

EVALUATION OF THE CONTRIBUTION OF RESIDUAL
FERTILIZER PHOSPHORUS TO PHOSPHATE STATUS AND
PLANT GROWTH UNDER CONSERVATION AGRICULTURE
PRACTICE

BY

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DECLARATION

I Mung'ambata Monica, hereby declare that all the work presented in this dissertation is my own and has never been submitted for a degree at this or any other university

Signature

Date

APPROVAL PAGE

This dissertation of Ms. Mung'ambata Monica is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Integrated Soil Fertility Management by the University of Zambia

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ABSTRACT

Conservation Agriculture (CA) practice is reported to increase the level of total P in soil after a few years of cultivation with fertilizer application. Measures to ensure efficient utilization of the residual P in soil can, therefore, be of great importance, especially in acid soils where the amounts of residual P which is not plant available can be significant. This study was conducted to establish the levels of residual fertilizer P in soils that had been under CA for five years and to investigate whether the residual fertilizer P could be made available to plants by applying, agricultural lime or organic matter or a combination of the two to the soils. Two acid soils under CA were used as test soils in the study. Total P contents and the chemical fractions of P in the cultivated and adjacent non-cultivated soils were determined. The residual fertilizer was calculated as the difference between the total P levels in the cultivated and non-cultivated adjacent soils. A greenhouse crop trial was carried out to investigate whether the release of the residual fertilizer P could be enhanced by applying agricultural lime or organic matter or a combination of the two to soils. This was laid out as a completely Randomized Design with four treatments, namely, soil alone (control), soil with organic matter, soil with agricultural lime, and soils with organic matter and agricultural lime with four replicates. The levels of total P in cultivated soils were significantly ($p < 0.05$) higher than those in the adjacent non-cultivated soils and P was mainly associated with Fe and Al compounds. The cultivated soils had significant amounts of residual fertilizer P which ranged from 7 to 38 % of the total P. Applying organic matter or agricultural lime or combination of these significantly ($p < 0.05$) increased the levels of plant available P, P uptake and dry matter yield. The order of the increase in available P, plant uptake of P and maize dry matter yield due to treatments were as follows: Agricultural lime + OM > agricultural lime alone > OM alone > the control. Further confirmation of the positive effect of soil amendments on the release of residual P was provided by significant positive correlations between plant available P in the soils and maize dry matter yield. Results of this study have demonstrated that applying agricultural lime and organic matter to soils enhances the release of residual fertilizer P in soils and can therefore, be used to increase fertilizer P use efficiency in CA cropping systems.

To you late dad, you will always be my greatest inspiration

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

In Zambia it is estimated that 70% of the population depend on agriculture for its livelihood and agriculture engages 67% of the labour (GRZ 2004). Most of small holder farmers who constitute this group, like in many other sub-Saharan African countries, still face serious challenges in production due to soil fertility problems and their inability to afford adequate amounts of chemical and organic fertilizers for maximum yields. The soil fertility problems according to Veldcamp (1987) are attributed to the fact that most tropical countries have acidic soils which generally have low levels of nutrients. Therefore, soil amendments such as application of lime, organic matter and adequate plant nutrients is necessary.

In addressing nutrient problems the Zambian Government through the Ministry of Agriculture and Livestock has used many wealth enhancement strategies such as the introduction of subsidies on inputs and adoption of Conservation Agriculture (CA) as a method of production. The subsidized input package to smallholder farmers consists of chemical fertilizer and seed which are based on a blanket fertilizer recommendation of 200 kg/ha of Compound D fertilizer (10:20:10) as basal dressing and 200 kg/ha of Urea (46%) as top dressing every cropping season. This practice and CA have been Zambia's cornerstone of government policy to improve smallholder productivity in recent years. According to Minde *et al.* (2008) CA increases the fertilizer use efficiency and can result in accumulation of nutrients in the soil. However, although farmers have adopted CA practices for the reason above and have access to subsidized fertilizers the challenges of low yields remain unsolved. In a study that was done in Zambia, Umar (2012) reported

that no evidence of soil improvement benefits due to CA system were observed and this was attributed to failure in incorporating the important soil fertility enhancing components of CA.

It is clear that even when fertilizers are applied soils still remain unproductive due to low fertilizer use efficiency. The low fertilizer use efficiency is mainly caused by soil fertilizer reactions which render nutrients unavailable. This was also corroborated by Donovan *et al.*, (2002) whose findings showed that chemical fertilizer use is not profitable particularly in Zambia and suggested that farmers were better off focusing their efforts on improving soil and crop management practices than increasing the use of fertilizer.

Among all the soil nutrients phosphorus (P) is one of the most limiting to plant nutrition (Donahue *et al.*, 1983; Wang *et al.*, 2010) whose deficiency is a major constraint that limits crop production in acid soils. In soils P reacts with most common cations where it is strongly held and remains insoluble (Basamba *et al.*, 2006). It is very clear that these soil deficiencies can, therefore, be in absolute terms where soils are inherently deficient in P or that it can be due to its presence in forms that are unavailable for plant uptake. Phosphorus deficiencies are usually remedied by applying phosphate fertilizers (Donahue *et al.*, 1983).

In Zambia an average of 35 kg/ha P₂O₅ is applied every cropping season. However, the recovery of applied fertilizers differ depending on the soil type. It is reported that when P fertilizers are applied in soils it reacts with common cations and form stable compounds, rendering it less soluble (Sample *et al.*, 1980). In a recent study it was reported that the recovery of the applied P fertilizer was in the range 15-25% in irrigated areas and approximated to be much lower in arid areas

(Chattha *et al.*, 2007). This means that very little is used in one cropping season, implying that a residual value of at least 80% remains in the soil with annual crop utilization estimated only at 20%. A portion of this residual fertilizer P could be potentially available to plants with selected management practices and therefore represents a valuable pool of P that can be used to optimize P fertilization, especially in CA systems where fertilizers are banded with a minimum soil disturbance of between 9-11% (Umar, 2012).

With minimum soil disturbance to dilute the P concentrations, repeated P fertilizer applications can result in a steady build-up of residual fertilizer P in the soil. For this reason the amount of residual fertilizer P in CA systems could be higher than in conventionally cultivated soils. Depending on the pH levels residual P is in the form of insoluble compounds. In acid soils these compounds are dominated by Fe/Al phosphate compounds and in alkaline soils are in Ca phosphates. Therefore, selected management practices such as application of lime and organic matter reported to influence the soil pH can release the insoluble P. Sanchez and Uehara, (1980) reported that both lime and the humic acids released during mineralization of organic matter precipitates exchangeable Al, hence decreasing P fixation.

Although repeated P fertilizer applications result in a steady build-up of residual fertilizer, there is paucity of information on the residual fertilizer P value, the agronomic effectiveness of this residual fertilizer P and how its release for the following crop can be effected especially under CA in Zambia. The knowledge of the magnitude of residual fertilizer P and the composition of P in this component of soil P can provide a key to finding appropriate management practices that could be used to release this unused P to enhance its contribution to the plant available phosphate status of the soil and plant growth.

1.2 Objectives

The objectives of this study were to:

1. Determine the residual value and forms of phosphorus fertilizer in soils under Conservation Agriculture practices.
2. Determine whether applying organic matter, lime or a combination of the two to an acid soil unlocks residual P and increase plant available P
3. Determine whether applying organic matter, lime or a combination of the two to an acid soil increases plant uptake of P

1.3 Research Hypotheses

The hypotheses that were tested were;

1. There are significant differences in the total P content and forms in which it occurs in soils under Conservation Agriculture practices and those of the similar adjacent soils that have not been fertilized.
2. Applying either agricultural lime, organic matter or a combination of the two to acid soils with residual fertilizer P increases the levels of available P.
3. Applying either agricultural lime, organic matter or a combination of the two to acid soils with residual fertilizer P increases plant uptake of P.

CHAPTER TWO

LITERATURE REVIEW

2.1 Phosphate Levels in the Soil

Phosphorus makes up only 0.1 % of the earth's crust and mainly occurs as the mineral apatite which serves as the natural source of soil phosphorus (Tisdale *et al.*, 1985; Barančíková *et al.*, 2007). However the native sources of P for plant growth are the minerals and organic matter present in the soil. According to Barančíková *et al.*, (2007) in soils about 90% of the phosphorus occurs in insoluble or soluble fixed forms and mainly exists as either organic or inorganic P. Depending on the on the soil type the levels of these two major components of P varies. The organic P levels generally accounts for between 20-50% of soil total P (Lupwayi *et al.*, 2007). Very high levels have also been reported in highly weathered Oxisols, Ultisols and Alfisols (Youdeowei *et al.*, 1985; Sattell and Morris, 1992). In a recent study done on a wide range of Zambian soils organic P was reported to be 15% on average (Yerokun 2008). Due to its high levels organic P is the main source of P under traditional farming systems in Africa although inorganic P pool is generally more important for crop nutrition as it is the most common form of P in soil. Landon (1984) also reports that inorganic P levels are generally higher than organic P in mineral soils except in organic soils where organic P levels are higher.

2.2 Availability of soil P for plant uptake

Phosphorus reacts with common cations where it is strongly held and remains insoluble. It is generally not mobile in soil (Tracy *et al.*, 1990). Its availability depends on pH which influences the nature of its reactions and the products formed thereof (Engelstad and Terman., 1980). In acid soils, strong acid

reactions and the abundance of Al and Fe ions are the major causes of phosphorus deficiencies, as is typical of most highly weathered tropical soils (Moazed *et al.*, 2010). Chattha *et al.* (2007) report that other factors which influence P availability include abundance of calcium carbonates, organic matter, crop husbandry practices and soil texture. The abundance of Ca, Al and Fe ions in soil can lead to formation of oxide and hydroxide compounds of P. These are generally insoluble and make P remain unavailable to plants.

In comparison with other major nutrients, P is by far the least mobile and it is therefore likely to be greatly affected by land husbandry practices such as tillage. This effect is facilitated by the mechanical manipulation of soil done during tillage operations which increases the chances of contact between soil P and the exposed soil particles resulting into formation of insoluble P compounds (Basamba *et al.*, 2006).

According to Lungu (2009) high amounts of clay and soil organic matter have a high capacity for retention of H^+ and Al^{3+} ions which are closely related to P sorption. In soils with similar pH, P fixation tends to be more and P release tends to be lowest in soils with high clay content (Chattha *et al.*, 2007). Youdeowei *et al.* (1985) also report that the rate and amount of organic matter mineralized determined the availability of organic P to plants.

The above reactions create various pools of P that are not plant available, and consequently increase the need for P fertilizer application. Depending on the pH levels, P deficiencies remain a limiting factor to crop production even on soils fertilized with P. The deficiencies observed on such soils are mainly due to conversion of P applied as phosphate fertilizers to less available forms resulting in the accumulation of residual P that is not available to plants (Basamba *et al.*, 2006). According to Mahmood *et al.* (2000) more than 80% of fertilizer P

applied becomes unavailable for plant uptake either due to adsorption to the soil, precipitation into the insoluble compounds or both. This phenomena in which P fertilizer in soils are converted from soluble states to less soluble states is P retention or P fixation. This according to Samadi (2006) is attributed to surface sorption and precipitation mechanisms

2.3 Phosphate Sorption

Phosphorus fixation is generally a frequent problem in acid soils with high content of finely divided sequioxides and less frequent in calcareous soils and rarely in soils without sequioxides or carbonate (Sanchez and Uehera, 1980). Phosphate fixation is the removal of phosphate from a phosphate solution by chemisorption and anion exchange (Sample *et al.*, 1980). Several models have been used to describe P sorption and the most popularly used equations are those of Langmuir and Freundlich. The sorption isotherms are used to estimate buffering capacities of the different soils and also provide a basis for estimating amounts of P required to bring the different soils to various levels of adequacy for crop production (Kamprath and Watson, 1980). Barrow (1980) showed that the P sorption of soil depends on the P buffering capacity of the soil which is agronomically important for it can be a limiting factor in P uptake (Holford and Mattingly, 1975). The ratio between the amount of P fixed and soil solution P at an equilibrium concentration is regarded as the buffering capacity of a soil (Holford and Mattingly, 1975). Different soil constituents such as clay, CaCO₃, Fe-oxides and Al-oxide are involved in the P sorption reactions and these constituents of the soil contribute to the different binding strengths and buffering capacities of soil P pools.

Sanchez and Uehara (1980) report that the critical level of P in solution required for plant growth is 0.2 ppm and that concentrations below this are an indication

of P deficiency. Phosphorus availability to plants, however, depends on the common cations and in most soils it is maximum when pH levels are maintained near neutral Barančíková (2007). It is, therefore, important to know the different fractions of P in the soil in order to devise management practices that can release the fixed P to increase P in solution to the required level for plant growth. Because of this, the use of agricultural lime and organic matter becomes very critical especially in the tropics (Basamba *et al.*, 2006) where most soils are generally acidic.

2.5. Effect of Organic Matter on the levels of soil P.

Organic matter is an important buffer which reduces fluctuations in soil acidity, (Donahue *et al.*, 1983) and makes P available by enhancing microbial activities. Organic matter increases soil microbial activity consequently increasing the products of decay such as humus and organic acids which include sulfuric acid and nitric acid (Khau *et al.*, 2009). These organic acids solubilize the insoluble P compounds by chelating the cations bound to P through their hydroxyl and carboxyl groups. Sample *et al.* (1980) reported that organic matter affects the reaction of P in soil by complexing Ca ions and competing for exchange sites with P. This reduces the bonding energy of P to solid particles and consequently increases the P concentration in the soil solution.

In CA tillage systems where crop residues are retained, with continued application of organic matter, P levels are reported to be higher. However, a study in Zambia by Umar *et al.* (2011) found that there is low usage of manure in households that do not own livestock and that there is no retention of crop residues in fields under CA especially in the southern and central regions of the country where residues are routinely fed to livestock and grazed by free range livestock even in fields belonging to farmers that do not own livestock. This

practice defeats the purpose of CA, as farmers cannot get the full benefit of CA, achieved through usage of organic matter and retention of crop residues in their fields. Demonstrating the beneficial effect of residue management can encourage small holder farmers to find ways of protecting their fields from free range livestock.

2.6 Effect of Lime On soil P levels

The most common and effective way of correcting soil acidity is to apply agricultural lime (Lungu, 2009). Agricultural lime causes chemical reactions that raise soil pH by neutralizing H^+ and Al^+ after converting H^+ ions to water and precipitating Al to $Al(OH)_3$. The reaction that converts H^+ to water is $2H^+ + CaCO_3 \leftrightarrow Ca^{+2} + CO_2 + H_2O$ and the hydrolysis reaction according to according to Sanchez and Uehara (1980) is $Al^{3+} + 2H_2O \rightarrow Al(OH)_3 + 2H^+$ which result into precipitation of exchangeable Al. Once the exchangeable Al is precipitated the soils fix less P and the bonding energy between sorbed P and oxides surface is reduced as their negative charge increases with increasing pH. In a study by Costa and Rosolem (2007) it was shown that liming was an effective way to deal with soil acidity and Al toxicity. It increased the pH and levels of Ca and Mg and decreased toxicity of Al. In another study on Brazilian Oxisols, Sanchez and Uehara (1980) reported that a significant proportion of the P sorbed at pH 4 was released when pH was increased to 7. Results such as these demonstrated the potential benefit of using agricultural lime to optimize the usage of phosphate fertilizers.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area

Soils used in this study were obtained from Monze District, in the Southern Province of Zambia (Table 1). The district is in Region II of Zambia’s Agro-ecological Zone. The selection of the study area was premised on findings by Derpsch (2008) that showed that P accumulation in CA fields begins to show between 5 and 10 years “the transition period”. Monze has had a long history of CA practice that covers this period. The other consideration in the selection of the site was accessibility of the area to the researcher for close monitoring. The study area has three seasons, namely a hot- rainy season from November to March, cool - dry season from April to August and a hot- dry season from September to October.

Table 1: The geographical location and altitude of the sites selected for the study.

Site	Location				Altitude
Kaumuhya	S	16 ^o	05'	09.5"	1063m
	E	27 ^o	35'	00.5"	
Kayuni	S	16 ^o	11'	22.5"	1090m
	E	27 ^o	30'	49.1"	
Little valley	S	16 ^o	15'	30.5"	1108m
	E	27 ^o	34'	51.6"	
Muzuri	S	16 ^o	18'	01.8"	1132m
	E	27 ^o	30'	14.6"	

3.2 Soils

The soils used in this study were pairs of cultivated soils and similar adjacent (inter-row / non-cultivated) soils obtained from sites with five year old CA fields where farmers rotate maize with cotton, groundnuts and beans. According to the Exploratory Soil Map of Zambia (1991) these soils used in the study are moderately weathered fine loamy to clayey classified as Alisols according to FAO UNESCO revised legend (1997) or Alfisols in the USDA system. The soils are well drained, moderately deep to deep, friable and moderately weathered fine loamy to clay soils.

3.3 Site Selection Criteria

The selection of sites used in the study was based on the soils being acid, and their having been used for at least 5 years under CA practices, and therefore, expected to have a considerable accumulation of residual fertilizer P.

3.4 Methods of Sampling

A stratified random sampling method was used to collect soil samples. Samples were collected from the top 20 cm of the soil. At each site the field was divided into approximately 4 equal quadrants and samples were collected in each quadrant from both the ripped furrows and adjacent inter-row spaces in the field at sites where farmers used ripping as a means of tillage and from the basins and adjacent inter-row space at sites where farmers dug permanent basins as a means of tillage. Two sets of bulk samples were collected consisting of paired samples from cultivated and non-cultivated adjacent soils. The soil samples were air dried for several days, crushed, and passed through a 2 mm sieve. The portion of soil passing through the 2 mm sieve was retained for further analysis.

3.5 Data Collection

Lead farmers whose fields were selected for sampling were interviewed to find out the land management practices they employed on the CA plots. These included information relating to the application of inorganic fertilizers, lime, practices of crop rotation and the type of crops grown. Field observations were also made to establish the extent of crop residue retention on land, the size of plots, tillage system used and type of crop residues retained in the field.

3.5.1 Characterization of soils obtained from the field.

The soils obtained from the four sites selected (presented in Table 1) were analyzed for their pH, bulk densities, particle size distribution, plant available phosphorus and total P. The residual fertilizer phosphorus was then calculated for each soil obtained from cultivated fields. Detailed description of the methods used to determine the above listed soil properties are described below.

3.5.1.1 Soil reaction

The soil samples were analyzed for soil reaction (pH) in 0.01M CaCl₂ according to McLean (1982). Ten grams of soil was weighed into a beaker and 25 ml of 0.01 M CaCl₂ was added. The samples were shaken for 30 minutes on a mechanical shaker before measuring pH in the supernatant solution using a pH meter.

3.5.1.2 Bulk Density

The core ring method was used to determine the soil bulk density. Undisturbed samples of soils were collected from the field using 5 cm long x 5 cm wide

cylindrical steel core rings with open ends .The samples were oven dried at 110⁰ C for 24 hours, allowed to cool in a desiccator. The soils were then weighed to determine the oven dry mass. The soil bulk density was calculated using oven dry mass of the soil and the internal volume of the core ring.

$$\rho_b = \frac{\text{mass of oven dry soil}}{\text{internal volume of core ring}} \left(\frac{g}{cm^3} \right)$$

The dry bulk densities of the soils were used to calculate the amounts of various soil amendments to be applied to the soils in a greenhouse experiment.

3.5.1.3 Particle Size Distribution

The particle size distribution of the soil samples was determined using the Hydrometer Method. Fifty grams of soil sample was placed in a dispersing cup to which 50 ml of dispersing agent sodium hexamataphosphate (calgon) solution was added. The dispersing cup was half filled with distilled water and the soil suspension was then stirred using an electric stirrer for 5 minutes. The suspension was then transferred in a 1 litre sedimentation cylinder. A blank solution was also prepared using the dispersing fluid and distilled water only. The temperature of the suspension was then measured and a plunger was used to agitate the suspension after which the hydrometer was carefully lowered into the suspension after 20 seconds and the reading taken at 40 seconds. This was repeated after 2 and 8 hours for both the sample suspension and the blank. The percentage of sand in the sample was calculated as:-

$$\% \text{ Sand} = 100 - 2\{ (40 \text{ seconds reading} - \text{blank}) \pm \text{temperature correction factor} \}$$

The hydrometer reading taken after 8 hours was used to determine the amount of clay in the sample and was calculated as:-

$$\% \text{ Clay} = 2\{ (8 \text{ hour reading} - \text{blank reading}) \pm \text{temperature correction factor} \}$$

The percentage of silt present in the soil was calculated as the difference of 100% and the sum of the percentages of clay and sand, as:-

$$\% \text{ Silt} = 100 - \% \text{ Sand} + \% \text{ Clay}$$

The percentages of sand, silt and clay obtained from the analysis of the particle size distribution were plotted on the USDA Textural Triangle to determine the textural class of the soil.

3.5.1.4 Plant Available Phosphorus

The plant available P content of the soil were determined using the Bray-1 extracting method as described by Olsen and Sommer (1982). Three grams of air dried soil was placed in a 100 ml plastic and 21 ml the Bray 1 extracting solution was added and the mixture shaken for one minute. The Bray 1 extraction solution consisted of 15 ml of 1N ammonium fluoride salt (NH_4F) mixed with 25 ml of 0.5 M HCl and 460 ml distilled water. The soil suspension was then filtered and 5 ml of the filtrate was pipetted into a 25 ml volumetric flask to which 4 ml of a solution consisting of freshly prepared ascorbic acid mixed with 12 g ammonium molybdate ($(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$) dissolved in 250 cm^3 distilled water and 1000 cm^3 of 2.5 M H_2SO_4 was added to it. The volumetric flask was then filled to the mark with distilled water. The color was allowed to develop and measurements of P in the solution were read on a UV-Visible spectrophotometer at 882 nm.

3.5.1.5 Total P

The total phosphorus contents of the soils were determined colorimetrically following the procedures described by Olsen and Sommer (1982) where 1 g of soil was placed in a 250 ml flask and digested in 10 ml 70 % perchloric acid for 45 minutes. The digest was then transferred into a 250 flask, to which distilled water was added to fill the flask to the mark. A 15 ml aliquot of this solution was then placed in a 25 ml volumetric flask, to which 4 ml of a solution consisting of freshly prepared ascorbic acid mixed with 12 g ammonium molybdate ($(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}$) dissolved in 250 cm^3 distilled water and 1000 cm^3 of 2.5 M H_2SO_4 was added. The volumetric flask was then filled to the mark with distilled water. The colour was allowed to develop and the concentrations of P in solution were read on a UV-Visible Spectrophotometer at 882 nm.

3.5.2 Residual Fertilizer P

The residual fertilizer P in this study was defined as the amount of fertilizer P that remains in soil after cropping. It was calculated as the difference between the quantities of total P in soils where fertilizer P had been applied and that of adjacent soils where fertilizers P has not been applied. Thus the residual P was evaluated as:-

Residual fertilizer P =

$$\textit{Total P in fertilized cultivated} - \textit{Total P in un fertilized adjacent soil}$$

In a preliminary study the residual fertilizer P values for the four soils were calculated and two soils with the highest residual value were then selected for detailed characterization and greenhouse crop trial.

3.5.2 Further Characterization of Two Selected Soils.

The two soils selected based on their high residual fertilizer P values were further tested for their exchangeable acidity, exchangeable bases, organic carbon, fractionation of P to determine the forms in which residual fertilizer P occurs and for P sorption characteristics.

3.5.2.1 Exchangeable Acidity

Exchangeable acidity (Al^{3+} and H^+) were extracted in 1M KCl and determined by titration with NaOH (Grant, 1982). Ten grams of air dried soils was placed in a 250 ml flask and 100 ml of 1M KCl solution added. The suspension was shaken and then filtered. To the filtrate 5 drops of phenolphthalein indicator was added and the mixture titrated with concentrated NaOH to determine exchangeable acidity. To the same flask NaF solution was added and 0.01M HCl used to titrate the filtrate to determine exchangeable Aluminium and hydrogen.

3.5.2.2 Exchangeable bases

The exchangeable bases Ca, Mg, K and Na were extracted in 1M ammonium acetate and determined by Atomic Absorption Spectroscopy as described by Grant (1982). Five grams of air dried soil was placed in a 100 ml plastic bottle to which 25 ml of ammonium acetate solution buffered at pH 7 was added. The suspension was shaken, filtered and the filtrate analyzed for Ca, Mg, K and Na by Atomic Absorption Spectroscopy (AAS).

3.5.2.3 Soil Organic Carbon

The Organic Carbon content of the soil was determined by the Walkley and Black Wet digestion Method as described by Nelson and Sommers (1982). One gram of sample was placed in a conical flask and 10 ml 1N $K_2Cr_2O_7$ added followed by 20 ml of concentrated H_2SO_4 . The mixture was swirled and left to react for 30 minutes in a fume hood cupboard. After cooling 150 ml of distilled water was added followed by 10 ml of concentrated H_3PO_4 . To this 10 drops of diphenylamine indicator was added to the solution which was then titrated with $FeSO_4$. A Blank was prepared alongside the sample that consisted of all the reagents used in the samples with the only exception being that no soil was added to the reagents. The blank was also titrated with the solution of ferrous sulphate. From the titration volume of the $FeSO_4$ used in the samples and the blank, the organic carbon of the soil was calculated using the formula presented below;

$$\% \text{ Org C} = \frac{0.4 \times (\text{Vol. of blank} - \text{Vol. sample}) \times N}{g \text{ sample}}$$

Where N= Normality of $FeSO_4$ used for filtrating

Vol. blank = volume of $FeSO_4$ used titrate blank in ml

Vol. sample = volume of used $FeSO_4$ titrate sample in ml

g = grams of sample used

From the percentage of organic carbon determined in the sample the organic matter content of the soil was calculated by multiplying it by 2 as given in the formula below

$$\% \text{ OM} = \% \text{ Org C} \times 2$$

3.5.3 Phosphate Sorption (P-sorption)

The P sorption characteristics of the soil were determined following the method of Fox and Kamprath (1970). The soils were treated with potassium dihydrogen

phosphate (KH₂PO₄) prepared in 0.01M CaCl₂ .A 100 mg/l P stock solution was prepared by dissolving 0.43 g KH₂PO₄ in 1litre 0.01M CaCl₂ .From this solution dilutions where made to prepare solutions with concentrations of P ranging from 0, 2.5 5, 10, 25 and 40 mg/l. Two grams of air dried soil samples were placed in a 100 ml plastic container to which 20 ml stock solutions with concentrations of P ranging from 0 to 40 mg/kg were added to plastic containers containing 2 gram samples of soil. Few drops of toluene an organic toxic substance to inhibit microbial activity were added to each container. The soil suspensions were shaken for 30 minutes twice daily for 6 days taking temperature readings at each shaking time. On day 6 after the second shaking the suspensions were filtered. The concentrations of P in the filtrates were then read on a spectrophotometer at 882 nm. The P adsorbed was calculated as the difference between the amount of P initially added to the soil and that recovered after equilibration. The data were then plotted to find out the relation between the amount of P adsorbed and the equilibrium soil solution P concentration. The sorption curves were found to best fit the Freundlich model of adsorption whose linear form is given by the equation below.

$$\text{Log } \frac{x}{m} = \frac{1}{n} \log C + \log K$$

where $\frac{x}{m}$ is the amount of P adsorbed mg/kg , C is the concentration in equilibrium solution and n and K are constants. The data were fitted in this linearized form of the equation to obtain the constants k and n.

3.5.4 Fractionation of soil Phosphorus

The chemical fractions of P refer to the various chemical pools in which soil P occur. The major components of total P include inorganic and organic portions. The fractionation of the different chemical forms of residual fertilizer P was carried out using sequential fractionation method of Chang and Jackson (1957) by

selective dissolution with various reagents described Olsen and Sommer (1982), in preparation the crucibles were first boiled in 1% nitric acid, rinsed and dried. Analysis of the P fractions are described as follows:-

3.5.4.1 Total Soil Phosphorus (Total P)

One gram of soil samples in crucibles were placed in a furnace of 550°C temperature for 3 hours. The samples were then cooled and the cool ignited samples placed in 100 ml containers in which 50 ml of 1N H₂SO₄ was added. The mixture was then shaken for 16 hours after which it was centrifuged for 5 minutes at 2400 revolutions per minute. Five milliliter of the supernatant was used for the colorimetric determination of P on a Spectrophotometer at 882 nm.

3.5.4.2 Inorganic bound Phosphate (Inorganic P)

Inorganic P is phosphorus present in minerals such as apatite, strengite and variscite. To determine soil inorganic P, one gram of soil sample was placed in a 100 ml plastic container, to which 1N H₂SO₄ was added. The suspension was then shaken for 17 hours after which it was filtered. An aliquot of 5 ml of filtrate was then used to determine concentrations of P on a Spectrophotometer at 882 nm.

3.5.4.3. Organically bound Phosphate (Organic –P)

Organic P is the phosphorus present in organic form. This fraction was determined by the loss on ignition method. The amount was calculated by subtracting P in unignited soil samples from P in ignited soil samples, as given in the formula below.

$$\text{Organic P} = \text{P in ignited soil (Total P)} - \text{P in unignited soil (inorganic P)}$$

This method has two major sources of error in extraction procedure which include underestimation due to incomplete extraction or hydrolysis of organic P during extraction (Chang and Jackson, 1957)

3.5.4.4 Iron and Aluminum bound Phosphate (Fe /Al – P)

One gram of soil was weighed into a 100 ml plastic container to which 50 ml of 0.01N NaOH–NaCl solution was added. The suspension was shaken for 17 hours at room temperature and centrifuged at 2400 revolutions per minute. Five milliliter of aliquot was used for the colorimetric determination of P on a Spectrophotometer at 882 nm. The soil residue was then used to determine calcium bound P.

3.5.4.5 Calcium bound Phosphate (Ca- P)

Fifty milliliters of 1N HCl was added to the soil residue that remained in the determination of Fe/Al-P. The suspension was then shaken for one hour, centrifuged at 2400 revolutions per minute for five minutes. Five milliliter of supernatant was used for colorimetric P determination of Ca bound P on a Spectrophotometer at 882 nm.

3.5.4.6 Occluded Phosphorus (Occluded-P)

Occluded P is Al, Fe and Ca-bound phosphate enclosed within coatings of Fe oxides and hydrated oxides. It was calculated by subtracting inorganic P and organic P from total P.

$$\text{Occluded P} = \text{Total P} - (\text{Fe / Al-p} + \text{Ca-P} + \text{Organic P})$$

3.5.5 Greenhouse Experiment

Before the greenhouse crop trials were conducted the following analyses were carried out on the soils and amendments that were used in the greenhouse experiment.

3.5.5.1 Determination of Neutralizing Value of Agricultural lime.

One gram of agricultural lime was weighed into a 250 ml flask to which 25 ml of 1N HCl was added. A blank sample was prepared to which 25 ml of 1N HCl was added without any lime. The suspension with lime was swirled and placed on a hot plate for 10 minutes after which 100 ml distilled water was added and the mixture placed on a hot plate for another minute to boil. The suspension was then cooled, five drops of phenolphthalein indicator added and 1N NaOH was used to titrate to the end point. Exactly the same treatment were carried out on the blank sample. The NV was calculated using the normality (N) of NaOH used in the titration and the volume of NaOH consumed during the titration of sample with lime and the blank. The following formula below was used to calculate the neutralizing value of the lime.

$$\%NV = \frac{N(\text{Vol. blank} - \text{Vol. sample}) \times 5}{g \text{ sample}}$$

Where N= Normality of NaOH used for titration

Vol. blank = volume of NaOH used to titrate blank in ml

Vol. sample = volume of NaOH used to titrate sample in ml

g = grams of sample used

3.5.5.2 Determination of the Lime Requirement

The lime requirements of the test soils were determined using Soil-Lime incubation method described by McLean, (1982). Ten grams of soil samples with 7 replicates were placed in 100 ml plastic container and to the replicates increments of NaOH ranging from 0-5 ml were added. Distilled water was then added to each replicate to make up the volume to 25 ml after which the sample was shaken for 30 minutes. The pH reading was taken immediately after equilibration and the suspension incubated for 10 days. The pH readings were then taken on days 3, 5 and 10. A titration curve relating the pH of the soil to the amount of NaOH used was plotted. The best fitting equation was obtained from which the amount of agricultural lime required to raise the pH to 6.5 was calculated.

3.5.5.3 Analysis of Maize Stover used as organic matter for the experiment.

The dry ashing method was used to determine the mineral composition of the organic residues as described by VanRanst *et al.* (1999). One gram of ground organic residues was placed in crucibles initially treated with 1% nitric acid. The crucibles were placed in a muffle furnace and ashed for 4 hours at 550 ° C and then cooled. The ash was transferred in a conical flask and dissolved in 20 ml of 1% nitric acid. The mixture was heated for 20 minutes, cooled, filtered and the filtrate diluted to 100 ml. The filtrate was then analyzed for Ca, Mg, K, Fe, Zn, Mn, and Cu using the Atomic Absorption Spectroscopy while the colorimetric method was used to determine the P concentrations. The Walkley and Black method was used to determine organic carbon content of the crop residues.

3.5.9 Greenhouse Crop Trials

The soils used in the pot experiment were from Muzuri and Little Valley farms. To each of the two soils used in the crop trials four treatments summarized in the Table 2 were applied.

Table 2: Description of the treatment used in the study

Treatment	Description of Treatments
Control	Soil Alone (3 kg soil / pot for both soils)
Soil + Organic matter	(2.91 kg soil + crop residues 90 g / pot (for both soils)
Soil + Lime	(3 kg soil +1.2 g Lime) /pot for Muzuri, (3 kg soil + 2.7 g Lime) /pot for Little Valley
Soil +Lime +Organic matter	(2. 91 kg soil + 90 g crop residues + 1.2 g lime) /pot for Muzuri (2.91 kg soil + 90 g crop residues + 2.7 g lime)/pot for Little Valley

The treatments were laid out as a Completely Randomized Design (CRD), with 4 treatments and 4 replications on two soils, giving a total of 32 experimental units. Maize was used as a test crop. The rates of lime used for the soils depended on the lime requirement of the soil and the bulk densities. The rates of lime for soils from Muzuri was 120 kg/ha in basins where it was only applied to 1/10 of the hectare. This rate is equivalent to 1.2 ton/ha when broadcast. For soils from Little Valley this was 270 kg/ha equivalent to 2.7 ton/ha when broadcast.

The organic matter was pulverized and applied at the rate of 3% which is equivalent to 6 ton/ha for soils from Muzuri and 14.9 ton/ha for Little Valley.

Nitrogen supplementation was made at 92 kg/ha N rate. No P and K were added since the soils had sufficient K, and P was the nutrient under investigation. The amendments and the soil were thoroughly mixed and incubated in the greenhouse for two weeks before planting the maize. The soils were watered as necessary for the period of crop growth. Six weeks after planting the above ground biomass was harvested, dried in the oven at 65°C, then weighed. A portion of the dry matter was kept for analysis of P.

3.5.9.1 Determination of P uptake by Crop

An analysis of the P content of maize dry matter was done using the dry ashing method described by VanRanst *et al.*, (1999). One gram of dried ground plant material was placed in crucibles initially boiled in 1% nitric acid. The plant materials were ignited in the muffle furnace at 550 °C for 4 hours after which the ignited samples were cooled and the residue dissolved in 20 ml 1N nitric acid. The solution was heated for 20 minutes on a hot plate, cooled, filtered and diluted to 100 ml. One milliliter of sample was used to develop color and P determined colorimetric on a Spectrophotometer at 882 nm. Phosphorus uptake was calculated by multiplying the P concentrations by dry matter yield mass.

3.5.9.2 Determination of available P in treated soils.

To determine the effect of the treatments on plant available P in soil, 100 g of soil was thoroughly mixed with each of the soil amendments according to the treatment and incubated in the greenhouse for eight weeks. The soil was kept moist at field capacity. The soils were then analyzed for plant available P using the Bray 1 Method described by Olsen and Sommer, (1982).

3.6 Statistical Analysis

Paired t- tests were done to compare soil properties, in the cultivated and adjacent non-cultivated soils. Analysis of variance (ANOVA) was conducted to establish whether there were significant differences in soil available, P uptake and maize dry matter yield due to the different treatments. Duncan's Multiple Range Test was conducted to separate the means. Regression analyses were used to establish the relationships between available P concentrations and P uptake and between dry matter yields and available P. The analyses were carried out using SAS software and Excel statistical tools.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil Characterization

The characteristics of the two soils used in this study are presented in Table 3.

Table 3: Selected characteristics of the two soils used in the study

Farm	Source of Soil	pH (CaCl)	Exchangeable cations (cmol /kg)						Org. C %	Ava-P mg/kg
			H ⁺	Al ⁺	Ca	Mg	K	Na		
Little Valley	Adjacent	4.08	0.25	1.2	1.78	1.23	0.93	0.13	1.82	22.01
	Rip line	4.08	0.26	0.8	1.96	1.11	1.05	0.09	1.27	43.53
Muzuri	Adjacent	5.01	0.18	0.28	2.40	0.37	0.67	0.04	1.50	10.26
	Basins	5.12	0.15	0.25	2.62	0.32	0.58	0.05	1.65	8.73

The results show that the pH of the soils at both study sites was low. Soils at Little Valley farm were very strongly acid, while those at Muzuri were moderately acid. The soils had adequate levels of potassium and moderate calcium and magnesium at both sites. The organic matter contents were moderate to high with organic carbon levels ranging from 1.27 to 1.82%. Soils at Muzuri had low levels of available P, while those at Little Valley Farm had moderate to high levels of P.

4.2 Total Phosphorus

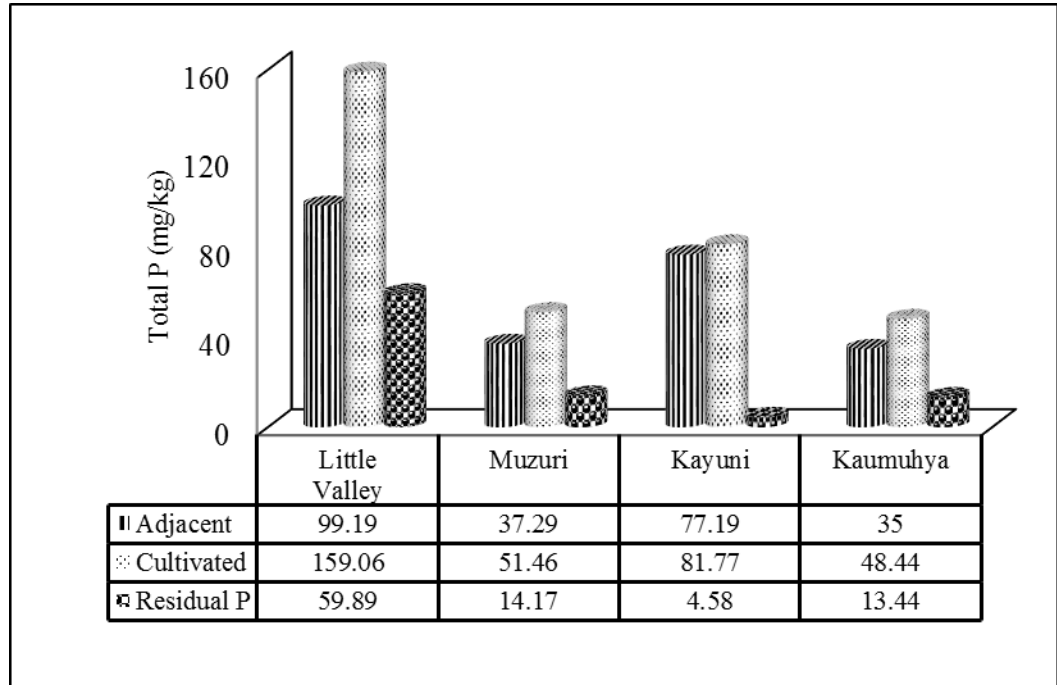


Figure 1. Total P levels in fertilized cultivated and adjacent (non-cultivated) soils.

The results in Figure 1 show the levels of total P and the residual fertilizer P values of the soils used in the study. As earlier indicated the residual P referred to in this study is the difference in the total P quantities of soils where fertilizer P had been applied and adjacent soils where P had not been applied. As stated earlier only a small portion of the residual P is plant available.

For the soils investigated in the study the levels of total P ranged from 35 mg/kg in the loamy sand soil from Kaumuhya Farm to 159.0 mg/kg in the sandy loam soil from Little Valley Farm. These values of total P in soil were lower than those reported by Yerokun (2008) for the 20 Benchmark soils of Zambia where values ranged from 126 mg P/ kg to 742 mg P /kg. In Nigeria, a range of 579 mg P /kg to 1715 mg P/kg was reported by Raji (2006) while a range of 78 to 282 mg P /kg was also reported in Ghana (Nartey *et al.*, 1997). Using the ratings by Landon (1984) a soil with < 200mg/kg of total P is rated

low. Following this criterion soils used in this study had low total P which is in consistent with most literature that show that Zambian soils have low P levels. This finding is also in agreement with statement of Youdeowei *et al.*, (1985) that the total P levels in the tropical soils are generally low with a mean range of 83 to 1248 mg P /kg for the countries in the tropical savanna region. A comparison of total P levels in the non-cultivated soils with those of the cultivated soils, showed that cultivated soils had significantly higher ($p < 0.05$) levels of total P than the non-cultivated soils which resulted in residual fertilizer P. However, it should be noted that only a portion of this residual fertilizer P could be available to plants depending on the management practices applied.

4.3 Residual fertilizer P

The high total P levels in the cultivated soils resulted in residual fertilizer P ranging from 4.58 to 59.89 mg P /kg accounting for 7 % - 38 % of the total P. These results are similar to those observed in Florida where the total P content was found to be higher in cultivated soils than non-cultivated soils (Castillo and Wright, 2008). They are also in agreement to those reported by Sharpley and Smith (1985) where total P levels in soils from the major agricultural areas of USA on average were 236 mg /kg higher in cultivated soils than in non-cultivated soils.

The higher levels of P in cultivated soils can be attributed to past fertilizer P applications that have resulted in a steady build-up of P. This steady build-up of P in CA and the use recommended practices such as application of agricultural lime and organic matter can result in increased availability of P. This demonstrates one of the long term benefits of CA. Minde *et al.* (2008) reported that CA enhances the availability of P. However, it is widely reported that this effect depends much on adherence to the basic principles of CA which include little or no soil disturbance, retention of residues on land , crop rotation,

permanent soil cover and the use of green manure cover crops with consistent fertilizer use (Derpsch, 2008; Diaz-Zorita and Grove, 2002).

4.4 Phosphate Sorption

When the current status of P and the effect of past fertilization in the two soils with the highest residual fertilizer P were assessed using the P sorption isotherms the results showed that soils in adjacent non-cultivated areas had higher P retention than the cultivated soils. Figure 2 and Figure 3, show the P sorption curves of soils from Little Valley and Muzuri Farm Respectively.

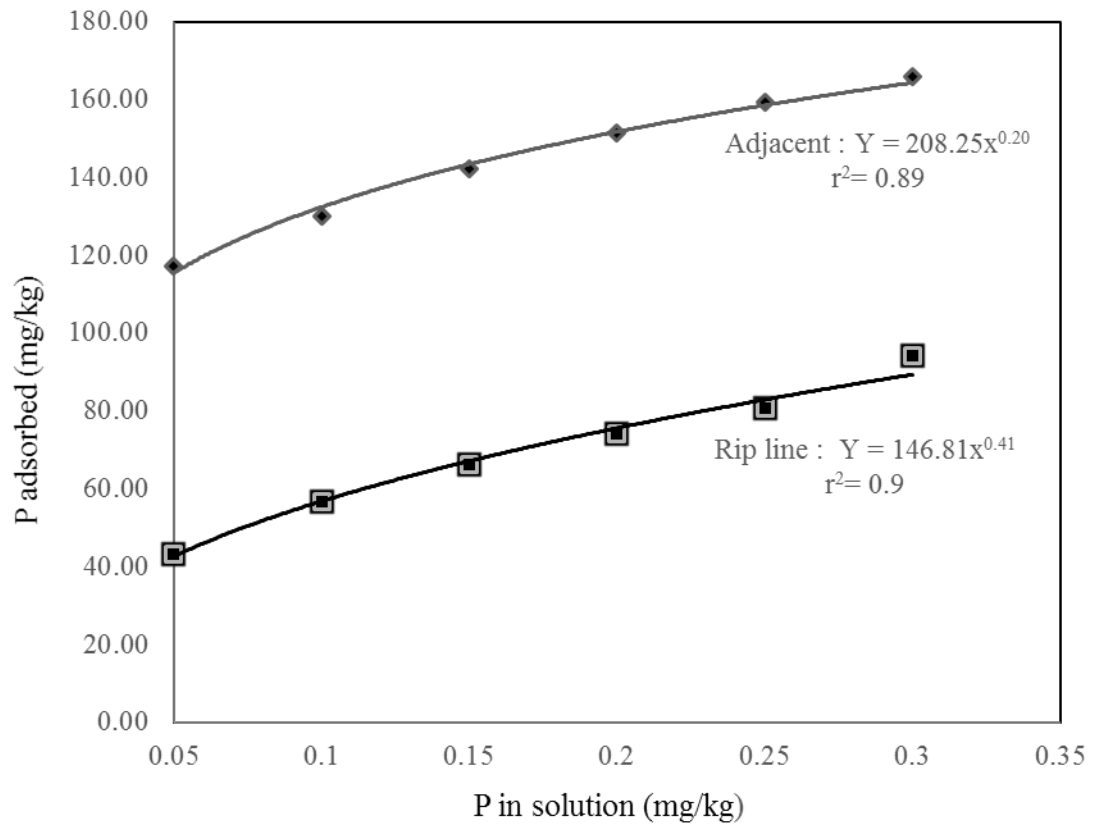


Figure 2: Phosphorus adsorption on cultivated and non-cultivated soils from Little Valley Farm.

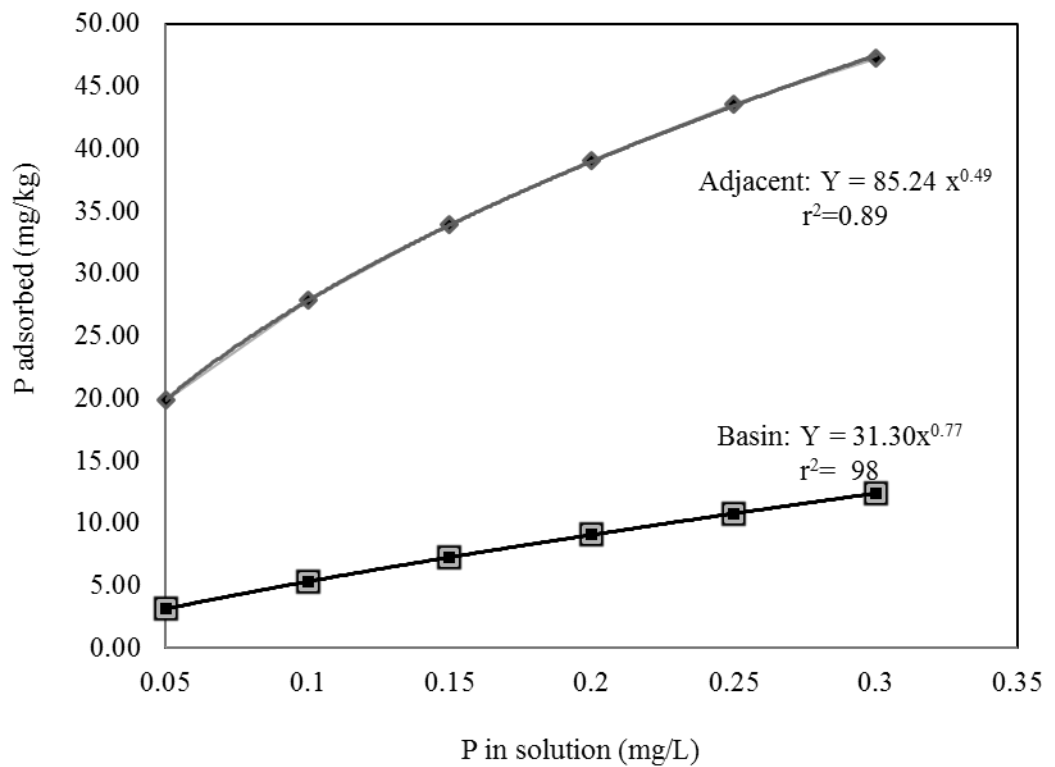


Figure 3: Phosphorus adsorption on cultivated and non-cultivated soils from Muzuri farm

It is clear that the soils from adjacent sites that did not receive any fertilizer application adsorbed greater amounts of P. This can be attributed to the accumulated P in the fertilized soils. Using the Freundlich model the results showed that the non-cultivated adjacent soils had higher standard P requirement than the fertilized cultivated soils. According to Fox and Kamprath (1970) the standard P requirement is the amount of P that should be applied to a soil to give a soil solution P concentration of 0.2 mg P/l. For Little Valley the adjacent soils required 129 kg P₂O₅/ ha while the cultivated soils required 69 kg P₂O₅/ha which is only half the amount. The same trend was observed on the soils from Muzuri where the standard P requirement for the non-cultivated soils was about 39 kg

P_2O_5 /ha compared to about 16 kg P_2O_5 / ha for the cultivated soils. This result shows that where P had accumulated less P is required, suggesting the potential of using residual P. For soils from Little Valley the cultivated soils need two times less the amount of recommended P fertilizer than to the non-cultivated soils that have not been fertilized. Similarly the cultivated soils from Muzuri requires two times less of P fertilizer than the non-cultivated soils.

In Zambia where compound D fertilizer (10% N: 20 % P_2O_5 :10% K_2O) is commonly used as the source of P, in order to meet the P requirement for the non-cultivated soils at Little Valley Farm an equivalent of about 12 x 50 kg bags of the fertilizer which cost \$480 for 12 bags is required, while that of the cultivated soils would be 6 x 50 kg bags costing \$240. For the soils at Muzuri the standard P requirement for the non-cultivated soil is equivalent to applying 4 x 50 kg bag which cost about \$80, while that of the cultivated soils is approximately 2 x 50 kg bag, costing \$40. In general the P requirement of the cultivated soils is about 50% less than that of the non-cultivated soils. This reduction is due to the accumulated fertilizer P from the previous application of P fertilizer.

4.5 Mineral forms of residual P

The composition of the total P in the soils used in the study are presented in Figure 4. The results show that total P in soils consisted of both organic and inorganic P. Most of the inorganic P fractions were associated with Fe/Al compounds. Soils that were fertilized with P contained more Ca-P and less Fe/Al-P than the non fertilized adjacent soils. This result suggests that Ca-P compounds are a pathway, that is the first products of P fertilizer reaction with soil.

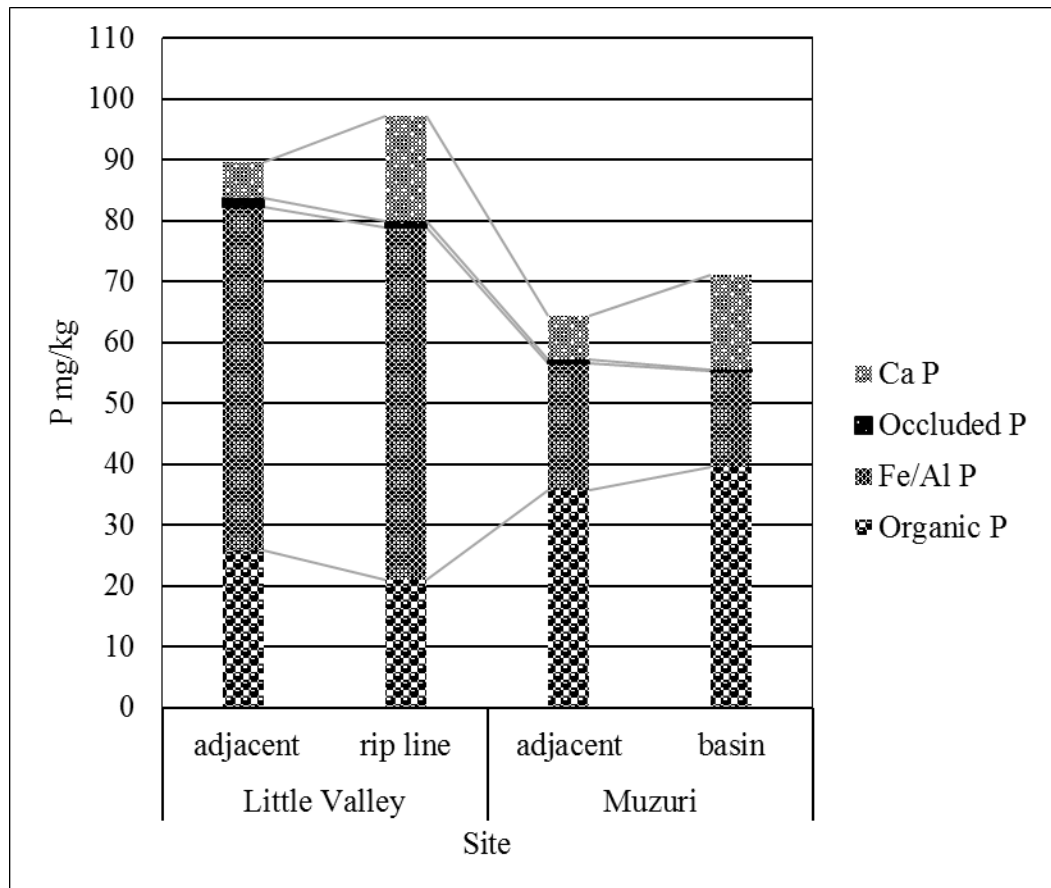


Figure 4a: Distributions of total P in the two soils used in the study.

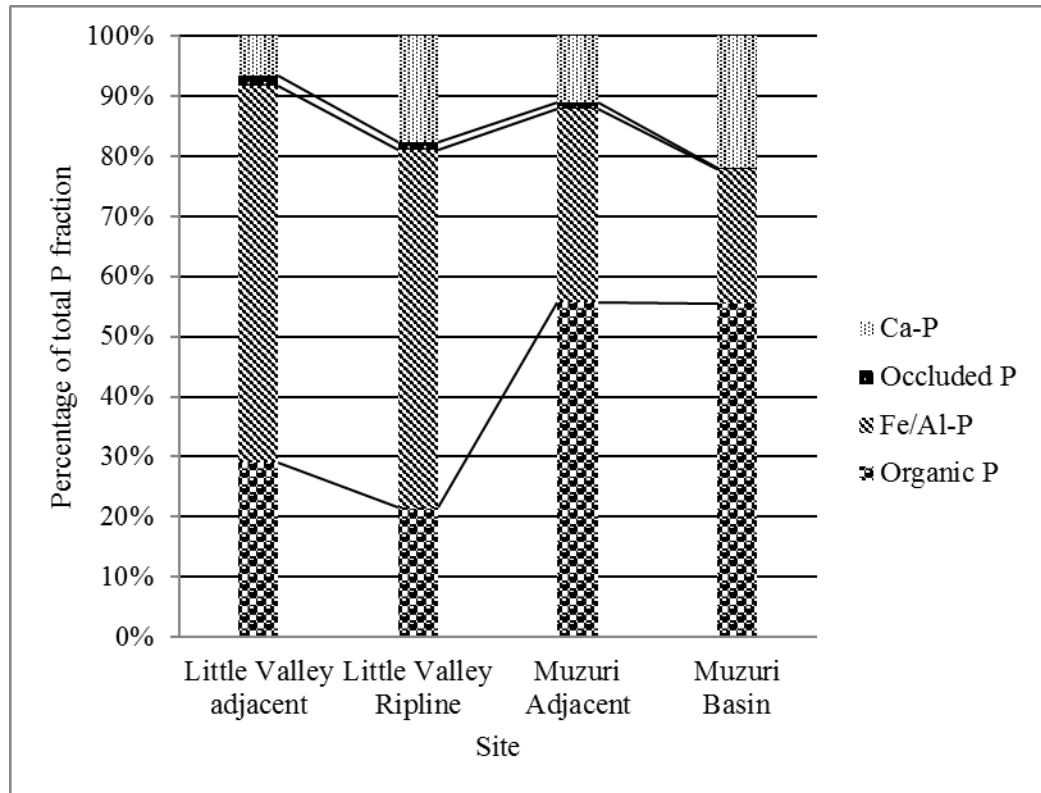


Figure 4b: Percent Distributions of total P in the two soils used in the study.

4.5.1 Organic P pools

The organic P content of the soils used in this study ranged from 21 mg P /kg to 39.52 mg P/kg with an average of 25.5 mg P/kg. It accounted for 22 % to 61% of the total P. The results are similar to those reported by Youdeowei (1985) and Barančíková (2007)). Comparison of the soil organic P in the cultivated soils with those of non-cultivated soils showed that the organic P fraction decreased significantly in the cultivated soils, the difference being 6 %. In contrast to this the loamy soils from Muzuri had an increase of 5% in the cultivated soils. Similar results to those recorded in the soils from Little Valley were reported by Sharpley and Smith (1985) who observed that organic P declined with cultivation. This decrease in organic P can be attributed to the decline in the amount of labile and moderately resistant organic P. Basamba (2006) indicated that soil organic matter was the major source of organic P.

Comparison of the soils from Little Valley with those from Muzuri show that the latter had slightly higher amounts of organic carbon, which could have resulted into higher levels of organic P in the soil. The levels of soil organic carbon were generally found to be low ranging from 1.27% in soils from Little Valley farm to 1.87% in the soils from Muzuri farm. This result is consistent with that reported by Umar (2012) and Youdeowei (1986) attributes the low levels of organic matter in the tropics to high mineralization rates.

4.5.2 Inorganic P pools

The levels of inorganic P in soils ranged from 28.60 mg P/kg to 76.23 mg P/kg and accounted for 44% to 78% of the total P. A Comparison of the inorganic P in non- cultivated soils to those of cultivated soils showed that the cultivated soils had higher levels of inorganic P than the non-cultivated soils. The cultivated soils from Little Valley Farm were found to have 12.56 mg P/kg higher than the non-cultivated soils. Similarly at Muzuri Farm the inorganic P levels in cultivated soils were 3.01 mg P/kg higher than the non-cultivated soils. This is consistent with the findings of Sharpley and Smith (1985) and Wang *et al.*, (2010) who reported that long term fertilizer P addition increased inorganic P in soil. The inorganic P fractions consisted of Fe/Al-P, Ca-P and occluded P and was dominated by Fe/Al-P (22.3% to 62.76% of the total P). The domination of inorganic P by Fe/Al-P can be attributed to the acid nature of the soils used in the study which tended to promote the fixation of P into Fe/Al-P rather than Ca-P fractions. The cultivated soils had lower amounts of Fe/Al-P and occluded P generally than the non-cultivated soils. This result suggests that Ca-P is a transition pathway in the conversion of soil P into available P forms.

The Ca-P ranged from 5.89 mg/kg to 17.28 mg/kg, accounting for 6.56 % to 21.89% of the total P. Cultivated soils had significantly higher amounts of Ca-P

than in the non-cultivated soil. These levels of Ca-P obtained in this study were within the range of 1-78% range reported for seventeen Benchmark soils of Zambia by Yerokun (2009) and the 1-25% range reported by Yerokun (2008). The higher levels of Ca-P in the cultivated soils could be attributed to past fertilizer application and to the proposal by Kumoyo *et al.*, (2005) that Ca P is an important intermediate pool in the transformation of organic P and other P pools for plant uptake in Zambian soils. Castillo and Wright (2008) also reported that most Ca-P may be moderately labile in acid soils, therefore, the increase in Ca-P indicated greater potential for plant availability.

The levels of Fe/Al-P in the soils ranged from 15.87 mg/kg to 57.95 mg/kg, and accounted for 22.30% to 62.76% of the total P. These results were consistent with those reported by Yerokun (2009). The occluded P ranged from 0.17 mg/kg to 1.55 mg/kg and accounted for 0.2% to 1.72% of the total P. From this result it is probable that Fe/Al-P might be an intermediate fraction in the transformation of inorganic P fractions from Ca-P to occluded P. The reduced levels of occluded P in the cultivated soils could be indicative of mineralization which might have resulted into higher levels of Ca – P providing a great potential in the availability and utilization of residual P.

It is not surprising that on average the Fe/Al-P was the most abundant inorganic P fraction in both the cultivated and non-cultivated soils used in this study. These soils were essentially strongly acid suggesting that most of the fixed P was likely to be associated with Fe and Al which are usually the most abundant cations in acid soils. This implies that if management practices such as application of organic matter and agricultural lime reported to promote the release Fe and Al are employed a significant amount of the P associated with Fe and Al can be converted into forms that are available for plant up take. As reported earlier use of organic matter and agricultural lime reduces the bonding energy of P to solid particles and consequently increases the P concentration in the soil solution. This

is achieved by agricultural lime causing chemical reactions that raise soil pH by neutralizing H^+ and reducing Al^+ after converting H^+ ions to water and precipitating Al to $Al(OH)_3$. The organic acid produced during the decay of organic matter solubilizes the insoluble P compounds by chelating the cations bound to P through their hydroxyl and carboxyl groups.

4.6. Greenhouse crop trial

4.6.1 Effect of soil amendments on the plant available P

The mean values of plant available P in soils that received soil amendments intended to release P in soils are presented in Table 4.

Table 4: Mean values of plant available P on soils (mg/kg)

Treatments	Site	
	Little Valley	Muzuri
Lime + Organic matter	67.88 ^a	19.78 ^a
Lime	61.13 ^b	16.70 ^b
Organic matter	28.60 ^c	11.15 ^c
Control	14.93 ^d	8.35 ^d

Figures followed by the same letter in a column were not significantly different ($P < 0.05$) according to Duncan Multiple Range Test.

The results show that there were significant differences ($P < 0.001$) in the levels of available P in soils that received different amendments. The highest level of plant available P was obtained from treatments where agricultural lime was combined with organic matter. This was followed by the treatment of lime alone which in turn was significantly higher than that of organic matter alone and the control.

In general the effect of the amendments in increasing the levels of plant available P was four times higher than the control on the soils treated with both agricultural lime and organic matter, three times higher on soils amended with agricultural lime alone and two times higher on soils amended with organic matter alone. The trend of the effects of various treatment on plant available P was of the order Lime + Organic matter > Lime > Organic matter > Control.

It is not surprising that the lowest levels of available P were observed in the control treatment or soil alone. The soils used in this study were found to be strongly acid on average (Table 2) consistent with the findings reported by Phiri *et al.*, (2009). In acid soils of pH less than 6.0 Al and Mn become toxic to plants and limit the availability of many nutrients such as P which is found in Fe/Al bound form. The implication is that in the control treatment the fixed P remained stable as soils were maintained under conditions leading to P fixation while in the soils that were treated the amendments removed the conditions that favor P fixing thereby leading to desorption.

Significant desorption of fixed P was observed (Table 4) when soils were amended with agricultural lime alone and when agricultural lime was applied together with organic matter. The raising of the pH to above 5.5 probably reduced the H^+ concentration and precipitated Al^{3+} . This could have further reduced the bonding of the sorbed P to the soil and resulted into the release of plant available P. These results are similar to those reported by Engelstad and Terman (1980) where levels of available P increased when the pH was increased to between 5.5 and 7.0. Similar results were also reported by Sanchez and Uehara (1980) on Brazilian Oxisols where a significant proportion of the P sorbed at pH 4 was released at pH 7. The superior effects of amending soil with agricultural lime alone over that of organic matter can be attributed to soil acidity that could have slowed down the decomposition of organic residues on soils amended with organic matter only, consequently reducing the release of intermediate organic substances. It is also hypothesized that the increase in porosity, water infiltration,

drainage and water holding capacity of the soil caused by addition of organic matter improved the activity of the lime on the soil (Youdeowei, 1986).

The results of this study showed that when lime was applied in combination with organic matter it resulted into superior positive effects on the availability of the fixed P over the control. This implies that addition of organic matter and agricultural lime in acid soils is an important agro-technology in optimizing yields, increase of P fertilizer use efficiency and restoration of soil fertility. The use of both organic matter and lime are promoted in CA practice.

4.6.2 Effect of soil amendments on dry matter yield

Results of the dry matter yield obtained from the various treatments applied on the two soils are presented in Table 5.

Table 5: Mean values of the maize dry matter yield (g/pot).

Treatment	Site	
	Little Valley	Muzuri
Lime + Organic matter	9.88 ^a	5.55 ^a
Lime	7.40 ^b	4.45 ^b
Organic Matter	5.90 ^c	3.00 ^c
Control	3.80 ^d	1.22 ^d

Figures followed by the same letter in a column were not significantly different ($P < 0.05$) according to Duncan multiple range test

The result show that there were significant ($P < 0.05$) differences in the effect of different amendments on the dry matter yield. The highest maize dry matter yield was obtained from the soils amended with the combination of agricultural lime and organic matter. This result corroborates the results from soil test that showed higher plant available P from this treatment. On average the maize dry

matter yield was found to be four times greater than that of the control. This was followed by the yield obtained from soils amended with lime alone which was about three times greater than the control and two times greater for those obtained from soils amended with organic matter only.

These results showed that the use of both agricultural lime and organic matter had a positive effect on the availability of fixed P which in turn increased the maize dry matter yield.

4.6.2.1 Relationship of available P and dry matter yield

Figures 5a and 5b show the relationship between available P in soil and maize dry matter yield for the soils from Muzuri and Little Valley Farm.

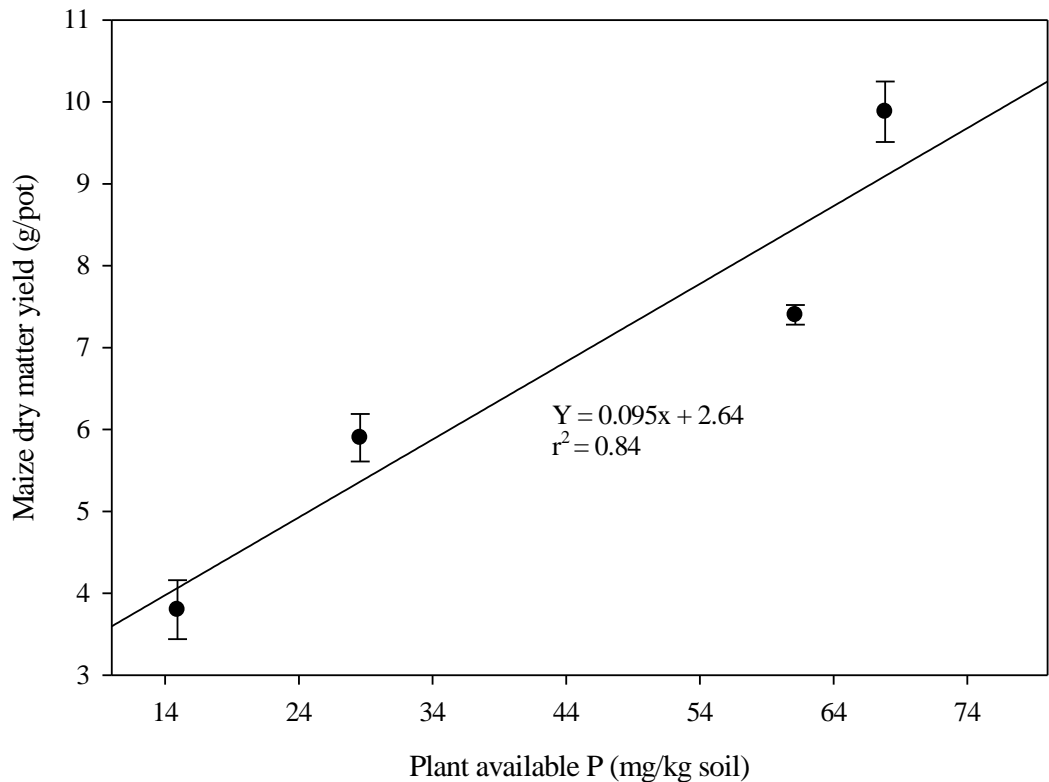


Figure 5a: Relationship of maize dry matter yield and plant available P for soil from Little Valley.

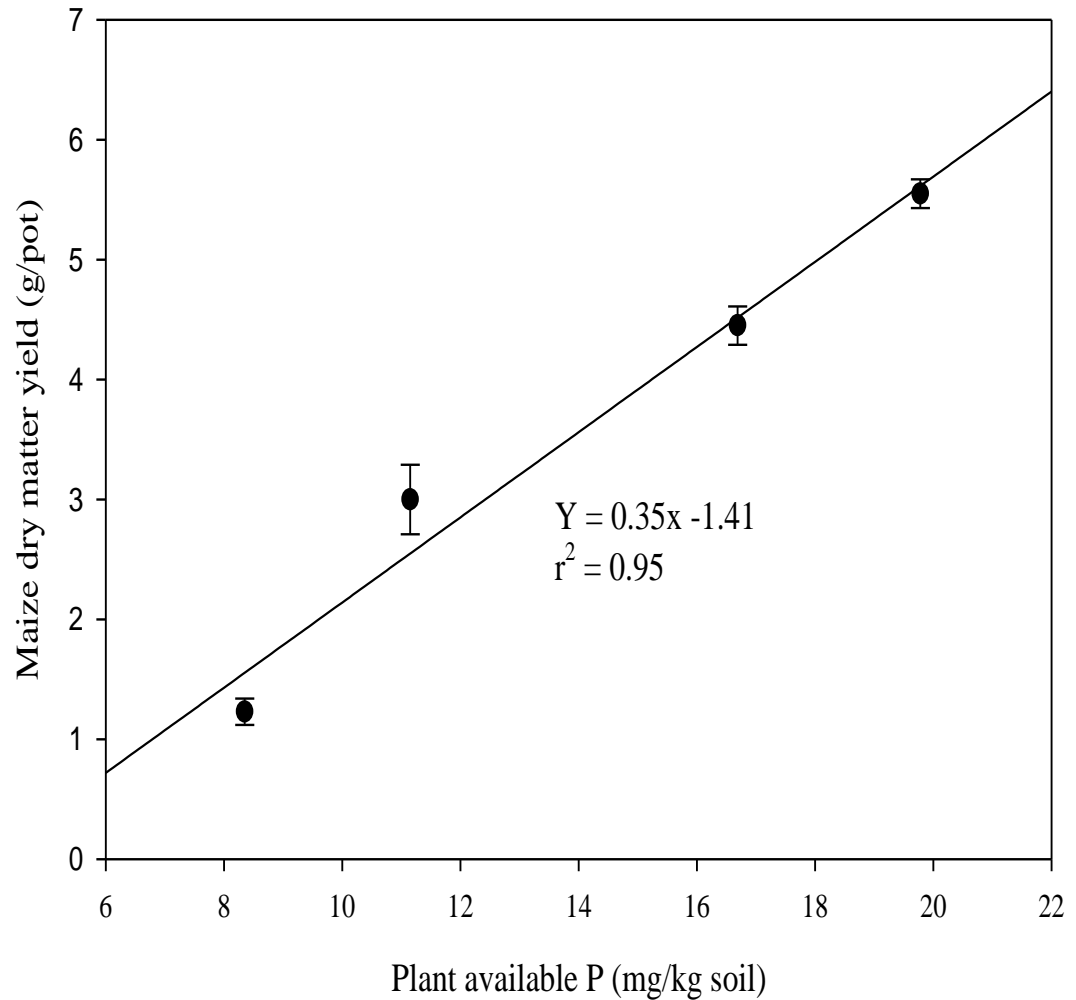


Figure 5b: Relationship of maize dry matter yield and plant available P for soils from Muzuri.

A very significant linear relationship between the levels of available P in the soil and maize dry matter yield was observed in both soils. The maize dry matter yield increased with increasing levels of available P in the soil. The Linear response was found to be greater in the soils from Little Valley Farm than in soils from Muzuri farm.

This could be due to a higher P status of soils from Little Valley Farm than soils from Muzuri Farm (Table 3). The available P content was 4 times higher in soils from Little Valley than those from Muzuri farm.

4.6.3 Effect of soil amendments on P uptake by maize plants

Table 6 shows the mean values of P taken up maize plants grown on soils treated by different soil amendments.

Table 6: Mean value of P taken up by maize (mg/pot).

Treatment	Site	
	Little Valley	Muzuri
Lime + Organic matter	0.40 ^a	0.14 ^a
Lime	0.21 ^b	0.08 ^b
Organic matter	0.14 ^c	0.03 ^c
Control	0.05 ^d	0.01 ^d

Figures followed by the same letter in a column were not significantly different ($P < 0.05$) according to Duncan multiple range test.

Significant differences ($P < 0.0001$) were observed between the levels of P taken up by plants grown on soils treated with different amendments. The highest uptake was associated with soils treated with both lime and organic matter. On average the level of P uptake in soils amended with both lime and organic matter was nine times that obtained in the control. The general trend of the level of P uptake by plants was in the order agricultural lime + organic matter > lime > organic matter > control. These results can be explained in terms of the increased available P in soils which resulted in increased uptake of P by plants increasing the yield.

4.3.1 Relationship of plant P uptake with Available P

Figure 6 shows the relationship between available P in soil and P taken up by plants for the soils from Little Valley and Muzuri Farm.

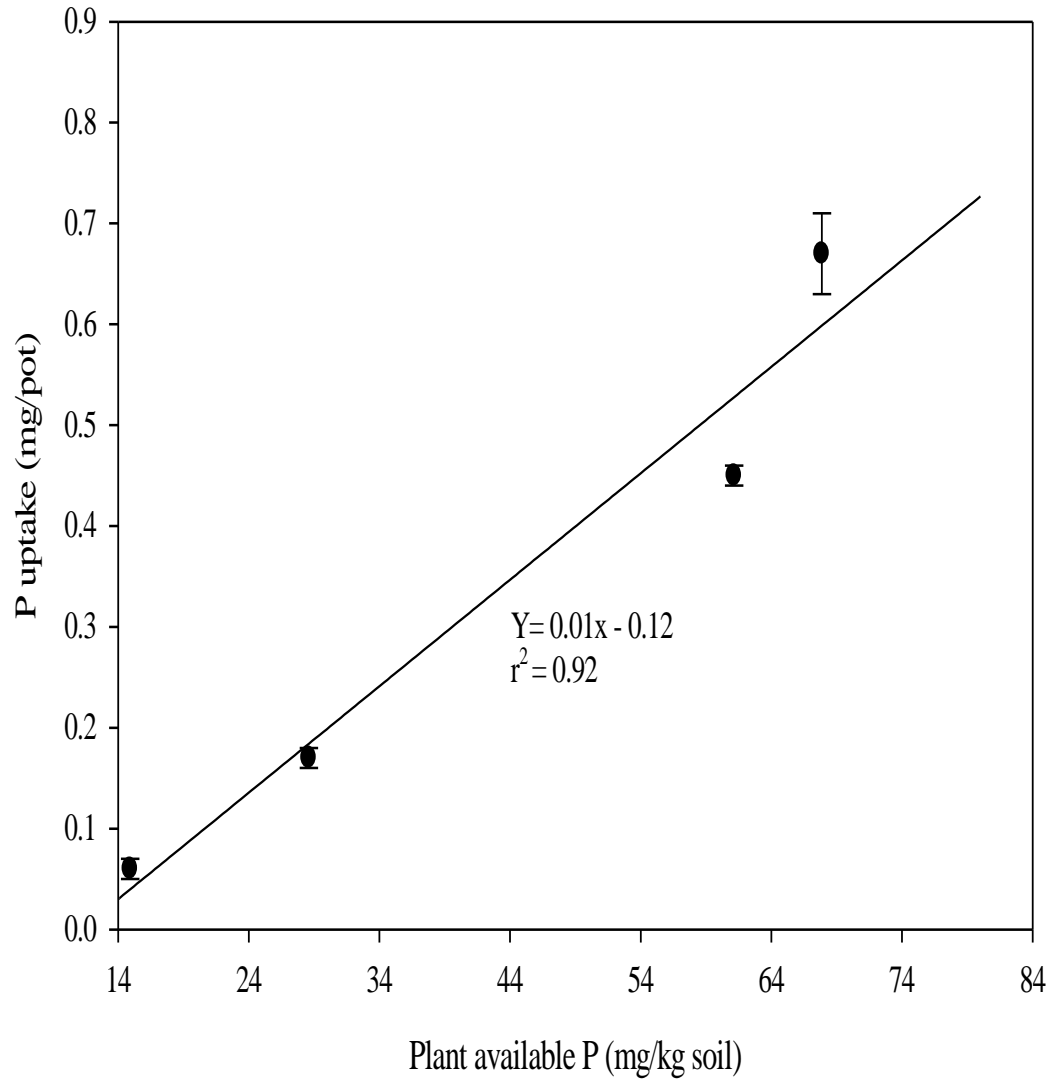


Figure 6a: Relationship of P uptake and plant available P in soil from Little Valley Farm

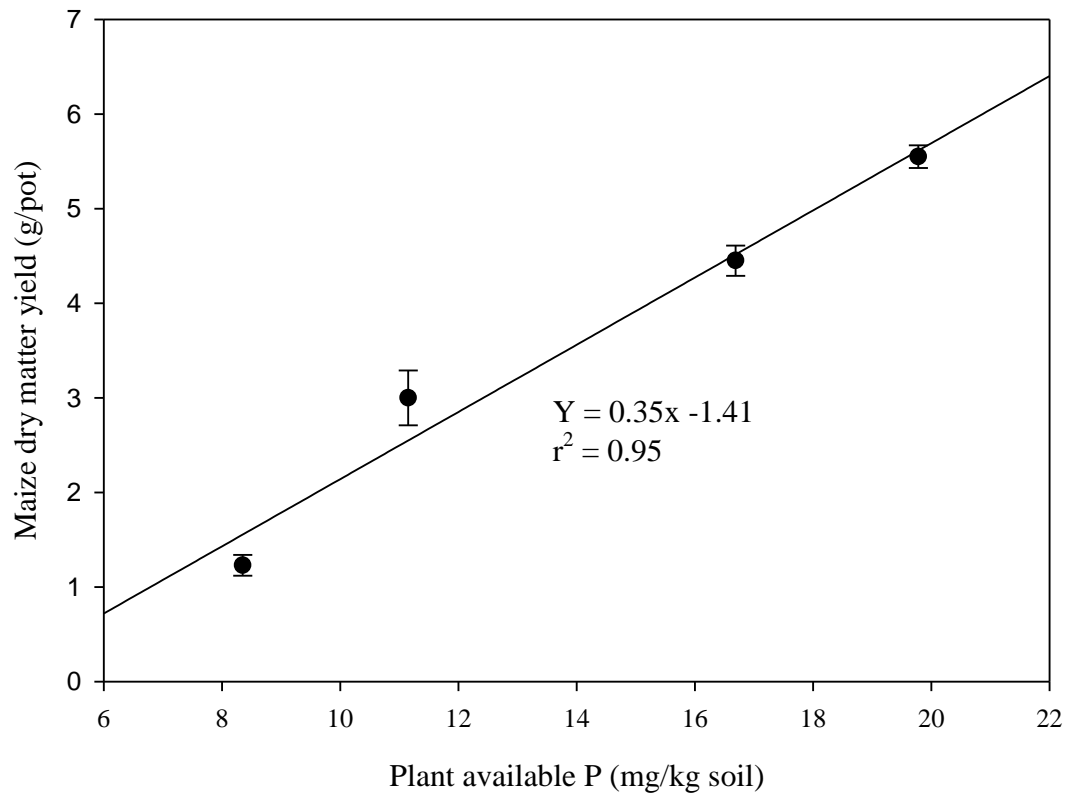


Figure 6b: Relationship of P uptake and plant available P in soil from Muzuri Farm

There was a highly significant linear relationship between the levels of available P in the soil and the uptake of P by plants from both soils. The P uptake increased with increasing levels of available P in the soil. The response in P uptake to increasing levels of available P was greater in the soil from Little Valley Farm compared to that of soil from Muzuri. This can be attributed to the observation made by Sanchez and Uehara (1980) that liming soils that are near neutral is of little influence on decreasing P fixation. Soils from Little Valley were acid (pH 4.08) compared to Muzuri with pH 5.01. The effect of this was clearly seen in the different performance of the crops in the greenhouse (Figure 7).

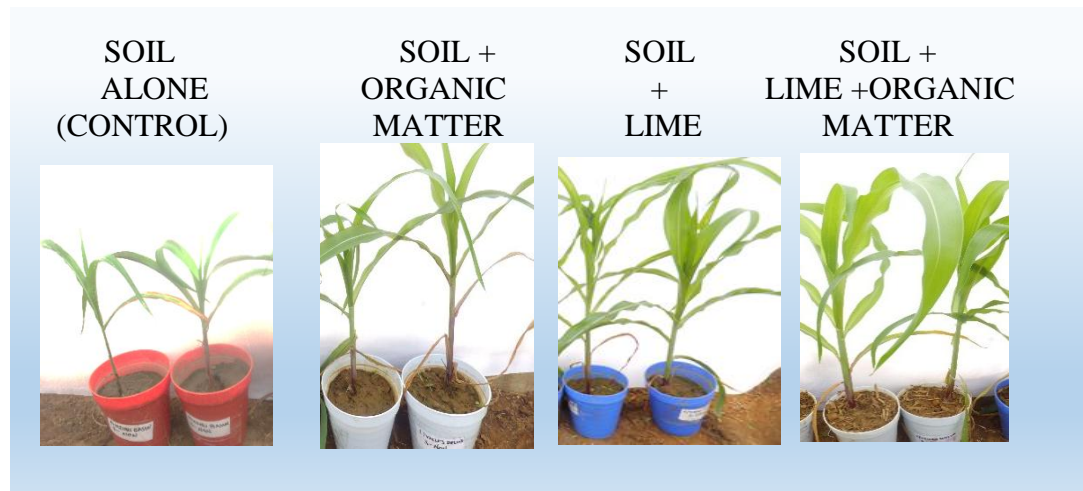


Figure 7: Maize crop performance on different treatments at six weeks of age.

The observation in the greenhouse showed that the plants grown on the un-amended soils were stunted and showed severe purpling of leaves and stems, an indication of P deficiency. Similar but less symptoms were observed in the soils treated with agricultural lime only and organic matter only. In contrast, on soils treated with lime and organic matter no plants showed any of these symptoms. The features exhibited by plants in the control treatments are typical symptoms of P deficiency (Food and Agriculture Organization, 1984). In the control treatment the pH remained low and in low pH aluminium toxicity reduces yields because it restricts root development and uptake of nutrients. In addition to this the residual P remained fixed to the soil was unavailable to plants. This was clearly reflected in the low dry matter yield and the poor crop performance (Figure 7). The positive effect of using lime and organic matter indicate an alternative potential management practice to utilize residual P. This could lead to a reduction in fertilizer P requirements and reduce fertilizer costs for the farmer.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

Residual P was determined as the difference in the amounts of total P in the cultivated soils under CA which had received P fertilizer continuously and the non-cultivated soils. The results of this study have shown that the cultivated soils had significantly higher levels of total P than the adjacent non-cultivated soils, resulting in residual P values of 38% and 27% of the total P.

This study has shown that the total P in soils used in the study consisted of both organic and inorganic P. The inorganic P fraction comprised of Fe/Al- P, Ca-P and occluded P. Most of the P in the soil (22% to 63%) was associated with both Fe and Al compounds.

Applying lime and organic matter to acid soils containing residual fertilizer P significantly increased the level of plant available P. The highest amount of released plant available P were observed when both agricultural lime and organic matter were applied in combination. This is consisted with the recommended the CA practice.

Applying lime and organic matter to acid soils containing residual fertilizer P significantly increased the amounts of P taken up by plants and the maize dry matter yield. Higher amounts of P uptake and dry matter yield were observed when agricultural lime was added in combination with organic matter than either of these amendments alone. This result may partly explain the higher crop yields obtained under CA.

This study has demonstrated that after five years of CA practice with fertilizer P application there is substantial accumulation of P averaging to 30% of the total P. This fraction of P is fixed and not plant available. A portion of this P can be made available to plants by applying agricultural lime and organic matter.

5.2 RECOMMENDATIONS

1. Farmers practicing CA on acid soils should continue using agricultural lime and organic matter. For better results agricultural lime and organic matter should be applied in combination.
2. Further research work should be conducted to establish how long the unlocked P remains available to the crop after applying the amendments.

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APPENDIX A

SUMMARY TABLES

APPENDIX A 1: Selected chemical characteristics of the organic material used (maize stalks)

Cu	Zn	Mn	Fe	K	Ca	Mg	P
mg/kg			%				
6.80	8.37	4.20	154.20	1.32	3.32	1.11	0.40

APPENDIX A 2: Soil reaction (pH) of soils used in the study

Farm	Source of Soil	pH	Status
Little Valley	Adjacent	4.08	Very Strongly acidic
	Rip line	4.08	Very Strongly acidic
Muzuri	Adjacent	5.01	Moderately Strongly acidic
	Basins	5.12	Moderately Strongly acidic
Kayuni	Adjacent	4.48	Very Strongly acidic
	Rip line	4.43	Very Strongly acidic
Kaumuhya	Adjacent	4.30	Very Strongly acidic
	Rip line	4.53	Strongly acidic

APPENDIX A 3: Selected physical properties of Soils used in the Study

Farm	Source of Soil	Bulk density	Sand	Clay	Silty	USDA Textural Class
		(g/cm ³)	%	%	%	
Little Valley	Adjacent	1.42	73	19	9	Sandy Loam
	Rip line	1.40	72	23	6	Sandy Loam
Muzuri	Adjacent	1.39	86	13	2	Loamy Sand
	Basins	1.55	83	11	7	Loamy Sand
Kayuni	Adjacent	1.45	75	25	1	Sandy loam
	Rip line	1.47	77	23	1	Sandy loam
Kaumuhya	Adjacent	1.57	83	11	7	Loamy sand
	Rip line	1.58	83	9	9	Loamy sand

APPENDIX A 4: Phosphate status of Soils used in the study.

Farm	Source of Soil	Available P (mg/kg)	Status	Total P (mg/Kg)	Status
Little Valley	Adjacent	22.01	Moderate	99.17	low
	Rip line	43.53	Moderate	159.06	low
Muzuri	Adjacent	10.26	low	37.39	low
	Basins	8.73	low	51.46	low
Kayuni	Adjacent	5.35	low	35	low
	Rip line	8.06	low	48.44	low
Kaumuhyia	Adjacent	8.57	low	77.19	low
	Rip line	4.53	Low	81.77	low

APPENDIX A 5: Acidity levels of the two soils used in the study

Source of Soil	Little Valley farm		Muzuri farm	
	Adjacent	Rip line	Adjacent	Basin
Al ⁺ Saturation	21.70	15	7	6.30
Al ⁺³ (cmol/kg)	1.2	0.8	0.28	0.25
H ⁺ (cmol/kg)	0.25	0.26	0.18	0.15

APPENDIX A 6: Status of selected soil chemical properties of Soils used in the study

Site	Soils from Muzuri				Soils from Little Valley			
	Adjacent soils		Cultivated soils		Adjacent soils		Cultivated soils	
	Mean	Status	Mean	Status	Mean	Status	Mean	Status
Ca (cmol/kg)	1.78	low	1.96	low	2.40	low	2.62	low
Mg(cmol/kg)	1.23	Low	1.11	low	0.37	low	0.32	low
K(cmol/kg)	0.94	high	1.05	high	0.67	high	0.58	high
Na(cmol/kg)	0.13	normal	0.09	normal	0.04	normal	0.05	normal
Org C %	1.82	low	1.27	low	1.50	low	1.65	low

APPENDIX 6.B

ANNALYSIS OF VARIANCE TABLES

APPENDIX B 1: ANOVA table for treatment effect on available P in soils from Little valley.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	7771.11	2590.37	599.83	<.0001
Error	12	51.82	4.31		
Corrected Total	15	7822.93			

Coefficient of variance 4.82%, Alpha 0.05

APPENDIX B 2: ANOVA table for treatment effect on available P in soils from Muzuri Farm.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	322.85	107.62	207.93	<.0001
Error	12	6.21	0.52		
Corrected Total	15	329.07			

Coefficient of variance 5.14%, Alpha 0.05

APPENDIX B 3: ANOVA Table for effect of treatments on plant P uptake for soils from Little Valley Farm.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1405.83	468.61	108.38	<.0001
Error	12	51.88	4.32		
Corrected Total	15	1457.72			

Coefficient of variance 16.36%, Alpha 0.05

APPENDIX B 4: ANOVA Table for effect of treatments on Plant P uptake for soils from Muzuri Farm.

Source	DF	sum of Squares	Mean Square	F Value	Pr > F
Model	3	762.94	254.31	975.46	<.0001
Error	12	3.13	0.26		
Corrected Total	15	766.07			

Coefficient of variance 10.53 %, Alpha 0.05

APPENDIX B 5: ANOVA Table for effect of treatments on Dry Matter Yield for soils from Little Valley Farm.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	78.45	26.15	73.19	<.0001
Error	12	4.29	0.36		
Corrected Total	15	82.74			

Coefficient of variance 8.86%, Alpha 0.05

APPENDIX B.6: ANOVA Table for effect of treatment on Dry Matter Yield for soils from Muzuri Farm.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	42.07	14.02	102.15	<.0001
Error	12	1.65	0.14		
Corrected Total	15	43.72			

Coefficient of variance 10.42 %, Alpha 0.05

APPENDIX 6.C

APPENDIX C1 SUMMARY OF RESULTS FOR CROP TRIALS

Obs	Farm	Treat	Avail P	PlantP	DM	Puptake
1	Little Valley	Control	14.10	13.646	3.0	0.04094
2	Little Valley	Control	14.70	14.407	3.4	0.04898
3	Little Valley	Control	15.50	14.787	4.4	0.06506
4	Little Valley	Control	15.40	15.167	4.4	0.06673
5	Little Valley	OM	29.60	24.860	6.6	0.16408
6	Little Valley	OM	27.90	23.910	5.3	0.12672
7	Little Valley	OM	28.60	24.480	6.1	0.14933
8	Little Valley	OM	28.30	24.195	5.6	0.13549
9	Little Valley	LIME	59.60	27.806	7.1	0.19742
10	Little Valley	LIME	60.60	28.566	7.4	0.21139
11	Little Valley	LIME	62.40	30.277	7.7	0.23313
12	Little Valley	LIME	61.90	29.042	7.4	0.21491
13	Little Valley	LIME+OM	65.70	42.536	10.5	0.44663
14	Little Valley	LIME+OM	67.10	34.838	9.4	0.32748
15	Little Valley	LIME+OM	73.50	43.676	10.5	0.45860
16	Little Valley	LIME+OM	65.20	41.301	9.1	0.37584
17	Muzuri	Control	7.66	7.469	1.0	0.00747
18	Muzuri	Control	9.37	8.420	1.1	0.00926
19	Muzuri	Control	8.04	8.325	1.3	0.01082
20	Muzuri	Control	8.32	8.040	1.5	0.01206
21	Muzuri	OM	10.60	10.701	2.4	0.02568
22	Muzuri	OM	12.20	11.461	2.8	0.03209
23	Muzuri	OM	10.40	11.841	3.8	0.04500
24	Muzuri	OM	11.40	11.556	3.0	0.03467
25	Muzuri	LIME	16.40	18.683	4.1	0.07660
26	Muzuri	LIME	17.00	19.158	4.8	0.09196
27	Muzuri	LIME	16.80	18.873	4.6	0.08682
28	Muzuri	LIME	16.60	18.873	4.3	0.08115
29	Muzuri	LIME+OM	20.60	26.191	5.7	0.14929
30	Muzuri	LIME+OM	19.60	25.335	5.6	0.14188
31	Muzuri	LIME+OM	18.60	25.240	5.2	0.13125
32	Muzuri	LIME+OM	20.30	26.856	5.7	0.15308