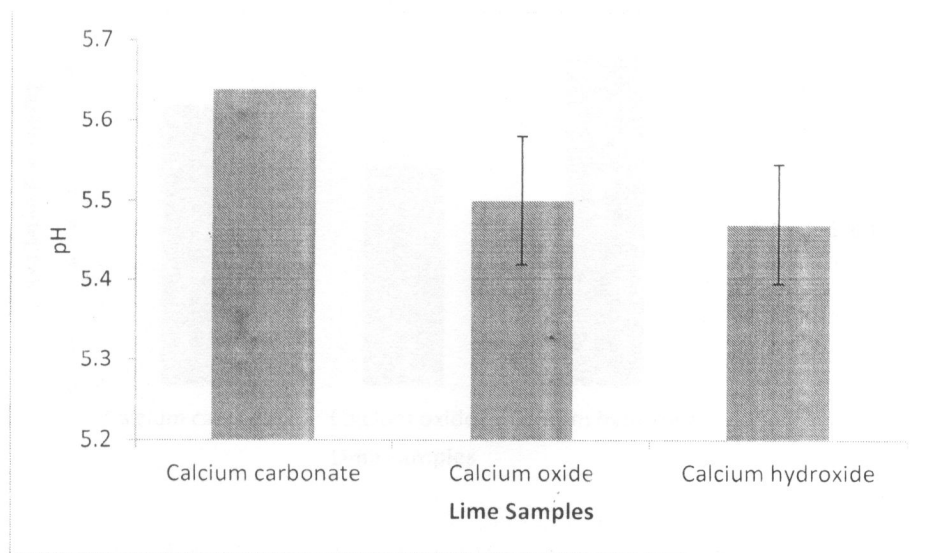


**Figure 1. Reactivity of liming materials**

#### 4.3 Characterization of lime reactivity

Figure 1 shows the reactivity of calcium oxide, calcium hydroxide and calcium carbonate. As shown above calcium oxide had the highest acid-neutralizing capacity, followed by calcium carbonate and the least-effective being calcium hydroxide. The pH values for the different liming materials ranged from 10.1 to 12.19, 5.63 to 6.85 and 5.63 to 6.08 for calcium oxide, calcium carbonate and calcium hydroxide, respectively after 15 minutes reaction with 0.2 *M* acetic acid with an initial pH of 3.0. Calcium oxide reacted with acid and raised the pH of the soil faster than calcium carbonate and calcium hydroxide.

#### 4.4 Effect of type of lime on pH and P availability

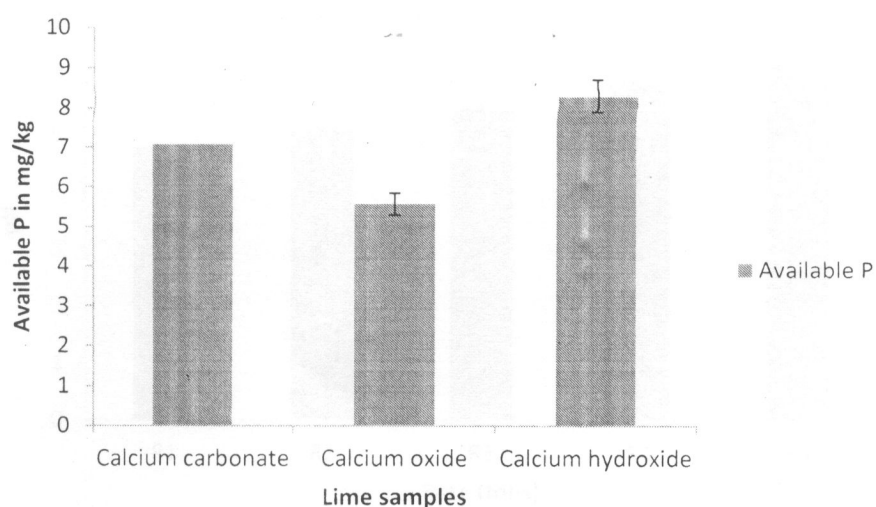


**Figure 2. Effect of type of lime on soil pH**

#### 4.5 Effect of lime type on pH

From figure 2 above, there were no significant differences in the mean pH values attributed to the type of liming material applied. The pH values ranged from 5.48 to 5.64, with mean values of 5.64, 5.50 and 5.48 for calcium carbonate, calcium oxide and calcium hydroxide, respectively. The three types of lime had a similar effect on pH, in that the experiment was short- term and also the fact that the applied quantities depended on Neutralizing values. Lime with low NV meant applying more lime compared with the lime with a higher NV.

On the other hand, there were significance differences in P availability among the different liming materials. The means of available phosphorus were as follows: 8.30, 7.08 and 5.56 mg P/kg for calcium hydroxide, calcium carbonate and calcium oxide, respectively.

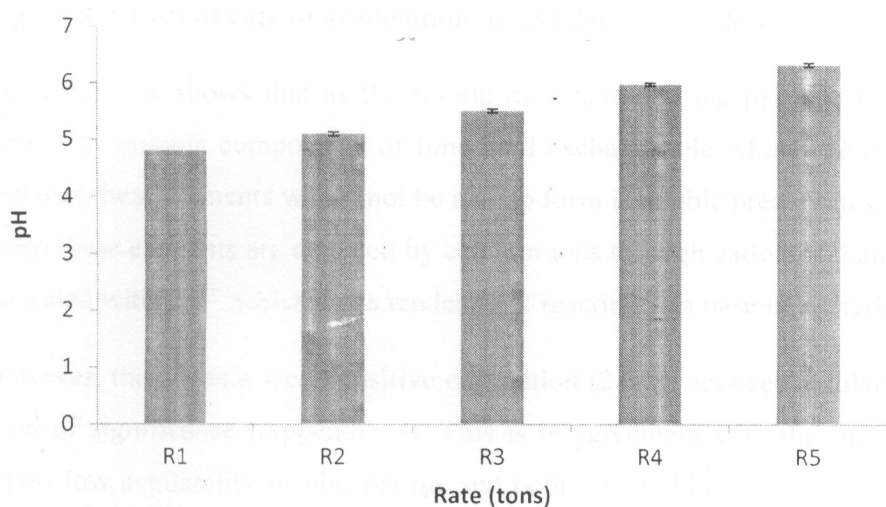


**Figure 3. Effect of lime type on P availability.**

Figure 3 shows that, there were was significances differences in the observed mean values of available P. Mean value of available phosphorous were 7.08, 5.56 and 8.30 for Calcium carbonate, Calcium hydroxide and Calcium oxide respectively. These differences could be as result of differences in chemical composition of elements in their molecular and chemical structures and the particle size distribution of the liming material (Taworn, 2004).

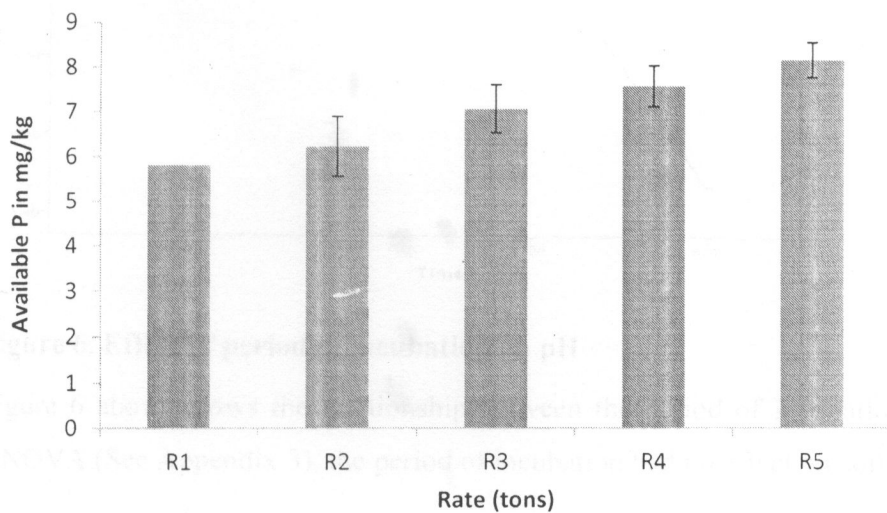
#### **4.6 Effect of application rate on pH and P availability**

Appendix 2 shows that the rate of lime application had a significant effect on pH and available phosphorus.



**Figure 4. Effect of rate of application on pH**

Liming rate significantly ( $P < 0.001$ ) increased soil pH and phosphorus availability. Mean pH values ranged from 4.80 to 6.31, while mean Bray-1 extractable phosphorous ranged from 5.80 to 8.18 mg P/kg. The minimum values were from the lowest rate of application while the highest values were obtained from the highest rate of application, respectively.



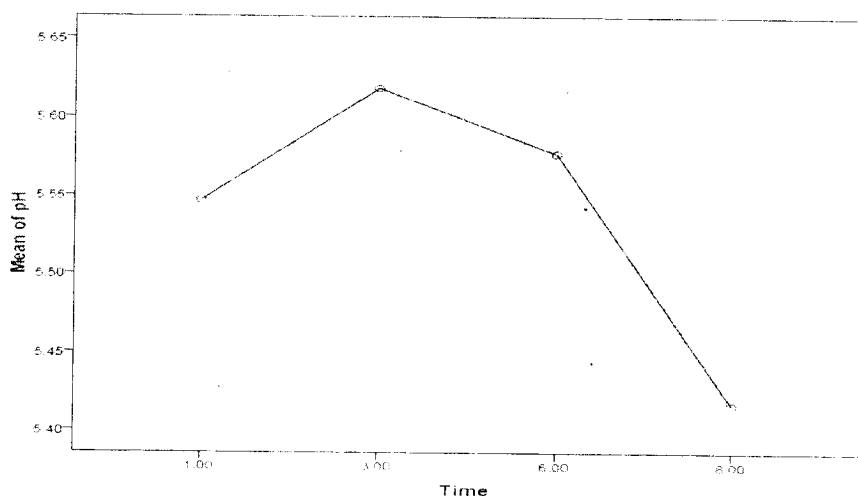
**Figure 5. Effect of rate of application on available phosphorus**

From figure 4 shows that as the liming rate increased the pH also increased. When an acid soil is limed, the anionic components of lime bind exchangeable Al and Fe and form insoluble compounds, and thus these elements would not be able to form insoluble precipitates with available P. Additionally, when these elements are replaced by calcium ions through cation exchange, the exchange sites become saturated with  $\text{Ca}^{2+}$ , which has a tendency of reacting as a base in its hydrolysis reactions.

However, there was a weak positive correlation (24 %) between available phosphorus and pH at 0.01 level of significance (Appendix 4). This is in agreement with the findings of other researchers who report low availability of phosphorus and both low and high pH levels (Brady and Weil, 2010). This implies that as the pH decreases, the plant extractable phosphorus also tends to decrease.

#### **4.7 Effect of period of incubation on pH and available P**

Appendix 3 shows that the period of incubation had no significant effect soil pH, while significant differences were observed in the mean values of available phosphorus.

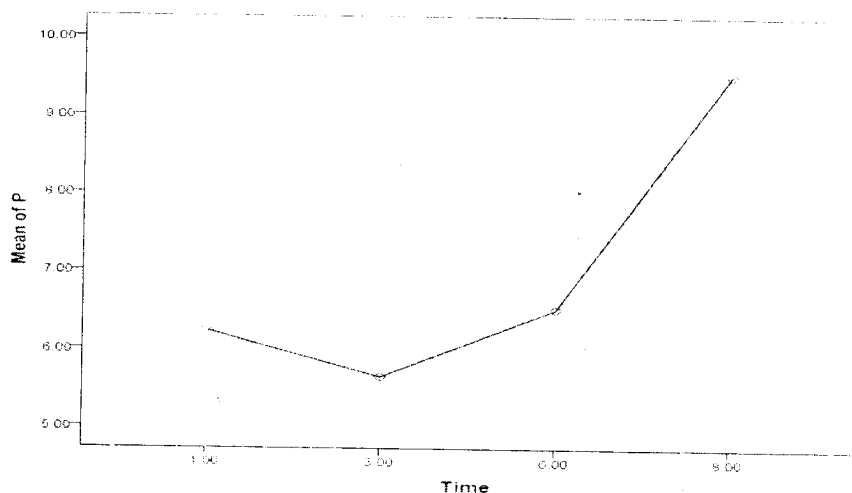


**Figure 6. Effect of period of incubation on pH**

Figure 6 above shows the relationship between the period of incubation and soil pH. Based on the ANOVA (See Appendix 3), the period of incubation had no effect on soil pH.

The insignificance of the period of incubation on soil pH can be explained by the fact that the neutralization reaction between lime and exchangeable acid in the soil could not be sustained for a

longer-term probably due to good buffering capacity of the soil under study. Strongly acid soils tend to be very well buffered due to high levels of exchangeable aluminium which hydrolyses to produce hydrogen ions. To solve this challenge, frequent liming is recommended until a stable pH is attained (Barrow, 1967).



**Figure 7. Effect of period of incubation on available phosphorus**

#### **4.8 Effect of period of incubation on available phosphorus**

Figure 7 above shows the relationship between the periods of incubation and available phosphorus. Based on the ANOVA (See Appendix 3), the period of incubation had a significant effect on available phosphorus. The observed means of available phosphorus ranged from 6.23 to 9.53mgP/kg. This could be due to formation of insoluble compounds when anion groups from the lime react with exchangeable acidity, manganese and iron. This may have allowed the fixed phosphorus in the soil to be released into the soil solution with time resulting in a raised mean available phosphorous content of the soil. It is important to note however, that this effect can only go on up to a certain pH level beyond which the mean values of available P would fall due to complexation of available P with exchangeable calcium to form insoluble calcium phosphate compounds (Marschner, 1995).

## **CHAPTER FIVE**

### **5.0 CONCLUSIONS**

Results of the study have shown that increasing the rate of lime raised the pH significantly. This also raises the amount of available P only up to the pH of 6.5 beyond which the amount of available P is expected to start falling.

The neutralizing values of calcium oxide, calcium hydroxide, and calcium carbonate were, 160%, 117% and 95%, respectively. The reactivity of lime was in the order calcium oxide, calcium hydroxide and calcium carbonate, starting with the most reactive lime to the least reactive. The effectiveness of the liming materials was influenced by their reactivities. Calcium oxide was able to raise the pH of the soil at a faster rate than calcium carbonate and calcium hydroxide. However, there was a weak positive correlation between the levels of available phosphorus and pH at 99% confidence level with a correlation coefficient of 0.24.

### **5.1 RECOMMENDATION**

I would recommend that a similar study should be done to compare aluminum saturated method of calculating actual lime required and buffer pH method to come up with the most effective method. This could then be followed by an economic evaluation of cost and assess which one is economically feasible.



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7.0 APPENDICES

Appendix 1. ANOVA Table showing the effect of type of lime on pH and available phosphorus

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.925	2	.462	1.342	.264
	Within Groups	60.986	177	.345		
	Total	61.910	179			
P	Between Groups	224.991	2	112.495	13.249	.000
	Within Groups	1502.871	177	8.491		
	Total	1727.862	179			

Appendix 2. ANOVA Table showing the effect of application rate on pH and P availability

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	54.575	4	13.644	325.485	.000
	Within Groups	7.336	175	.042		
	Total	61.910	179			
P	Between Groups	134.783	4	33.696	3.701	.006
	Within Groups	1593.079	175	9.103		
	Total	1727.862	179			

Appendix 3. ANOVA Table showing the effect of period of incubation on pH and available P

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	1.026	3	.342	.988	.400
	Within Groups	60.885	176	.346		
	Total	61.910	179			
P	Between Groups	407.704	3	135.901	18.118	.000
	Within Groups	1320.158	176	7.501		
	Total	1727.862	179			

Appendix 4. Pearson correlation coefficients between pH and P

		pH	P
pH	Pearson Correlation	1	.240**
	Sig. (2-tailed)		.001
	N	180	180
P	Pearson Correlation	.240**	1
	Sig. (2-tailed)	.001	
	N	180	180

\*\* Correlation is significant at the 0.01 level (2-tailed).