

**EFFECT OF P-FORTIFIED COMPOST MANURE ON GROWTH AND YIELD OF
MAIZE IN SMALLHOLDER MIXED FARMING OF SOUTH NANDI
SUB COUNTY, KENYA**

OKUMU MONICA ATIENO



**A Thesis submitted to the Graduate School in partial fulfillment for the requirements of
Master of Science Degree in Agronomy (Crop Production) of Egerton University**



EGERTON UNIVERSITY

APRIL 2016



DECLARATION AND RECOMMENDATION

DECLARATION

This is my original work and has not been previously presented for an award of degree in this or any other university.

Okumu Monica Atieno

KM12/2802/10

Signature.....

Date...21/4/2016.....

RECOMMENDATION

This proposal has been submitted for examination with approval of my supervisors.

Professor Samuel M. Mwonga

Associate Professor

Department of Crops, Horticulture and Soil Sciences

Egerton University

Signature.....

Date...21/4/2016.....

Professor Isaiah M. Tabu

Associate Professor

Department of Crops Horticulture and Soil Sciences

Egerton University

Signature.....

Date...21/4/2016.....

COPYRIGHT

© 2016 Monica A Okumu

All rights reserved; no part of this thesis may be reproduced in any form or by any means including photocopying, recording or any information storage and retrieval without the permission of the Author or Egerton University on that behalf.

DEDICATION

I dedicate this thesis to my husband Samuel Owino Nyambok, daughters Tracy Nyambok and Brenda Owino, Son Joel Nyambok. You have contributed so much in my career growth

ACKNOWLEDGEMENT

I acknowledge the contribution of my supervisors; Professor S. Mwonga Professor I. M. Tabu of Crops, Horticulture and Soils Department, Egerton University and Dr Ojiem of Kenya Agriculture and livestock Research Organization (KALRO) Kibos for their technical guidance and advice throughout this study. Professor S. M. Mwonga and Professor I. M. Tabu, my thesis supervisors thanks for believing enough in me to join this project and for tireless efforts during the entire period of study. I feel honoured to be associated with you all. Dr Ojiem, thank you for ensuring that funds to support my research were available when required and for allowing me access research facilities at KALRO, Kakamega. Special thanks to Mcknight Foundation for financial support towards the field work, providing research materials and for scientific engagement during project meeting. My gratitude also goes to Mr John Kamwana, Mr James Nyongesa and Mrs Janet Kasiti of the multipurpose legume Project for technical assistance during field trials in South Nandi, Kenya. My students' colleagues at Egerton University provided me with constant morale and constructive criticism which carried me through the study. I appreciate all the support accorded to me by all the Crops, Horticulture and Soils Department members of staff. My sincere gratitude goes to my husband Samuel Owino Nyambok, my daughters, Tracy Nyambok, Brenda Owino and Son Joel Nyambok who constantly supported and encouraged me.

ABSTRACT

In Western Kenya, maize yields in farm fields is usually less than 1ton/ha compared to the potential of up to 10tons/ha. The low yields are largely due to low soil fertility coupled with poor management. The main fertility constraints are low levels of available phosphorus associated with the high soil acidity. Nandi south sub-county farming systems are associated with the above constraints. Farms productivity in the area is classified as high, medium and low soil fertility, depending on time of conversion to arable farming from forest. Farmers are 'resources poor', can hardly afford the relatively costly inorganic fertilizers and neither do they have access to high quality manure alternative to either restore or maintain the farm soil fertility. The need for sustainable product is necessary to improve the local farming system by introducing higher quality P-fortified manure as alternative to the costly inorganic fertilizer. An experiment was therefore set up to compare P-fortified compost with compost and two inorganic phosphorus sources. A Randomized Complete Block Design (RCBD) replicated three times with six treatments namely control, rock phosphate (RP) 60 kg P_2O_5 /ha, Triple super phosphate (TSP) 60 kg P_2O_5 /ha, Compost (6t/ha), P-fortified Compost (30 kg P_2O_5 /ha) and P-fortified Compost (60 kg P_2O_5 /ha), was set up at the three sites low, medium and high soil fertility. Maize H513 and was used as a test crop in the short rain season and repeated in the long rain season without additional treatments to evaluate the residual phosphorus effect of the treatments. The P-source experiment (season II) was set up in new site on adjacent farms during the long rain season. All experimental plots received blanket application of nitrogen fertilizer (60 kg N/ha) applied as CAN in split application. Data collected included plant height, leaf area index, chlorophyll content, 100 seed weight and grain yield. Plant samples were also collected and analyzed for total P. The data was subjected to Analysis of variance (ANOVA) and the mean separated using Tukey's Honestly Significant Difference (THSD) Test at 0.05 level of significance using SAS. P-fortified Compost (60 kg P_2O_5 /ha), and TSP increased plant growth and yields in all the sites. P-fortified compost (30 kg P_2O_5 /ha), had higher Agronomic Phosphorous Use Efficiency (APUE) of 40, 26.7, and 30 kg kg^{-1} in high, medium and low fertility site respectively. P-fortified compost manure (60 kg P_2O_5 /ha) and P-fortified compost manure (30kg P_2O_5 /ha) had the highest residual effect on maize growth and yield across sites. Generally, the results of the study indicate that application of P-fortified compost manure significantly increased growth and yield of maize.

TABLE OF CONTENTS

DECLARATION AND RECOMMENDATION.....	ii
COPYRIGHT.....	iii
DEDICATION.....	iv
ACKNOWLEDGEMENT.....	v
ABSTRACT.....	vii
TABLE OF CONTENTS.....	vii
LIST OF TABLE.....	x
LIST OF FIGURES.....	xi
LIST OF PLATES.....	xii
LIST OF APPENDICES.....	xiii
LIST OF ACRONYMS AND ABBREVIATIONS.....	xiv
CHAPTER ONE.....	1
INTRODUCTION.....	1
1.1 Background information.....	1
1.2 Statement of the problem.....	3
1.3 Objective.....	3
1.3.1 Broad objective.....	3
1.3.2 Specific objectives.....	3
1.4 Hypotheses.....	3
1.5 Justification of the study.....	4
CHAPTER TWO.....	5
LITERATURE REVIEW.....	5
2.1 Maize Production in Western Kenya.....	5
2.2 Soil degradation.....	5
2.3 Phosphorus fertility management strategies.....	6

2.3.1 Inorganic fertilizer	7
2.3.2 Organic fertilizers	8
2.3.3 Compost manure	9
2.4 Fortification of compost organic material	9
2.4.1 Fortification with soluble phosphorus source	9
2.4.2 Fortification with Rock Phosphate (RP)	10
2.5 Phosphorous uptake and use efficiency	11
2.6 Residual P effect	12
CHAPTER THREE	13
MATERIALS AND METHODS	13
3.1 Site description	13
3.2 Experimental design and treatments	15
3.3 Compost preparation and chemical characterization	16
3.3.1 Compost preparation	16
3.3.2 Chemical characterization of compost manure	17
3.4 Land preparation, and crop management	18
3.5 Soils and compost manure and plant tissue analysis	19
3.5.1 Soil sampling and analysis	19
3.5.2 Compost manure sampling and analysis	19
3.5.3 Plant sampling and analysis	20
3.6 Agronomic Phosphorus Use Efficiency (APUE)	20
3.7 Data analysis	20
CHAPTER FOUR	21
RESULTS	21
4.3 Effect of P-fortified compost manure on growth of maize	21
4.3.1 Short rains season	21
4.3.2 Long rains season	23
4.4 Effect of P-fortified compost manure on maize yield	25
4.4.1 Short rains season	25
4.5 Effect of Phosphorous fertilizer source on Phosphorus Use Efficiency (APUE)	28

4.5.1 Short rains season28

4.5.2 Long rains season29

4.6 Residual effects of P-fortified compost on growth of maize.....29

4.7 The residual effect of P-fortified compost manure on P-uptake and yield of maize.....32

4.7.1 Yield32

4.7.2 Plant P uptake.33

CHAPTER FIVE.....35

DISCUSSION35

5.1 Effects of P-fortified compost manure on maize growth and yield.....35

5.2 Agronomic Phosphorus Use Efficiency (APUE)36

5.3 Residual value of P-fortified compost on maize growth and yield36

CHAPTER SIX.....38

CONCLUSION AND RECOMMENDATIONS38

6.1 Conclusion38

6.2 Recommendation38

REFERENCES39

APPENDICES.....56

LIST OF TABLE

Table 1: The chemical characteristics of the soils in the selected sites.....	15
Table 2: Chemical characteristics of different compost manure.....	18
Table 3: Effects of P-fortified compost on growth of maize across the sites during short rains season.....	22
Table 4: Effects of P-fortified compost on growth of maize across the sites during short rains season.....	24
Table 5: Effects of P-fortified compost on 100 seed weight across the sites during the short rain season.....	26
Table 6: Effects of P-fortified compost on 100 seed weight across the sites during the Long rain season.....	28
Table 7: Agronomic Phosphorous Use Efficiency (APUE) of selected P fertilizer on maize yield.....	29
Table 8: The residual effects of P-fortified on plant growth across sites.....	31
Table 9: The residual effects of P-fortified compost on 100 seed weight across different sites.....	33

LIST OF FIGURES

Figure 1: Map of Kenya showing study site.....	13
Figure 2: Rainfall received at the three sites during the short rain season.....	14
Figure 3: Rainfall received at the three sites during the long rain season.....	14
Figure 4: P-fortified compost set up.....	17
Figure 5: Effect of P-fortified compost manure on maize yield in the short rain season...	25
Figure 6: Effect of P-fortified compost manure on maize yield in the long rain season...	27
Figure 7: Residual effects of P-fortified compost on maize yield across sites.....	32
Figure 8: Residual effects of P-fortified compost on maize P-uptake yield across sites.....	34

LIST OF PLATES

Plate 1: Maize stalk.....	17
Plate 2: Cattle manure	17
Plate 3: Mature compost.....	17
Plate 4: Chlorophyll content meter (SPAD).....	19
Plate 5: Grain moisture tester.....	19

LIST OF APPENDICES

Appendix 1: Fertilizer calculations.....	56
Appendix 2: Analysis of variance (ANOVA) for plant height, leaf area index, chlorophyll content, hundred seed weight, and yields for Kiobem long rain season (Sept-Feb, 2011-2012).....	57
Appendix 3: Analysis of variance (ANOVA) for plant height, leaf area index, chlorophyll content, hundred seed weight, and yields for Kiptaruswo long rain season (Sept- Feb, 2011-2012).....	57
Appendix 4: Analysis of variance (ANOVA) for plant height, leaf area index, chlorophyll content, hundred seed weight, and yields for Kapkerer long rain season (Sept-Feb, 2011-2012).....	58

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA:	Analysis of variance
APUE:	Agronomic Phosphorus Use Efficiency
DAP:	Di-ammonium Phosphate
FAO:	Food and Agriculture Organization.
Ha:	Hectare
KALRO:	Kenya Agricultural and Livestock Research Organization
RCBD:	Randomized Complete Block Design
MRP:	Minjingu Rock Phosphate
SAS:	Statistical Analysis System.
TS ^p :	Triple Super Phosphate
USDA:	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 Background information

Only about 18% of Kenya's land mass is classified as medium to high potential agricultural land (GOK, 2010). Western Kenya is mainly medium to high potential and covers approximately 13,000 Km² of total land mass. The area has a population density of more than 1100 persons/km² and an average farm size of 0.6 ha per capita (Marenja and Barret, 2009). Western Kenya comprises about 52% of the maize growing area in Kenya (Jayne *et al.*, 2001). Farmers in the western Kenya region commonly get maize yields below 1 ton/ha/season against the potential yield of 10 tons/ha (Nekesa *et al.*, 1999). Soils in this area vary from high through medium to low fertility depending on time from conversion from forest to cultivation. For example Kapkerer that has been under cultivation for between 80 to 105 years is classified as low fertility, while, Kiptaruswo and Kiobem that have been under cultivation for 60-80 and 5-30 years are classified as medium and low fertility respectively (Jaetzold and Schmidt, 2006).

The low maize productivity is mainly attributed to low soil fertility coupled with low resource level and lack of adaption of appropriate agronomic recommendations. Among the soil fertility constraints that contribute to low maize yield are low levels of P, pH and organic matter (Okalebo *et al.*, 2002; Kinyangi 2008). In addition to low soil fertility, heterogeneity is a common phenomenon both at farm and landscape level (Titonell *et al.*, 2005). Studies in Western Kenya have noted gradients in soil fertility, pH, N, P and organic carbon levels within different fields of the same farm or within different farms but same agro-ecological environments (Titonell *et al.*, 2005; Vanlauwe *et al.*, 2007). The blanket agronomic recommendations for maize in western Kenya which include 60 kg/N/ha and 60 kg/P₂O₅/ha assume that farms are homogenous in soil fertility (KARI, 1994). Studies have however shown that variations in soil fertility are significant and cannot be ignored (Ojiem and Odendo, 1997). Consequently adoption of recommendations does not often resolve the nutrient replenishment problem resulting in continuing soil fertility decline (Zingore *et al.*, 2007).

South Nandi District, Nandi County, in Western Kenya is one such area where soil fertility has been declining. Continuous maize cultivation and differential application of fertilizer has resulted in decreased organic carbon and nutrients (Kimetu *et al.*, 2008) at farm and landscape level. The soil fertility management approaches therefore call for interventions that specifically target the less fertile soils and those that maintain fertility of the areas that are more fertile.

Phosphorus is one of the major nutrients limiting crop production in the region. The soils are generally acidic hence deficient in P because of strong sorption of P by aluminum (Al) and iron (Fe) oxides and hydroxides and other amorphous material (Hinisinger, 2001). Large application of inorganic fertilizer P is thus required to overcome P sorption and achieve high crop yields (Warren, 1994; Henry and Smith, 2002). The practice is expensive and unaffordable by most small scale farmers. Affordable Phosphorous management systems that involve recycling of less expensive natural resources such as organic materials may be a more viable means of enhancing soil fertility in smallholder farms in the area.

Composting is a practical means of bulking organic resource and concentrating their nutrients. Compost manure has long been identified as a low cost locally available fertilizer at farm level. Compost manure has great potential for improving soil productivity and crop yield by improving the physical, chemical and microbiological properties of the soil as well as nutrient supply (Bertoldi *et al.*, 1983; Sarwar *et al.*, 2008). Addition of compost to the soil often results in reduced sorption (Sharply and Moyer, 2001), and increased efficiency of P utilization by crops. The benefits of compost manure use at farm level are limited by the amount and quality. The quality of compost can be improved by fortification through incorporating nutrients that are most limiting (Keziah *et al.*, 2007). Organic and mineral fertilizers are required for sustaining crop production (Vanlauwe *et al.*, 2002). The organic fertilizer improves soil structure, moisture content and soil organic matter, while the mineral fertilizer target the limiting nutrient, and also lowers the high C: N ratio of many crop residues (Misra *et al.*, 2003) hence increasing decomposition rate by micro-organisms. Minjingu Rock Phosphate (MRP) is one of the fertilizers that is locally available and recommended for use in acidic soils. The low solubility of MRP however limits its use (Ikerra *et al.*, 1994). Studies have shown that the availability of phosphate and rock phosphate to crops in acid soils is increased when composted (Ndung'u *et al.*, 2003; Schefe *et*

1.2 Statement of the problem

Maize is a major staple food crop in Western Kenya. Farmers in the region however realize low maize yields often below 1 ton/ha (Nekesa *et al.*, 1999). The low production is attributed to low levels of P, low pH and organic matter levels in the soils (Okalebo *et al.*, 2002; Kinyangi 2008). The high prices of inorganic fertilizers have made it difficult for most resource poor small-scale farmers who are the majority in western Kenya, purchase sufficient quantities to replenish soil nutrients. The farmer's low P-fertilizer input is ineffective on these highly P-fixing soils. Use of compost manure by farmers is however low because of its low P value in acidic soils. The low P value of compost manure can be improved by fortification through addition of P mineral fertilizer during composting. The effect of P-fortification in these soils has however not been quantified.

1.3 Objective

1.3.1 Broad objective

The broad objective of the study was to contribute to increased maize production among the smallholder farmers in Nandi South Sub-County through introduction of low cost P- fortified fertilizers.

1.3.2 Specific objectives

To determine the:

- i. Effects of P-fortified compost manure on growth and yield of maize in Nandi South Sub-County
- ii. Agronomic Phosphorus Use Efficiency (APUE) of different P-sources on maize production in the acidic soils of Nandi South Sub-County.
- iii. Residual value of P-fortified compost in maize production in Nandi South Sub-County.

1.4 Hypotheses

- i. P-fortified compost manure has no effect on growth and yield of maize.
- ii. Different sources of P have similar phosphorus use efficiency (PUE), in maize.
- iii. P-fortified compost manure has no phosphorus residual value on maize production in Nandi South Sub-County.

- iii. P-fortified compost manure has no phosphorus residual value on maize production in Nandi South Sub-County.

1.5 Justification of the study

Many rural households in Kenya highlands are no longer self-sufficient in maize production, a major staple food crop and source of income. Continuous cultivation of farms has led to decline in soil fertility due to constant removal of nutrients leading to reduction of crop yields. The high cost of inorganic fertilizers has made it difficult for most resource poor small-scale farmers to purchase sufficient quantities to replenish soil nutrients. Alternative methods for improving soil fertility in degraded areas and maintaining fertility in the high fertility zones are necessary. Organic manure use offer comparative advantage in enhancing soil fertility besides improving crop yields. Compost manure is one such organic amendment but it has low nutrient content. P-fortification (adding of P mineral fertilizer) is one of the ways for improving the quality of compost. Rock phosphate has been recommended as an effective, local and inexpensive P fertilizer option for smallholder farmers in western Kenya. The use of the cheaper form of P in composting can provide less costly p-fortified compost manure. This study will provide farmers with an alternative cheaper, cost-effective and environmental friendly source of effective P-fertilizer. P-fortified compost is an appropriate technology to increasing soil fertility for enhanced maize production in smallholder farming systems.

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize Production in Western Kenya

Maize is the main staple food crop in Kenya. It is grown in varied agro-ecological zones across the country. The area under maize production is estimated at 1.89 million hectares, with an expected national production of 2.8 million metric tons and a national consumption of 3.6 million tons per annum (USDA, 2013). This indicates a production deficit of up to 0.8 million tons, which is met through imports from the neighboring countries. Small scale producers accounts for about 70% of the overall production, which is mainly grown for subsistence. The remaining 30% of the output is from large scale commercial producers (Export Processing Zone Authority, 2005).

Western Kenya comprises about 52% of the maize growing area in Kenya (Jayne *et al.*, 2001). Farmers in this area generally realize less than 1 ton/ha against a potential yield of 10 tons/ha (Nekesa *et al.*, 1999). The low yield has been attributed to climatic conditions, inadequate use of fertilizers and high costs of external inputs (Kang'ethe, 2004). Low levels of P, low soil pH and organic matter (Okalebo *et al.*, 2002; Kinyangi 2008) are among the most important soil fertility constraints. Increase in maize production in western Kenya is a function of improved yield per unit area rather than expansion in area under production because most of the arable land is already under cultivation (Karanja and Oketch, 1992).

2.2 Soil degradation

Soil degradation and nutrient depletion due to continuous cultivation, removal or burning of crop residues, loss of nutrients through soil erosion, overgrazing between cropping seasons and inadequate use of inorganic fertilizers are the major causes of declining soil fertility in Sub-Saharan Africa (Bationo *et al.*, 1998; Bekunda *et al.*, 1997). In Sub Saharan Africa, conversion of forest area to small-scale permanent agricultural land accounts for 60% of land-use change (FAO, 2005) and is often followed by low or no use of nutrient amendments (Sanchez *et al.*, 1997; Sanchez, 2002; Smaling *et al.*, 2006). Thus the small scale farmers continue to suffer widespread nutrient deficiencies of N, P and base cations, Ca, Mg and K (Hartshorn *et al.*, 2006) due to continuous cropping without adequate soil amendment. Generally about 320 million hectares of land in sub Saharan African is affected

by human induced soil degradation (Oldeman *et al.*, 1991; Crosson and Anderson, 1995). In these cropping system the amount of nutrients extracted from harvesting of crops, leaching and water erosion normally outweigh those imported naturally through atmospheric deposition, biological nitrogen fixation, and artificially through organic manure and mineral fertilizer (Smaling, 1993).

In many farming systems in the tropics, large differences in nutrient balance can often be observed between fields within farms, resulting to substantial differences in soil fertility status between fields (Smaling *et al.*, 2002). In a study in Central Kenya, Murage *et al.* (2000) reported differences in chemical and biological soil properties of productive and non-productive fields within a farm as a result from past soil management. Gradients in both soil fertility status and in soil nutrient balances have also been reported for 'village fields and 'bush fields' in Central Mali (Dembele' *et al.*, 2000). Soil fertility tended to decrease with distance from the homestead, continuous concentration of nutrients in the smaller areas around the homestead, at the expense of nutrient depletion in further and larger fields, coupled with continued export of produce and a lack of external inputs into the farm, leads to an overall negative nutrient balance at farm level (Giller *et al.*, 1997). In Western Kenya, Tittone *et al.*, (2005) observed that soil fertility indicators and nutrient concentration on smallholder farms varied between different fields. The difference was attributed to variation in cropping patterns and frequencies of cultivation. In Western Kenya, nutrient balance studies show about 22 kg N, 2.5 kg P and 15 kg K/ha are lost annually (Smaling *et al.*, 1993), although losses can be high as 112 kg N, 3.0 kg P, and 70 kg K/ha in the intensively cultivated highlands of western Kenya (Van den Bosch *et al.*, 1998). Crop yield decline arising from the nutrient depletion not only affect viability of individual farms but also the food security of sub Saharan Africa.

2.3 Phosphorus fertility management strategies

Phosphorus (P) is a vital component of a number of macromolecules and is an integral part of energy metabolism and major biological processes including photosynthesis, respiration, and membrane transportation. Its genetic role in ribonucleic acid and function in energy transfers via adenosine triphosphate are indispensable (Li *et al.*, 2011).

Phosphorus is found in all living beings as part of proteins, nucleic acids, membranes and energy molecules such as ATP, GTP and NADPH. Usually, it is the second element limiting

plant growth preceded by nitrogen, but depending on some environmental and biological factors it can be the main growth-limiting nutrient (Azziz *et al.*, 2012).

Phosphorous deficiency is widely spread in East Africa (Ngome *et al.*, 2012; Okalebo *et al.*, 2006). It is particularly acute in western Kenya where 80% of smallholder land used for maize has soil test value below 10 mg kg⁻¹ (Jama, and Van Straaten 2006) where as sufficient P in most agricultural soil range is 30-80 mg kg⁻¹ (Li *et al.*, 2004). Inherently low levels of soil P, low availability of P compounds and fixation of applied soluble source of P in the soil, are the major hindrances for sustained production of arable crops (Brady and Weil, 2002). One of the recent strategies proposed for sustainable intensification of food production in the tropics is P-recapitalization (Buresh *et al.*, 1997). This involves massive P application designed to permanently saturate the sorption sites and provide P for crop uptake. The strategy turns the soil P-fixing capacity from a constraint into an asset. Fixed P forms the stock that provides P over a period of 5–10 years, referred to as soil capital, whereas the P available during an annual cropping cycle is called liquid P (Buresh *et al.*, 1997). Generally, 10–20% of P applied is available for crop uptake in the year of application, whereas the remaining 80–90% soil P (residual P) is adsorbed on the soil constituents and builds up as the soil P capital. The use of P-recapitalization by the resource poor farmers has not been possible due to high rates of application hence high cost of inorganic P fertilizer (Onwonga *et al.*, 2008).

2.3.1 Inorganic fertilizer

Most inorganic fertilizers are mined from ores or sedimentary deposits, except for those that contain nitrogen (N) which is synthesized with high energy input from the air. As a result of the high element concentration and high solubility of the inorganic fertilizers, their beneficial effects on plant growth are quick and easy to recognize. The use of inorganic fertilizer is an important means of supplying the soils with necessary nutrients in crop production (Adeniyi and Ojeniyi, 2003). There inorganic fertilizers are too costly for the resource-poor farmers of tropics and subtropics (Egle *et al.*, 1999). Moreover, the high acidity of tropical and sub tropical soils fix P making it hardly available to crops (Marschner, 1995). In Kakamega, Western Kenya, Crowley and Carter (2000) noted that most farmers used sub optimal levels of chemical fertilizer, because of high costs. Studies have tested varied quantities of fertilizer P (Nziguheba *et al.*, 2000) besides combining chemical fertilizer

with organic resources including crop rotations (Kihara *et al.*, 2010) to mitigate the effects of P fixation by the soils.

2.3.2 Organic fertilizers

Organic fertilizers are all forms of organic soil amendments that originate from both livestock waste and crop residues, with the nutrients in them being mineralized by soil microbes and slowly making them available to plants over a long period of time (Lampkin, 2000). In addition organic fertilizers supply humus which increases the nutrient and water holding capacity of the soil. Organic fertilizers however contain mineral nutrients in the form of complex organic molecules and the levels of nutrients are much lower than inorganic fertilizers (Palm *et al.*, 1997). Despite the slow release of nutrients organic fertilizer offer good soil management practice in sustainable crop production because soil fertility is enhanced through the modification of soil physical, chemical and biological properties (Haering and Evanylo, 2005). In low-input system, management of organic resource is a viable option for improving agricultural productivity and compensating for nutrient loss in soil. The use of organic resource is important to farmers in Sub-Saharan Africa where the soils are highly weathered while socio-economic and environment conditions limit their access and/or use of right quantities of chemical fertilizer (Makokha *et al.*, 2001; Van Straaten, 2002). Improving soil fertility using organic resource in smallholder farming system of sub-Saharan Africa has not achieved the desired result because of unequal distribution of these organic resources across various cropping systems. Indeed, the availability of organic resource as nutrient source is limited by the alternative uses of fuel, and feed. In dry areas, the availability of organic resource in insufficient quantities pose a challenge to their utilization as a source of soil nutrient because of competing, uses such as fuel and feed for animals (Bationo *et al.*, 2006; Gichangi *et al.*, 2007). In the high potential areas of Rift Valley and Western Kenya, production rate of crop residues such as maize stover and wheat straw is high; about 15 tons/ ha/year (Savala *et al.*, 2003). Labour shortage is however a constraint in adoption of this technology (Quansah and Yeboa, 2000).

2.3.3 Compost manure

Supply of adequate nutrients for optimum crop growth will depend on the quality of the manure. One way of achieving this is through composting process. This process could be defined as a biotechnology where microorganism, worms and insects participate to produce an innocuous product, chemically stable and utilizable to improve soil fertility and crop production. (Brito *et al.*, 2009). Composting depends on a number of factors that have both direct and indirect influence on the activities of the microorganisms. They include the type of raw material being composted, its nutrient composition, moisture content, temperature, acidity or alkalinity and aeration. The microorganisms that do much of the work need high temperatures, plenty of oxygen, and moisture. In the traditional method of composting, the influence of the listed factors had been largely ignored and therefore the final composts obtained from such unimproved method are poor in quality (Paredes *et al.*, 2005).

Compost has been proposed as a means of simultaneously diverting organic materials from landfills while producing a valuable product that improves tilth, organic matter content and nutrient supply of agricultural soils (Levy and Taylor, 2003). However different composting methods have a great influence on the quality of the fertilizer (Taiwo *et al.*, 2004). If compost is not well decomposed, it will continue with the decomposition process leading to nutrient immobilization (Lampkin, 2000). The effectiveness of good quality compost manure can be increased by combining it with an inorganic fertilizer source. Studies by Hellal *et al.* (2012) indicate that composting organic resource with RP increased total N and soluble phosphorus thus increase in crop production.

2.4 Fortification of compost organic material

2.4.1 Fortification with soluble phosphorus source

Readily soluble P fertilizers have the potential to supply P to plants immediately after application but the P-availability to plants generally decreases with time due to the conversion of soluble P to less soluble forms as a result of reaction with soil constituents, especially in strongly P-fixing acidic soils of volcanic origin (Rivaie *et al.*, 2008). High rates of phosphate fertilizers are thus required to improve crop yields on highly acidic soils. Fortification of soluble phosphorus source includes composting inorganic P (soluble P) with organic materials (crop residues and manures). Upon composting of organic material improve

P availability through reduction in soil P sorption and increase in desorption of already-fixed P in acidic soils (Kisinyo *et al.*, 2011). Fortification of crop residues with DAP fertilizer in western Kenya was shown to result in higher organic resource in terms of N (2.2%), P (0.42%) and organic matter (52%) which increased maize grain yield (Ndung'u *et al.*, 2007). Hirzel *et al.* (2009) recorded tremendous increase in maize and rice yields following combined application of farm yard manure and mineral fertilizer.

2.4.2 Fortification with Rock Phosphate (RP)

Rock phosphates are regarded as valuable alternative to P fertilizer for a sustainable agriculture system and are increasingly recognized as potential fertilizers (Yu *et al.*, 2012). Rock Phosphate (RP), partially made of mineral apatite is an important commercial source because of its high concentration of P minerals (Kauwenbergh 2006). The benefit of RP over mineral fertilizers is that it's a cheaper source of P for crops (Jama *et al.*, 2006) and has some liming effect (Nekesa *et al.*, 2005). Types of RPs in Africa include *Tundulu* from Togo, Burundi and Malawi; *Minjingu* from Tanzania; *Busumbu* and *Sukulu* from Uganda; *Nkombwa* and *Kalume* from Zambia and *Dorowa* RP from Zimbabwe. Rock Phosphate originates mainly from igneous or sedimentary rock sources with sedimentary being the most widely used in world phosphate production.

A number of studies have also highlighted the suitability of Minjingu RP as P source for crops in P deficient soils. Shisanya *et al.* (2003) reported that this deposit may prove crucial to the amelioration of the 900,000 hectares of low-phosphorus soils in the highlands of Western Kenya for several years where farmers are currently cultivating several food legumes. A relative agronomic effectiveness (RAE) of 75% for Minjingu RP was reported in the five seasons following application to maize in Western Kenya. On-farm trials in P deficient soils in western Kenya demonstrate Minjingu Rock Phosphate to be as effective as triple superphosphate (TSP, 20% P) at equal P rates (Jama and Straaten, 2006). The major problem with using Rock Phosphate (RP) is their low solubility. The P in RP is not plant available where the pH of the soil is greater than 5.5 and even when conditions are optimal; plant yields are lower than those obtained with soluble phosphate (Singh and Reddy, 2011). In fact, of all RP sources in Sub Saharan Africa, only the RP from Mali, Senegal and Tanzania which are *Tilemsi*, *Matam* and *Minjingu* respectively have solubility in 2% citric acid exceeding 10% (Vanlauwe and Giller,

2006). In soils, insoluble P compounds can be solubilized by organic acids, phosphatase enzymes and complexing agents produced by plants and microorganism (Park *et al.*, 2011).

Fortification of composted organic material with RP otherwise known as phospho-compost would enhance the solubility and the subsequent availability to plants of phosphorus (P) from rock phosphate (Amberger *et al.*, 1992; Van de Berghe, 1996). Various approaches have been used to improve the solubility, and effectiveness of RP with different success. The dissolution of rock phosphate through composting varies with characteristic and kind of organic residue used (Mahimaraja *et al.*, 1995). Akanda *et al.* (2005) in a study that composted RP and poultry manure showed that solubilization of RP by poultry manure enhanced its effectiveness in maize and cowpea. The release of P from rock phosphate is a function of the acidification of rock phosphate by organic acids and more importantly their chelating ability on calcium, iron and aluminum which fixes soluble P (Pohlman and McColl, 1986). Another important factor in the release of P from rock phosphate is the participation of the Hydroxyl (OH) groups in the organic acids. Kpomblekou and Tabatabai, (1994) found that citric acid with three carboxyl (COOH) groups and an Hydroxyl (OH) group were able to dissolve more P from rock phosphate than cis-aconitic acid with three carboxyl groups but without the Hydroxyl (OH) group. Additional benefits that occur from application of phospho-compost are the movement of dissolved P to a greater soil depth, which provides a larger soil volume for P uptake by plants. Plant materials composted with animal wastes are favored because they produce more organic acids and humic substances (Palaniappan and Natarajan, 1993). Manna *et al.* (2001) and Srikanth *et al.* (2006) found that the application of phospho-compost at 10 Mg ha⁻¹ can give plant growth, dry matter accumulation, seed yield and P uptake of soybean crop equivalent to that when SSP is applied at 26.2 kg P ha⁻¹. Hellal *et al.* (2013) reported that application of phospho-compost gave higher maize growth parameter and Phosphorus use efficiency.

2.5 Phosphorous uptake and use efficiency

Phosphorus use efficiency is the ability of a crop plant to produce high yield in a soil (or other media) that is limiting in phosphorus supply (Fohse *et al.*, 1988; Gourley *et al.*, 1994). Phosphorus efficiency can be conceptualized in two ways:-the efficiency with which P is utilized to produce yield, i.e., the amount of P needed in the plant to produce one unit of grain. Its calculated using yield, $(Y_N - Y_O)/FN$, where Y_N and Y_O , are the crop yields with

and without the nutrient being tested, and FN is the amount of nutrient applied, all in kg ha⁻¹. The second way is P utilization efficiency or internal P requirement and is expressed as the P concentration in the plant to produce a given percentage of its maximum yield (Fohse *et al.*, 1988; Bhadoria *et al.* (2002), its calculated using nutrient uptake, $(UN - UO)/FN$, where UN and UO are the nutrient uptake by crops with and without the applied nutrient, all in kg ha⁻¹ and FN is the amount of nutrient applied, all in kg ha⁻¹. Phosphorus use efficiency has been used to compare the effectiveness of phosphorous sources (Mahimairaja *et al.*, 1995). Hellal *et al.* (2013) noted that Phosphorus use efficiency in maize was higher in phospho-compost as compared to the other P sources. Hellal *et al.* (2009) in an earlier study found that the combined application of compost and town refuse with rock phosphate increased the yield and P uptake of faba bean plants.

2.6 Residual P effect

The residual effect of P refers to P that can be taken up by crops for many years (Syers *et al.*, 2008; Nuruzzaman *et al.* (2005), depending on soil P fixation capacity, soil pH, crop species, and P application time (Sheida *et al.*, 2012). Crop uptake is generally only 10–20% of the P fertilizer applied in the first year, but a substantial part of applied P accumulates in the soil as residual P (Syers *et al.*, 2008). The efficiency of an application can be evaluated for one or more subsequent season. Proper evaluations of residual effects require longer time periods to truly capture their full impact (Syers *et al.*, 2008). Akande *et al.* (2003) reported an increase in soil available P of between 112 and 115 % and 144 and 153 % respectively for a two year field trials, after applying rock phosphate with poultry manure on okra. Akande *et al.* (2005) further reviewing the effect of rock phosphate amended with poultry manure on the growth and yield of maize and cowpea reported that when rock phosphate application had continued over a period of several years a large pool of undissolved rock phosphate could accumulate. Residual effects of manure or compost application can maintain crop yield level for several years after manure or compost application ceases since only a fraction of the P and other nutrients in manure or compost become plant available in the first year after application (Eghball, 2002). Residual effects of organic materials on soil properties can contribute to improvement in soil quality for several years after application ceases (Ginting *et al.*, 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site description

The research was conducted in three sites along a soil fertility gradient in Nandi County, Western Kenya. The soil fertility gradient was based on the time since conversion from forest to agriculture (1900 to date). High fertility site Koibem lies between latitude $00^{\circ} 09' 28.2''\text{N}$; Longitude $34^{\circ} 54' 31.9''\text{E}$, with an elevation of 1770 m above sea level. The medium fertility site Kiptaruswo lies between $00^{\circ} 02' 28.1''\text{N}$ and $034^{\circ} 56' 35.9''\text{E}$ at an altitude 1582 m above sea level. The low fertility site Kapkerer lies between $00^{\circ} 00' 31.9''\text{N}$ and $34^{\circ} 48' 14.6''\text{E}$, with an elevation of 1530 m above sea level ((Jaetzold and Schmidt, 1983). South Nandi receives a bimodal rainfall ranging from 1800mm to 2146 mm per annum. The long rains are experienced in March to August while short rains from August to December. The major dry season is between January and February. Temperatures are fairly constant throughout the year with mean daily minimum and maximum of about 12°C and 29°C respectively. The soils are predominantly Nitisols, characterized as dark red, well drained, deep, sandy to sandy loam texture (Jaetzold and Schmidt, 2006).

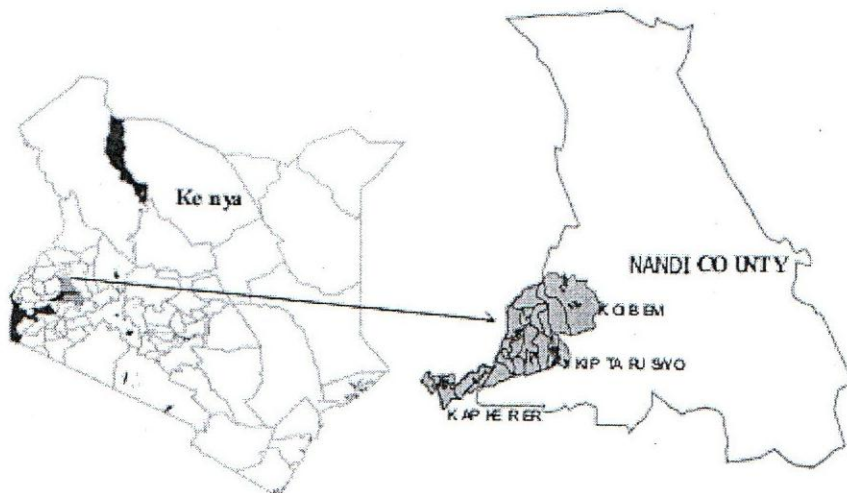


Figure 1: Map of Kenya showing study sites

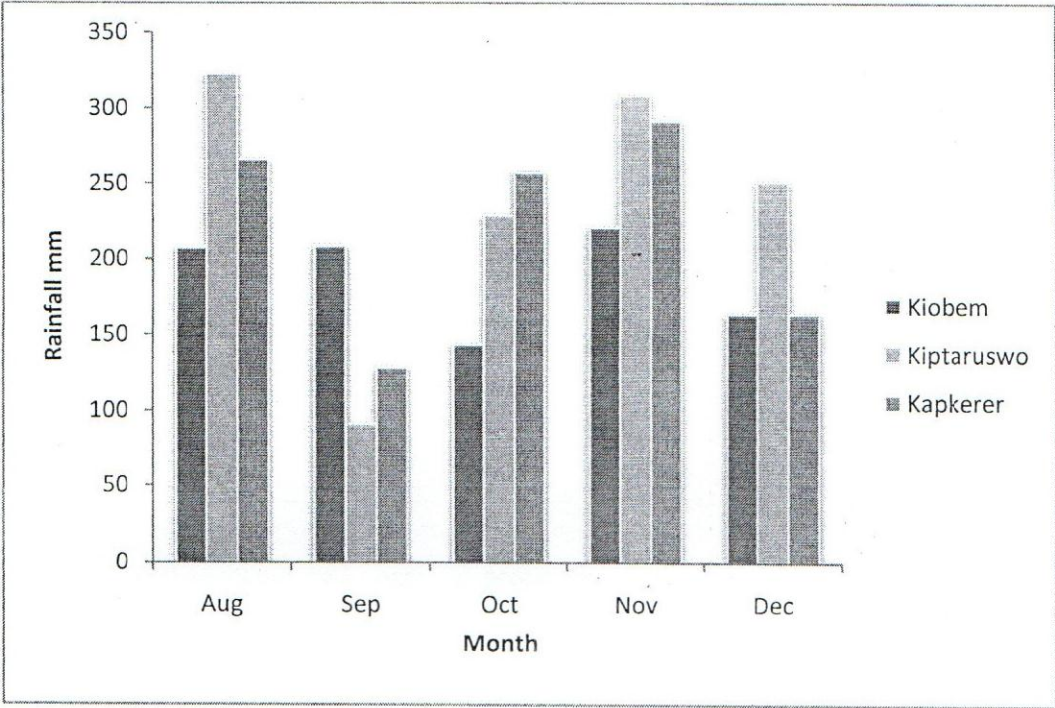


Figure 2: Rainfall received at the three sites during the short rain season (2011)

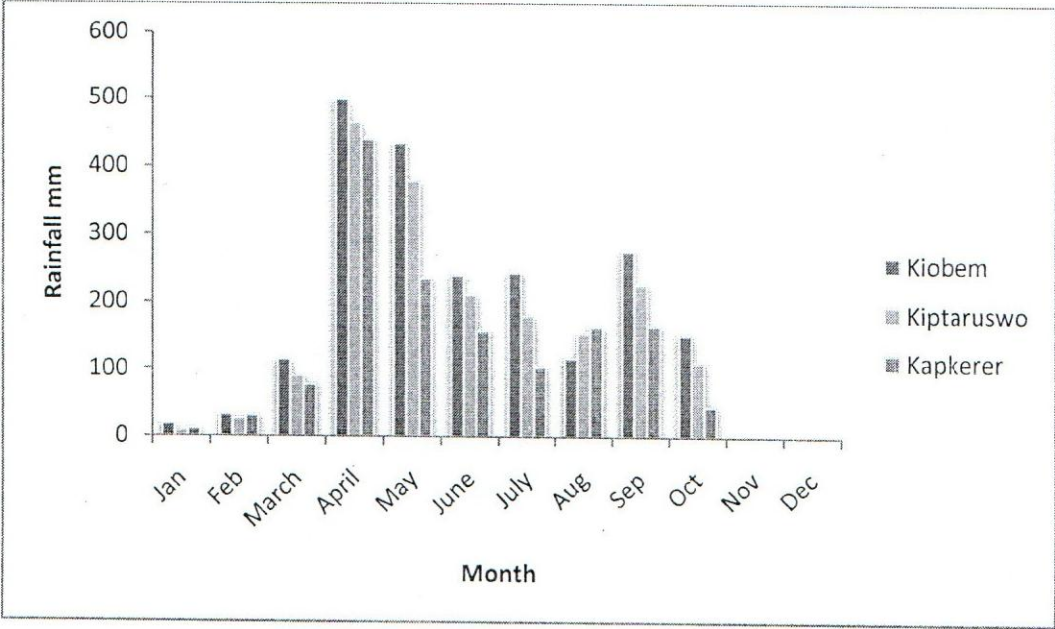


Figure 3: Rainfall received at the three sites during the long rain season (2012)

Table 1: The chemical characteristics of soils in the selected sites.

Soil property	Sites		
	Koibem	Kiptaruswo	Kapkerer
pH (water)	5.2	5.3	5.8
Available P(mg kg ⁻¹)	37.0	13.0	9.0
Exchangeable K(mg kg ⁻¹)	550	340	280
Exchangeable Ca(mg kg ⁻¹)	3820	3470	3240
Exchangeable Mg(mg kg ⁻¹)	82	84	82
Total N (%)	0.30	0.20	0.10
Organic C (%)	3.70	2.70	1.20

Initial physical and chemical properties of soil were determined before the experiments were set up (Table 1). The soil chemical characteristics generally varied with site. Soils in high fertility (Koibem) and medium fertility (Kiptaruswo) were more acidic compared to those in low fertility (Kapkerer). Soils in medium and low soil fertility site have a low amount of soil available phosphorus, since the sufficient P range in agricultural soil is 30-80 mg kg (Li *et al.*, 2004). This result is partly attributed to long period of continuous cultivation without P replenishment in low soil fertility site (Kapkerer), hence need for supplemental P addition (Ndung'u *et al.*, 2006). Organic carbon was high in high soil fertility site while in low soil fertility site (Kapkerer) it was low, the sufficient organic carbon range is between 1.5- 3.0% (Okalebo *et al.*, 2002). Total nitrogen was very high in Kiobem while in Kapkerer the nitrogen level was low, since the sufficient range in agricultural soil is 0.12- 0.25 (Okalebo *et al.*,2002).

3.2 Experimental design and treatments

The study was set across a soil fertility gradient range, categorized as low, medium and high fertility. The experimental design was randomized complete block design (RCBD) with three replications per site. The experiment had six treatments of different phosphorous sources and levels. The treatments assigned to each experimental unit were (i) Control with- no fertilizer input (ii) Rock Phosphate (RP) at the full recommended rates of 60 kg P₂O₅/ha, (iii) Triple Super Phosphate (TSP) at the recommended rates of 60 kg P₂O₅/ha (iv) Compost manure (COM) at 6 tons/ha. (v) P-fortified Compost at half rate 30kg P₂O₅/ha (PCOM30),

6t/ha, (delivered in 6t/ha compost) (vi) P-fortified Compost at recommended P rates of 60kg P_2O_5 /ha (PCOM60) 6t/ha, (delivered in 6t/ha compost). This experimental set up was carried out in the short rain season and repeated in the long rain season without additional treatments to evaluate the residual phosphorus effect of the treatments. The P-source experiment (season II) was set up in new site on adjacent farms during the long rain season to avoid confounding by residual phosphorus.

3.3 Compost preparation and chemical characterization

3.3.1 Compost preparation

Composts without fortification and those fortified at P-levels of 60 kg/ha and 30 kg/ha were prepared and used for this experiment. The respective composts were prepared based on method described by Ndung'u *et al.* (2003) with some modification. The materials used were mainly agro-organic wastes that included maize stovers, cattle manure, green vegetation and wood ashes. Fortification of P was done at two enrichment levels equivalent to 30 and 60 kg P_2O_5 per hectare using Mijingu rock phosphate (27-29% P_2O_5), a relatively cheaper therefore more affordable form of phosphorus fertilizer. The amount of rock phosphate added in the compost heap was calculated to achieve a final application rate of the intended treatment rates with an application of 6 tons/ha of compost i.e. at P-levels of 30 kg/ha, 1.3kg RP/layer was applied while at P-levels of 60 kg/ha, 2.58 kg RP/layer was applied.

The compost heap was done in a 0.3m deep pit of length 5m and width of 1.5m. Maize stalks were chopped to a maximum length of 20cm and layer first to a thickness of 30cm. Other materials added were cow dung (10cm layer), Rock phosphate (calculated amount), soil (2cm layer), green vegetation (15cm) and finally a sprinkle of wood ash. Water was added to each layer to achieve a moisture content of 40-60% (Lekasi *et al.*, 2003). This process was repeated two more times. The heap was then covered with a 10cm soil layer and dry grass to reduce loss of moisture during composting period. The compost heaps were turned after three weeks and thereafter every two weeks to facilitate even decomposition, with occasional sprinkling of water to maintain moisture content, for a duration of 12 weeks. The mature compost is the product is a dark mass with an earthy smell (Plate 3).



Plate 1: Maize stalks

Plate 2: Cattle manure



Plate 3: Mature compost

Ash
Green vegetation
Topsoil
Rock phosphate
Cattle manure
Maize stalk

Figure 4: P-fortified Compost heap set up

3.3.2 Chemical characterization of compost manure

PCOM60 had the highest available P, followed by PCOM30 and lastly the unfortified compost (Table 2). Exchangeable base Ca was relatively high (4.93 g kg^{-1} , 4.77 g kg^{-1} and 4.62 g kg^{-1}) in PCOM60, PCOM30 and unfortified compost respectively. In addition to increasing P, fortification of compost resulted in increase of total nitrogen .i.e. 60% for PCOM60 and 20% for PCOM30. Organic C was higher in PCOM60. P-fortified compost manure is among the highest organic resources in terms of N, P, K and Organic matter.

Table 2 Chemical characteristics of the different compost manure

Characteristic	COM	PCOM30	PCOM60
pH (water)	7.0	8.0	8.2
Extractable P(mg kg ⁻¹)	373.5	597.8	745.6
Exchangeable K(mg kg ⁻¹)	351	350	354
Exchangeable Mg(mg kg ⁻¹)	88	88	88
Exchangeable Ca(mg kg ⁻¹)	4630	4780	4930
Total N (%)	0.90	1.10	1.50
Organic C (%)	6.03	6.07	6.66

3.4 Land preparation, and crop management

In the first season during the short rains land was prepared using hand hoe to a moderate tilth. Maize variety H-513 was then planted in plots measuring (3.6x3.75) m² at a spacing of 75cm x 30cm. Nitrogen in form of CAN was applied in all plots at a rate of 60 kg N/ha in split application (33% at planting and 67% as top-dressed). The plots were generally kept weed free by mechanical weeding, while pests such as stalk borer was controlled by applying *Actelic*[®] 1% at a rate of 8 kg/ha. The plant height, leaf area, and chlorophyll content were determined at the 5th leaf stage and at 50% tasseling. Plant height and leaf area were measured using a measuring tape. The plant height was taken from the soil surface to the apical tip of the plant. The leaf length and breadth were measured to obtain the leaf area. The leaf area index was estimated as its length multiplied by its maximum width multiplied by 0.75 (maize leaf calibration factor), Elings (2000). Chlorophyll content was determined on the newest fully expanded leaf (Shapiro and Francis, 2006), using a chlorophyll content meter (SPAD[®]) (Plate 4). At physiological maturity, five sub-samples of maize cob from each plot were harvested. Maize grains were then separated from cob by shelling and total weight of grain recorded. The percentage moisture content was determined using a grain moisture tester (Plate 5). Total maize grain yield and 100 seed weight were then adjusted to the 13% moisture content. During the second season, the experimental set up was allowed to run without additional treatments to evaluate the residual phosphorus effect of the treatments. Residual effect was calculated as the difference in yield where fertilizer P had been applied

and that of adjacent plot where fertilizer P has not been applied. The experiment was repeated in new sites to avoid confounding by residual phosphorus.

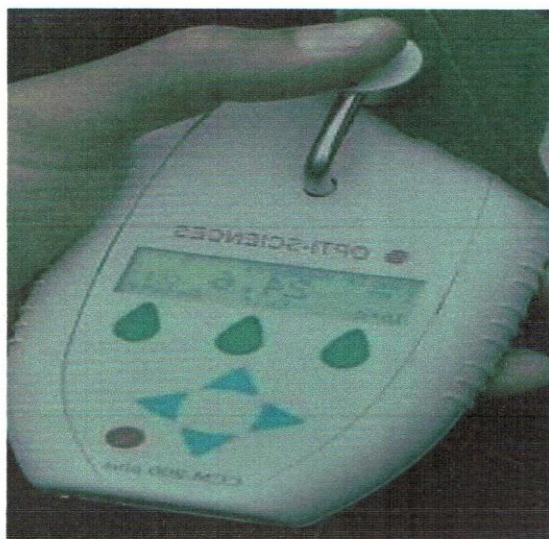


Plate 4: Chlorophyll content meter SPAD

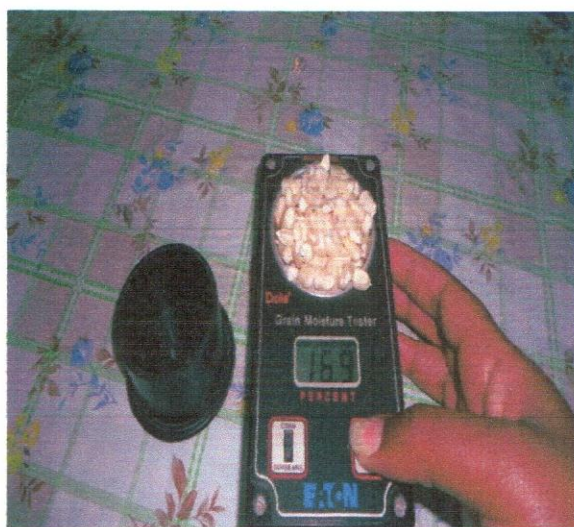


Plate 5: Grain Moisture tester.

3.5 Soils and compost manure and plant tissue analysis

3.5.1 Soil sampling and analysis

The soil samples were randomly taken across the experimental field, bulked and thoroughly mixed to form a composite sample. Air-dried soil, sieved through 2 mm mesh (Otinga *et al.*, 2013) was analyzed for pH (Soil: H₂O: 1:2.5), total N (Kjedahl method), organic Carbon (Walkley– Black, 1934), available P according to Okalebo *et al.* (2002). Exchangeable bases (K, Ca and Mg) were extracted with 1.0 M-ammonium acetate at pH 7. K was measured by Flame Emission Spectrophotometry, whereas Ca and Mg were measured by Atomic Absorption Spectrophotometry.

3.5.2 Compost manure sampling and analysis

Compost samples were taken prior to application in respective treatments in sampling bags for laboratory analysis. The analysis was done at the soil laboratory, KALRO, Kakamega. The samples were dried, sieved and then analyzed for nitrogen, phosphorus, organic carbon, calcium, magnesium and pH followed the procedures described in Okalebo *et al.* (2002).

3.5.3 Plant sampling and analysis

Leaf phosphorus uptake was determined on ear leaves taken at 50% tasseling from two randomly selected plants in each of the three harvest rows in each plot and analyzed for total phosphorus using the wet digestion method (Okalebo *et al.*, 2002).

3.6 Agronomic Phosphorus Use Efficiency (APUE)

The Agronomic P Use Efficiency was calculated as the yield obtained from the P (Yp) fertilized plot minus control (Yc), divided by the unit weight of the applied P fertilizer (Pw) according to Dobermann *et al.* (2005)

$$PUE = (Yp - Yc) / Pw$$

3.7 Data analysis

The data obtained was subjected to Analysis of Variance (ANOVA) using SAS Institute Version 9.1 statistical software. The treatment means were separated using Turkey's Honestly Significant Difference Test at 0.05 level of significance.

CHAPTER FOUR

RESULTS

4.3 Effect of P-fortified compost manure on growth of maize

4.3.1 Short rains season

Plant height

Generally, treatments significantly affected growth of maize (Table 3). The effect varied with site. In high fertility site, PCOM60, PCOM30 TSP and Compost had no significant difference in plant height. RP did not however increase plant height. In medium fertility site, PCOM60, PCOM30 and TSP had no significant difference in plant height. Compost and RP did not however affect plant height. In low fertility site PCOM60 and TSP significantly increased plant height. PCOM30, RP and compost had no significant difference in plant height.

Leaf area index

In high fertility site, PCOM60, PCOM30, significantly increased leaf area index. Compost, TSP and RP had no significant difference in leaf area index. In medium fertility site, PCOM60 and TSP significantly increased in leaf area index followed by PCOM30 then Compost. RP were comparable to control. In low fertility site PCOM60 and PCOM30, had the highest increased Leaf area index. TSP, RP and compost had no significant difference in Leaf area index.

Chlorophyll content

In high fertility site, PCOM60, PCOM30 and TSP significantly increased chlorophyll content. Rock Phosphate did not significantly increase the chlorophyll content. In medium fertility site PCOM60, PCOM30 and TSP had the highest chlorophyll content. RP and compost did not significantly affect the chlorophyll content. In low fertility site PCOM60, PCOM30, and TSP significantly increased chlorophyll content, followed by RP then control.

Table 3 Effects of P fortified compost on growth of maize across the sites during the short rains season.

Treatment	Plant height (cm)			Leaf Area Index			Chlorophyll content (SPADs)		
	Koibem	Kiptaruswo	Kapkerer	Koibem	Kiptaruswo	Kapkerer	Koibem	Kiptaruswo	Kapkerer
Control	45.5b	39.1b	48.0c	1.2b	1.1d	2.4b	13.5b	14.7c	12.9c
RP	46.5b	42.9b	57.8b	1.7ab	1.4cd	2.6b	14.4b	15.0c	14.5b
TSP	59.3a	51.9a	61.2ab	1.8ab	1.9ab	2.6b	19.6ab	19.7ab	15.9ab
Compost	56.1ab	45.2b	58.4b	1.7ab	1.5bcd	2.4b	18.0b	16.1bc	16.1ab
PCOM30	56.1ab	50.2a	57.6b	2.1a	1.8bc	2.8ab	18.5ab	19.7ab	15.7ab
PCOM60	60.2a	55.2a	67.9a	2.2a	2.1a	3.1a	21.3a	21.4a	19.3a
THSD _{0.05}	12.0	5.60	11.2	0.9	0.46	0.31	6.57	4.21	7.4

Means in same column followed by same letter are not significantly different at 5% level of probability

4.3.2 Long rains season

Plant height

Application of P increased the height of maize in the long rain season. PCOM60 and PCOM30, fertilizer resulted in significantly higher plant growth compared to other treatments (Table 4). In high fertility site, PCOM60 had the highest maize plant height. TSP and RP had no significant difference in plant height. Compost had a significant increase in plant height compared to control. In medium fertility site, PCOM60 had the highest maize plant height. PCOM30 was comparable to TSP and RP. Compost had a significant effect on plant height. In low fertility site, PCOM60 had the highest maize plant height followed by PCOM30 which was comparable to TSP. RP and compost had comparable in plant height.

Leaf area index

In high fertility site, PCOM60 had the highest leaf area index. PCOM30 was comparable to TSP. Compost and RP had comparable increase in leaf area index. In medium fertility site, PCOM60 had the highest increase in leaf area index. PCOM30 and RP had comparable increase to TSP and compost. In low fertility site, PCOM60 had the highest increase in leaf area index. PCOM30, TSP Compost and RP had comparable increase in leaf area index.

Chlorophyll content

In high fertility site, application of PCOM60, PCOM30, TSP and RP fertilizer resulted in significantly higher chlorophyll content. Compost was comparable to control. In medium fertility site PCOM60 and PCOM30 had the highest chlorophyll content compared to control. TSP, RP, was comparable to compost. In low fertility site, PCOM60 resulted in significant higher chlorophyll content. PCOM30, TSP, RP and compost had no significant difference in chlorophyll content.

Table 4: Effects of P-fortified on growth of maize across the sites during the long rains season

Treatment	Plant height (cm)			Leaf Area Index			Chlorophyll content (SPADs)		
	Koibem	Kiptaruswo	Kapkerer	Koibem	Kiptaruswo	Kapkerer	Koibem	Kiptaruswo	Kapkerer
Control	42.0c	50.7c	86.0c	0.35d	0.48b	1.24c	16.2c	18.0b	12.6c
RP	59.0b	71.2b	102.3b	0.49bc	0.83ab	1.59ab	28.8a	23.8b	22.2b
TSP	60.0b	70.9b	112.2ab	0.52b	0.80ab	1.63ab	23.9ab	23.3b	20.6b
COM	52.7bc	63.7b	93.0b	0.45cd	0.63ab	1.49bc	21.5bc	23.7b	20.9b
PCOM30	63.7ab	71.3b	111.0ab	0.52b	0.71ab	1.76a	23.7ab	31.3a	22.4b
PCOM60	73.4a	80.7a	127.0a	0.67a	1.12a	1.82a	27.8a	32.3a	25.9a
THSD _{0.05}	12.2	7.90	28.09	0.05	0.51	0.25	6.99	6.06	5.22

Means in same column followed by same letter do not differ significantly at 5% level of probability

4.4 Effect of P-fortified compost manure on maize yield

4.4.1 Short rains season

Yield

The maize yield varied significantly with P sources. PCOM60, PCOM30 and TSP had the highest crop yield (Figure 5). In high fertility site, addition of PCOM60, TSP and PCOM30 had the highest yield increase of 1.71, 1.57 and 1.2 tons/ha respectively compared to control. This was followed by Compost, which had an increase of 0.72 tons/ha. RP had the lowest yield increase of 0.6 tons/ha. In medium fertility site, PCOM60 and TSP had the highest yield increase of 1.7, 1.41 tons/ha compared to the control. PCOM30, RP and Compost had an increase of 0.85, 0.69 and 0.62 tons/ha respectively. TSP and PCOM60 significantly ($p\leq0.05$) had the highest yield in low fertility site. TSP had the highest yield increase of 1.74 tons/ha compared to control, followed by PCOM60 which had an increase of 1.56 tons/ha. PCOM30, RP and Compost increased by 0.47, 0.71 and 0.47 tons/ha respectively.

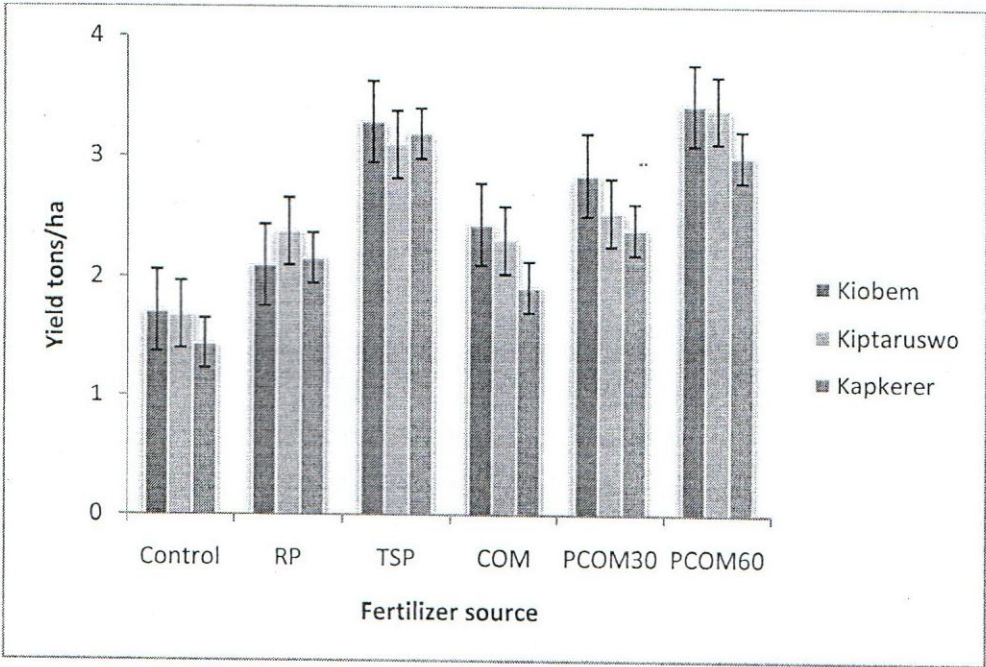


Figure 5: Effects of P-fortified compost on maize yield across sites in the short rain season

100 Seed weight

PCOM60 resulted in significantly higher 100 seed weight compared to other treatments across sites (Table 5). In high soil fertility site, PCOM60 and TSP had the highest 100 seed weight increase of 8.1 and 6.5g respectively. This was followed by PCOM30 and compost, RP did not significantly affect 100 seed weight. In medium fertility site, PCOM60 had the highest 100 seed weight increase of 7.4g followed by PCOM30 and TSP and lastly compost. Rock Phosphate had no significant effect on 100 seed weight, while in low soil fertility site, TSP and PCOM60 had the highest 100 seed weight increase of 4.3 and 4.2g respectively. This was followed by PCOM30, Compost and RP.

Table 5: Effects of P-fortified on 100 seed weight across the sites during the short rain season

Treatment	100 seed weight		
	Koibem	Kiptaruswo	Kapkerer
Control	22.0d	19.2c	19.2c
RP	22.5cd	20.6cb	21.0b
TSP	28.5ab	24.6ab	23.5a
COM	24.7bcd	23.3abc	22.9b
PCOM30	26.4abc	25.1ab	23.3ab
PCOM60	30.1a	26.6a	23.4a
THSD _{0.05}	4.04	5.0	3.31

Means in same column followed by same letter do not differ significantly at 5% level of probability

4.4.2 Long rains season

Yield

The trend in yield in response to the different P sources was similar to those found in short rain season. PCOM60, PCOM30 and (TSP) significantly increased maize yield in the three experimental sites as presented in Figure (3). In high fertility site, yields were significantly ($p\leq0.05$) higher in PCOM60 treated plot. There was a yield increase of 2.18 tons/ha compared to control plots, followed by TSP with an increase of 2.01 tons/ha, P-fortified compost 30 kg P_2O_5 /ha, Compost and RP had an increase of 1.83, 1.64 and 1.36 tons/ha respectively. In medium fertility, PCOM60 significantly ($p\leq0.05$) increased yields by 2.06 tons/ha compared to control, followed by TSP 1.94 tons/ha. PCOM30, Compost and RP

increased yield by 1.55, 0.75 and 1.18 tons/ha respectively. In low fertility site, PCOM60 and TSP had the highest yield increase of 1.8 and 1.76 tons/ha respectively compared to control, the lowest was RP with an increase of 0.91 tons/ha.

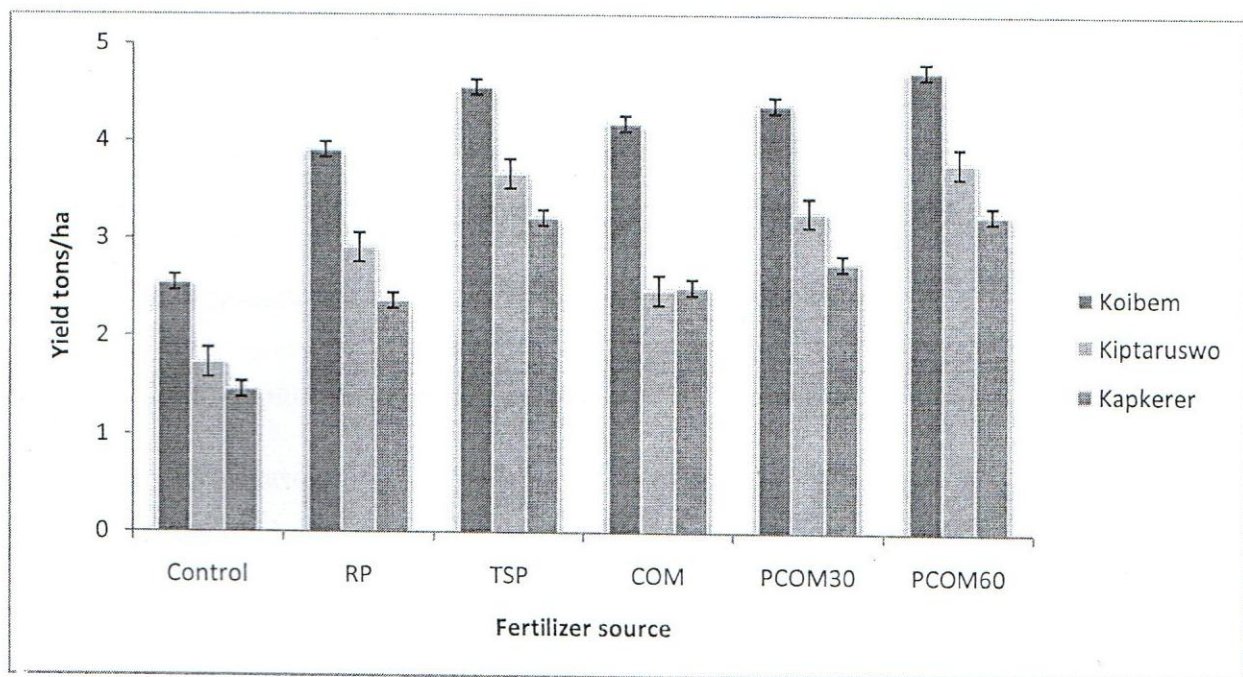


Figure 6: Effects of P-fortified compost on maize yield across sites in the long rain season

100 seed weight

PCOM60 resulted in significantly higher 100 seed weight compared to other across sites (Table 6). In high soil fertility site, PCOM60 and TSP had the highest 100 seed weight increase of 11.5 and 12.3g respectively. This was followed by PCOM30 and Compost and lastly RP. In medium fertility site, PCOM60 had the highest 100 seed weight increase of 14.3g followed by TSP, PCOM30 and RP and lastly compost. In low soil fertility site, TSP and PCOM60 had the highest 100 seed weight increase of 12.8 and 13g respectively. This was followed by PCOM30, RP and Compost.

Table 6: Effects of P-fortified on 100 seed weight across the sites during the long rain season

	100 seed weight		
	Koibem	Kiptaruswo	Kapkerer
Control	21.9c	19.0c	18.3d
RP	24.9bc	25.6b	25.7bc
TSP	34.2a	32.1a	31.1a
COM	24.7bc	23.8b	22.8c
PCOM30	27.1b	26.2b	27.2b
PCOM60	33.4a	33.3a	31.3a
THSD _{0.05}	4.83	1.61	2.22

Means in same column followed by same letter do not differ significantly at 5% level of probability

4.5 Effect of Phosphorous fertilizer source on Phosphorus Use Efficiency (APUE)

4.5.1 Short rains season

Agronomic Phosphorus Use Efficiency is considered as the efficiency of use of P by the plant. The (APUE) varied with different sources of phosphorus in high, medium, and low fertility sites (Table 7). In the high fertility site, P-fortified Compost (30 kg P₂O₅/ha) had the highest phosphorus use efficiency of 40 kgkg⁻¹ P₂O₅, followed by P-fortified Compost (60 kg P₂O₅/ha), TSP, RP at 28.5, 26.7, 6.3 kgkg⁻¹ P₂O₅ respectively. In the medium fertility site, P-fortified Compost (60 kg P₂O₅/ha) and P-fortified Compost (30 kg P₂O₅/ha) had the highest phosphorus use efficiency of 28.3 kgkg⁻¹ P₂O₅, followed by TSP 11.5 kgkg⁻¹. In low soil fertility site P-fortified Compost (30 kg P₂O₅/ha) had the highest phosphorus use efficiency of 30 kgkg⁻¹ P₂O₅, followed by TSP, P-fortified Compost (60 kg P₂O₅/ha), then RP at 29 ,26, 11.8 kgkg⁻¹ P₂O₅

Table 7: Agronomic Phosphorous Use Efficiency (APUE) of selected P fertilizers on maize yield

Treatment	Short rain season			Long rain season		
	Agronomic (PUE) (kgkg ⁻¹) P ₂ O ₅			Agronomic (PUE) (kgkg ⁻¹) P ₂ O ₅		
	Koibem	Kiptaruswo	Kapkerer	Kiobem	Kiptaruswo	Kapkerer
Control	0	0	0	0	0	0
RP	6.3	11.5	11.8	22.7	19.7	15.2
TSP	26.7	23.5	29.0	33.5	32.3	29.3
COM	0	0	0	0	0	0
PCOM30	40.0	26.7	30.0	61.0	51.6	43.3
PCOM60	28.5	28.3	26.0	36.3	34.3	30.0

The PUE were calculated relative to the control for TSP and RP and relative to compost for P-fortified compost treatments

4.5.2 Long rains season

In high fertility soil site, PCOM30 had the highest (PUE) of 61 kgkg⁻¹ P₂O₅ (Table 7). This was followed by PCOM60) TSP, RP at 36.3, 33.5, 22.7 kgkg⁻¹ P₂O₅ respectively. Control and Compost (6t/ha) treatment had no applied P. In medium fertility site, PCOM30 had the highest (PUE) of 51.6 kgkg⁻¹ P₂O₅, followed by, PCOM60, TSP, RP at 34.3, 32.3, 19.7 kgkg⁻¹ P₂O₅ respectively. In low fertility site, P -fortified Compost (30 kg P₂O₅/ha) had the highest (PUE) of 43.3 kgkg⁻¹ P₂O₅, followed by, P-fortified Compost (60 kg P₂O₅/ha), TSP, RP at 30, 29.3, and 15.2 kgkg⁻¹ P₂O₅.

4.6 Residual effects of P-fortified compost on growth of maize

Plant height

Residual P effect varied with treatments (Table 8). PCOM60 and PCOM30 had the highest residual effect on growth of maize. In high fertility site, PCOM60 and PCOM30 had the highest residual effect on plant height, followed by RP, compost and TSP. In medium fertility site, PCOM60, PCOM30 had the highest residual effect, followed by RP, TSP and compost and control in that order. In low fertility site, PCOM60, PCOM30 and TSP had highest residual effect, followed by TSP and control in that order.

Chlorophyll Content

In high fertility site, PCOM60, PCOM30 had the highest residual effect, followed by TSP, RP, compost and control in that order. In medium fertility site, PCOM60, PCOM30 had the highest residual effect, followed by RP, TSP, Compost and control. In low fertility site, PCOM60, PCOM30 and RP had highest residual effect, followed by compost and control in that order..

Leaf area index

In high fertility site, PCOM60, PCOM30 and RP had the highest residual effect, followed by TSP and Compost, and control. In medium fertility site, PCOM60, PCOM30 and RP had the highest residual effect, followed by TSP and Compost, and control. In low fertility site, PCOM60, PCOM30 and RP had highest residual effect, followed by TSP, compost and control in that order.

Table 8: The residual effects of P-fortified on plant growth across sites

Treatment	Plant height (cm)			Chlorophyll content (SPADs)			Leaf Area Index		
	Koibem	Kiptaruswo	Kapkerer	Koibem	Kiptaruswo	Kapkerer	Koibem	Kiptaruswo	Kapkerer
Control	35.3c	44.0d	73.4c	16.2c	16.0d	12.5d	0.34d	0.38d	1.24d
RP	60.0b	71.2b	102.3b	23.8ab	26.5b	22.2ab	0.64ab	0.69ab	1.69ab
TSP	58.3b	69.3bc	112ab	23.9ab	22.0c	20.5bc	0.58b	0.65b	1.63b
COM	52.6b	63.6c	□□b	21.5bc	19.7c	17.5c	0.45c	0.43c	1.49c
PCOM30	70.3a	76.3ab	111ab	25.7a	32.1a	24.3ab	0.63ab	0.71ab	1.76a
PCOM60	76.6a	80.6a	127a	28.5a	33.3a	25.8a	0.67a	0.80a	1.82a
THSD _{0.05}	8.32	7.21	16.7	5.62	2.72	4.14	0.10	0.33	0.36

Means in same column followed by same letter do not differ significantly at 5% level of probability

4.7 The residual effect of P-fortified compost manure on P-uptake and yield of maize

4.7.1 Yield

Treatments significantly influenced residual effect on maize yield (Figure 7). Irrespective of the site, PCOM60, PCOM30 and RP had comparative residual effect followed by TSP and Compost. In high fertility site, PCOM60, PCOM30 and RP had the highest yield increase 2.51, 2.15 and 2.24 tons/ha respectively. TSP and compost had an increase of 1.87 and 1.12 tons/ha respectively. In medium fertility site, PCOM60 had the highest yield increase of 2.49 tons/ha compared to control, followed by PCOM30 at 2.24 tons/ha, RP had an increase of 2.2 tons/ha. TSP and compost had the lowest increase of 2.19 and 1.38 respectively. In low fertility site, PCOM60, PCOM30 and RP significantly increased yield by 3.19, 2.79, 2.64 tons/ha compared to control. TSP and compost increased by 2.45 and 1.51 tons/ha respectively.

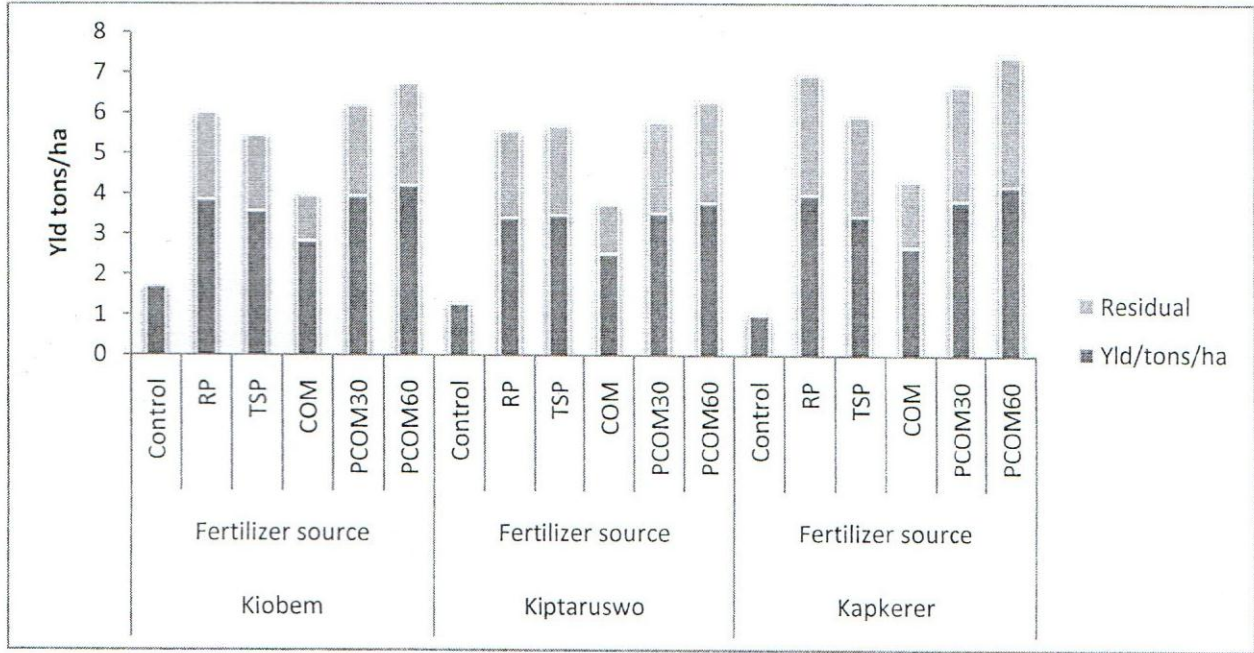


Figure 7: Residual effect of P-fortified compost on yield

100 Seed weight

Treatment significantly influenced residual effect on 100 seed weight (Table 9). In high fertility site PCOM60, PCOM30 and RP had comparable residual effect, followed by TSP compost and control. In medium fertility site PCOM60, PCOM30 had the highest residual effect on 100 seed weight, followed by RP, TSP and control in that order. In low fertility site, PCOM60, had the highest residual effect, followed by PCOM30, RP, TSP compost and control in that order.

Table 9: The residual effects of P-fortified compost on 100 seed weight across different sites

Treatment	100 seed weight (g)		
	Koibem	Kiptaruswo	Kapkerer
Control	19.8d	16.9e	18.9e
RP	30.8ab	26.6b	27.8b
TSP	27.9b	24.0c	25.4c
COM	23.5c	20.1d	23.3d
PCOM 30	31.8a	27.8ab	27.8b
PCOM 60	33.4a	28.8a	30.4a
THSD _{0.05}	3.42	1.29	1.67

Means in same column followed by same letter do not differ significantly at 5% level of probability

4.7.2 Plant P uptake

Treatments significantly influenced residual effect on plant P-uptake (Figure 5). Irrespective of the site, PCOM had the highest percentage increase, followed by PCOM30, RP and TSP respectively. Compost had the lowest increase. In high fertility site, PCOM60, PCOM30 and RP had the highest percentage increase on p-uptake of 96, 70, and 65% respectively. TSP and compost had an increase 47% and 15% respectively. In medium fertility site, PCOM60 had the highest P-uptake increase of 75% compared to control, followed by PCOM30, RP and TSP had an increase 56, 50 and 43%, respectively. Compost had the lowest increase of 30%. In low fertility site, PCOM60, PCOM30 and RP significantly increased plant P-uptake by 73, 67, and 59% compared to control. TSP and compost increased by 39% and 26% respectively.

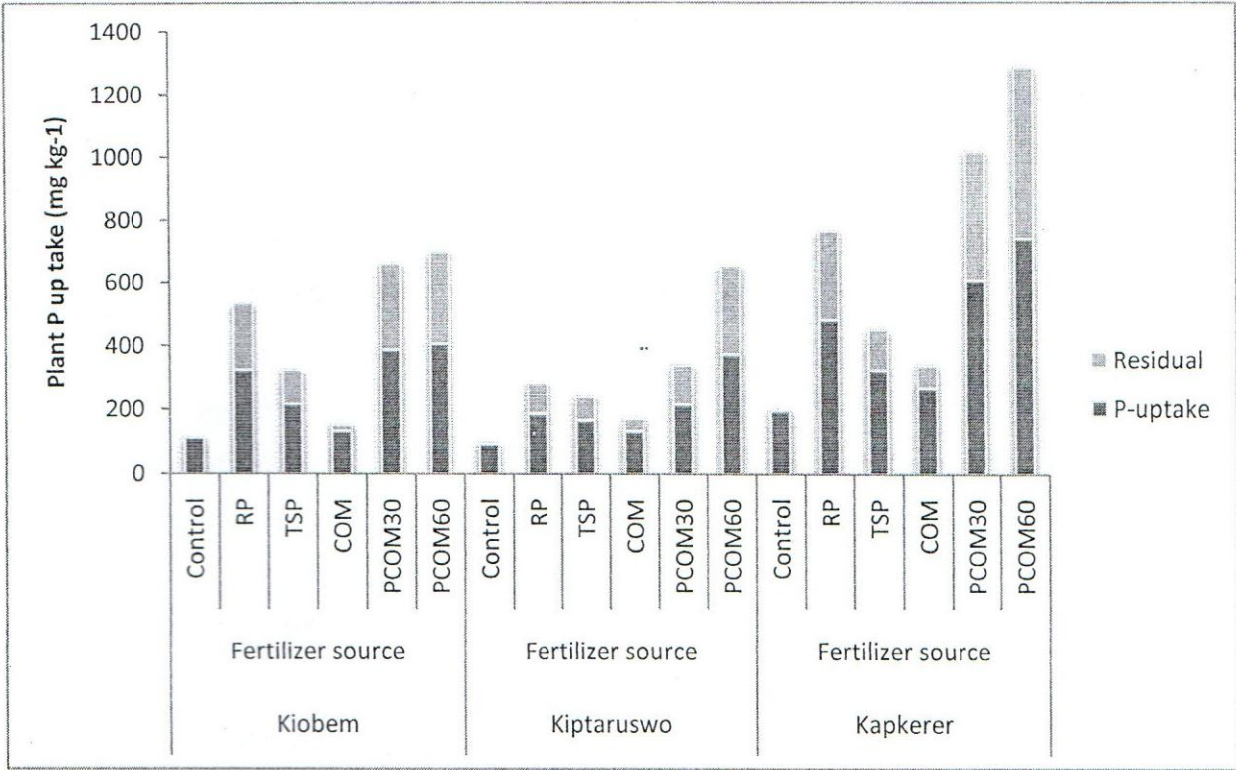


Figure 8: Residual effect of P-fortified compost on plant P uptake

CHAPTER FIVE

DISCUSSION

5.1 Effects of P-fortified compost manure on maize growth and yield

Application of P increased the growth and yield of maize in all the sites. This is because these soils are deficient in P (Table 1) and hence benefited from the application of available forms of P. Sufficient P in most agricultural soil range is 30-80 mg kg⁻¹. Kihara and Njoroge (2013) and Titonell *et al.* (2011) similarly noted that P is one of the important nutrients limiting crop production in soils of western Kenya. PCOM60, PCOM30 and TSP treatments significantly improved attributes of growth (plant height, leaf area index and chlorophyll content) in all the sites. This could be attributed to enhanced availability of P due to composting, it is likely that during composting, organic acids produced, enhanced the solubilization P of Minjungu Rock phosphate therefore improving the availability of rock phosphate. Several scientists have reported the importance of compost in increasing the solubilization of RP (Chien 2003; Zayed and Motaal, 2005; Hellel *et al.*, 2012). Higher chlorophyll concentration and leaf area index in PCOM60 and PCOM30 treatments could have been due to higher nitrogen level, leading to higher crop growth rate. Singh *et al.* (2011) also found improved leaf area and chlorophyll content on higher nitrogen levels, this lead to higher growth rate. Compost treated plots had better effect on plant height than RP, this may be due to calcium content in the compost which contributed to liming reaction hence increased the soil pH (Eghball 2002). Minjungu Rock phosphate applied directly without composting, did not perform better than the no treatment control, probably because of its poor solubility (Khan *et al.*, 2009) and thus low uptake by plant. This indicates that MRP at the rates applied, does not provide adequate available P and may not be of immediate benefit to the maize crop. Hellel *et al.* 2013 similarly observed that direct application of RP to mono-cropped maize resulted in lower yield compared to composted rock phosphate. Yield and yield attributes showed higher response in PCOM60, PCOM30 and TSP. PCOM60 had the highest 100 seed weight compared to other treatments across sites. This could be attributed to higher level of phosphorous. Similarly, Muhammad *et al.* (2011) documented the positive impact of RP-enriched organic fertilizer as an effective organic fertilizer for enhancement of growth and yield of maize.

5.2 Agronomic Phosphorus Use Efficiency (APUE)

Agronomic Phosphorous use efficiency (APUE) is calculated to express the efficiency of use of phosphorous in terms of additional yield obtained per unit of added P fertilizer, (Dobermann *et al.*, 2005). Agronomic phosphorous use efficiency (APUE) was significantly higher in PCOM30- over all the other treatment in all the sites. The high P use efficiency of maize associated with the application of PCOM30 is related to the availability of added P, the P use efficiency calculation assumes that all P was available and is taken up for use in yield accumulation. However, the low P use efficiency, like in the case of MRP and the fixed soluble P (TSP) could have been attributed to low P uptake. The P use efficiency of maize was highest in PCOM30 where as at the economical optimal rate PCOM60 the P use efficiency was lower. This is probably because the soil P tests levels are low, hence highest P use efficiency occur at lower rates of P application (Hadgul *et al.*, 2013). Hallel *et al.* (2013) also indicated that phosphorous use efficiency of Phospho-compost was higher compared to other fertilizers. Hadgul *et al.* (2013) similarly observed higher PUE in lower P fertilizer rates.

5.3 Residual value of P-fortified compost on maize growth and yield

Results obtained on residual effects of the P-sources indicate that in all the sites PCOM60 and PCOM30 had a higher residual effect on maize yield than all the other treatments during the second season. This indicates that composting with MRP resulted in higher fractions of P forms that had higher solubility, not only in the first season but also in the subsequent season, compared to the other P sources. It is possible that P in the composted manure occurred in forms that were somehow protected from P fixation (Hellal *et al.*, 2013) and therefore the higher availability. Hirzel *et al.* (2009) also indicated that compost application to soil can have significant carry over effects for several years. It was also observed that grain yields obtained from all treatments generally increased during the residual test period, this may be due to adequate amount of rain received during the period as compared to the previous season. The results also indicated that there was an increase in maize grain yield caused by MRP over TSP. This may be due to the fact that the residual effect of TSP decreases rapidly in soil with high P fixing capacity, while RP has a longer residual effect due to its slow dissolution in the soil with time. Gikonyo *et al.* (2008) in the

field experiment using *setaria* grass indicated that MRP had a higher residual effect compared to TSP. Similarly Muhawish and Razaq (2009) also found that residual effect of RP was higher than TSP on wheat grain yield. Residual effect of PCOM30 was similar to PCOM60 meaning that farmers can benefit from using lower MRP through composting. This is important as south Nandi farmers can apply P-fortified compost manure in the short rain season and still be able to benefit the long season maize crop. It could also mean that the farmers can apply lower rates of P-fertilizer in the second season therefore saving on fertilizer input cost.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The application of P-fortified compost manure increased growth and yield of maize across sites. The effect of PCOM60 and PCOM30 was comparable to TSP, the most soluble fertilizer. The value of compost can thus be increased by fortification using MRP. Composting MRP with organic resource enhanced its APUE compared to the mineral P sources namely TSP and MRP. Therefore MRP is beneficial in composted form than when applied alone. Residual effects of the P-sources indicate that PCOM60 and PCOM30 had a higher effect on maize yield during the season. This indicates that the value of compost can be improved by fortification, not only in the first season but also in the subsequent season, compared to the other P sources.

6.2 Recommendation

Farmers in South Nandi should therefore be encouraged to use rock phosphate in their compost as it improves the quality of compost. This requires the farmers to be trained in the processes of preparation and use of p-fortified compost. Further research should be done on cost benefit analysis of using P-fortified compost manure compared to inorganic P fertilizers.

REFERENCES

- Adeniyi, O. N., and Ojeniyi, S. O.,** (2003). Comparative effective of different level of poultry manure with NPK fertilizer on residual soil fertility, nutrient uptake and grain yield of maize. *Moor Journal of Agriculture. Research*, 4: 191-196.
- Akande, M. O., Adediran, J. A., and Oluwatoyinbo, F. I.,** (2005). Effects of rock phosphate amended with poultry manure on soil available P and yield of maize and cowpea. *Africa Journal Biotechnology*, 4: 444-448.
- Akande, M. O., Oluwatoyinbo, F. I., Adediran, J. A., Buari, K., W. and Yusuf, I., O.** (2003). Soil amendments affect the release of P from rock phosphate and the development and yield of okra. *Journal of Vegetable Crop Production*, 19:3-9.
- Amberger, A.** (1992) Solubilization and availability of phosphorus during decomposition of phos- phate rock enriched straw and urine. *Biological Agriculture and Horticulture*, 7: 261-269.
- Azziz, G., Bajsa, N., Haghou, T., Taulé, C., Valverde, A., Igual, J. M., and Arias, A.** (2012). Abundance, diversity and prospecting of culturable phosphate solubilizing bacteria on soils under crop–pasture rotations in a no-tillage regime in Uruguay. *Applied Soil Ecology*, 61:320-326.
- Bationo, A. Lompo, F. and Koala, S.** (1998). Nutrient Balances as Indicators of Production and Sustainability in Sub-Saharan African Agriculture. *Agriculture, Ecosystem and Environment*, 71: 19–36.
- Bationo, A., Hartermink, A., Lungu, O., Naimi, M., Okoth, P. and Thiombiano, L.** (2006). African Soils: Their productivity and profitability of fertilizer use. Background paper presented, for the African Fertilizer Summit, 9th – 13th June, 2006. Abuja, Nigeria.

- Bekunda, M. A.,** Bationo, A., and Ssali, H. (1997). Soil fertility management in Africa: A review of selected research trials, pp. 63-79. In R.J. Buresh *et al.*, (Ed.). Replenishing soil fertility in Africa. SSSA Special Publication. 51. SSSA, Madison, WI.
- Bertoldi, M. D.,** Vallini, G. and Pera, A. (1983). The Biology of Composting: A Review. *Waste Management and Research*, 2: 157-176.
- Bhadoria, P. S.,** Steingrobe, N. C., and Liebersbach, H. (2002). Phosphorus efficiency of wheat and sugar beet seedling grown in soils with mainly calcium, or iron and aluminum phosphate. *Plant and Soil*, 246: 41-52.
- Brady, N.C.,** and Weil, R.R., (2002). The nature and properties of soils: 13th edition, Pearson Educational, New Jersey, USA.
- Brito, L. U.,** Yanez, I. A., Maldonado, A. C., Franco, L. S., Correa, J. S., and Ricaldo, R. S., (2009). Effect of pig litter composted on growth of maize (*Zea mays*) and havanan pepper (*Capsicum chinense*) Plants. *Research Journal of Biological Sciences*, 4:514-518.
- Buresh, R. J.,** Smithson, P. C., and Heliums. D. T., (1997). Building soil phosphorus capital in Africa, Pp.111-149. In R.J. Buresh *et al.*, (Ed.) Replenishing soil fertility in Africa. SSSA Spec. Publ. 51.SSSA, Madison, WI.
- Chien, S.H.,** (2003). Factors affecting the agronomic effectiveness of phosphate rock: a general review. In. Rajan,S. S., and Chien, S. H., (Eds). Direct application of phosphate rock and related technology, IFDC. USA, p 441.
- Crosson, P** and Anderson, J. R., (1995). Achieving a Sustainable Agricultural System in Sub-Saharan Africa. Post-UNCED Series: Towards Environmentally Sustainable Development in Sub-Saharan Africa: Building Blocks for Africa 2025, Paper No. 2, AFTES, World Bank, Washington D C.

- Crowley, E. L., and Carter, S., E.** (2000), Agrarian change and the changing relationships between toil and soil in Maragoli, western Kenya (1900–1994) *Human Ecology*, 28: 383–414.
- Dembele' I., Kone' D., Soumare' A., Coulibaly, D., Kone' Y. and Kater, L.** (2000). Fallows and field systems in dryland Mali. In: Hilhorst T. and Muchena F. (Eds), *Nutrients on the Move. Soil Fertility Dynamics in African Farming Systems*. International Institute for Environment and Development, London, Pp. 83–102.
- Dobermann, A., Cassman, K.G., Walters, D.T., and Witt, C.** (2005). Balancing short- and long-term goals in nutrient management. In: *Processing of the international Plant Nutrient Colloquium*, 89: 16–19.
- Eghball, B.** (2002). Soil properties as influenced by phosphorus and nitrogen- based manure and compost applications. *Agronomy Journal* 94: 128 – 135.
- Egle, K., Manske, G. Romer, W. and Vlek, P.L.G.,** (1999). Improved phosphorus efficiency of three new wheat genotypes from CIMMYT in comparison with a Mexican variety. *Journal. Plant Nutrition. Soil Science*, 162: 353-358.
- Elings, A.** (2000). Estimation of Leaf Area in Tropical Maize. *Agronomy Journal*, 92: 436-444.
- Export Processing Zone Authority** (2005). Grain production in Kenya. Export Processing Zone Authority, Nairobi.
- Fohse, D., Claassen, N., and Jungk, A.** (1988). Phosphorus efficiency of plants. External and internal P requirement and P uptake efficiency of different plant species. *Plant and Soil*, 110: 101-109.

- F.A.O** (2005). Global Forest Resources Assessment 2005: 15 key findings. Food and Agricultural Organization of the United Nations, Rome, Italy.
- Gichangi , E., M. Karanja, N.K., and Wood, C., W.** (2007). Managing manure heaps with agro-organic waste and cover to reduce N losses during storage on small holder farms. In: Bationo, A, Waswa, B., Kihara, J and Kimetu, J. (Eds) Advances in integrated soil fertility management in sub-saharan Africa: Challenges and Opportunities, Pp 611-618.
- Gikonyo, E. W., Zaharah, A. R., Hanafi, M. M., and Anuar, A .R.** (2008). Evaluation of phosphorus pools and fractions in an acid tropical soil recapitalized with different phosphorus sources. *Communications in Soil Science and Plant Analysis*, 39: 9-10.
- Giller, K. Cadisch, G. Ehaliotis, C. Adams, E. Sakala, W. D., and Mafongoya, P.L.,** (1997). Building soil nitrogen capital in Africa. In: Buresh, R.J., Sanchez, P.A. (Eds.), Replenishing Soil Fertility in Africa. ASSA, CSSA, SSSA, Wisconsin, Pp. 151–192.
- Ginting, D., Kessavalou, A., Eghball, B. and Doran, J.W.** (2003) Greenhouse gas emissions and soil indicators four years after manure and compost applications. *Journal of Environmental Quality*, 32: 23-32.
- GOK,** (2010). Agriculture Sector Development Strategy, 2010-2020.
- Gourley, C. J. P., Allan, D. L., and Russelle, M., P.** (1994). Plant nutrient efficiency: A comparison of definitions and suggested improvement. *Plant Soil*, 158: 29-37.
- Hadgul, F. Heluf, G. and Kibebew, K.** (2013). Maize crop response to phosphorus fertilization on fluvisols in Northern Ethiopia. *Journal of Biodiversity and Environmental Science*, 3: 54 -67.

- Haering, K.,** and Evanylo, G., (2005). Composting and Compost Use for Water Quality. Department of Crops and Soil Environmental Sciences Virginia Technology, Blacksburg. www.infohouse.pzric.org/ref/41/40137.pdf.
- Hartshorn, A. S.,** Chadwick, O. A., Vitousek, P. M and Kirch, P. V., (2006). Prehistoric agricultural depletion of soil nutrients in Hawai'i, *Proceedings of the National Academy of Sciences of the United States of America*, 103; 11092–11097.
- Hellal, F.A.,** El-Hady, M. A., and Ragab, A. A. M., (2009). Influence of organic amendments on nutrient availability and uptake by faba bean plants fertilized by rock phosphate and feldspar. *Am-Eurasian Journal of Sustainable Agriculture*, 6: 271–279.
- Hellal, F. A.,** Nagumo, F. and Zewainy, R. M., (2012) Influence of phosphor-composting on enhancing phosphorus solubility from inactive rock phosphate. *Australian Journal of Basic and Applied Sciences*, 6; 268-276.
- Hellal, F. A.,** Ngumo, F. and Zewainy, R. M., (2013). Influence of phosphor-composting on enhancing phosphorous solubility from inactive rock phosphate. *Australian. Journal of Basis and Applied Science* 6:268-276.
- Henry, P. C.,** and Smith, M. F., (2002). Phosphorus sorption study of selected South African soils: *South Africa Journal of Plant and Soil*, 19:61–69.
- Hinsinger, P.** (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: A review. *Plant Soil*, 237: 173-137.
- Hirzel, J.** Novoa, F. Undurraga, P., and Walter, I. (2009). Short term effects of poultry litter application on silage maize yield and soil chemical properties. *Compost Science Utilization*, 17: 1890-1960.

- Ikerra, T. W., Mnkeni, P. N. S., and Singh, B. R.,** (1994). Effects of added compost and farmyard manure on P release from Minjingu PR and its uptake by maize. *Norway Journal of Agriculture Science*, 8: 13– 23.
- Jaetzold, R. and Sochmidt, H.** (1983). Farm Management Handbook of Kenya. Natural Conditions and Farm Management Information. Part B. Central Kenya (Rift Valley and Central Province). *Ministry of Agriculture* 2: 389- 413.
- Jaetzold, R., Sochmidt, H., Hornetz, B and Shisanya, C.** (2006). Farm management handbook of Kenya- natural conditions and farm management information (2nd Edition). Volume II/A western Kenya Ministry of Agriculture, Nairobi.
- Jama, B. and Van Straaten, P.** (2006). Potential of East African phosphate rock deposits in integrated nutrient management strategies, *Annals of Brazilian Academy of Sciences*, 78; 781–790.
- Jayne, T. S., Yamano, T. Nyoro, J. and Awour, T.** (2001). Do farmers really benefit from high food prices balance rural interests in Kenya's maize pricing and marketing policy. Paper 2b, Tegemeo Institute, Nairobi, Kenya.
- Kang'ethe, W. G.,** (2004). Agricultural development and food security in Kenya: A case for more support. A paper prepared for agriculture and food organization.
- Karanja, D. D., and Oketch, O. G.,** (1992). The Impact of Maize research in Kenya. In proceedings of a workshop. Review of the National Maize Research Program. KARI/ISNAR. Management Training Linkage Project. p 100.
- Kenya Agricultural research Institute, (KARI)** (1994). The Fertilizer Use and Recommendations Project (FURP): Manual 1, National Agricultural Laboratories (NARL), KARI, and Nairobi, Kenya.

- Kauwenbergh, S. J.**, (2006). Fertilizer raw material resources for Africa. Reference Manual IFDC R-16, IFDC Muscle Shoals, Alabama USA, p 440.
- Keziah, W. N.**, Mary, N. K., and Okalebo, J. R., (2007). Producing fortified compost from crop residues: In organic resource management in Kenya; Perspectives and Guidelines, Savala, E. N., Omare, M. N., and Woomer P. L, (Eds). Format, Nairobi, Kenya, Pp 71-74.
- Khan, A. A.**, Jilani, G. Akhtar, M. S., Saqlan, S. M., and Rasheed, M. (2009). Phosphorus solubilizing bacteria: occurrence, mechanisms and their role in crop production. *Journal of Agriculture and Biological Science*, 1: 48–58.
- Kihara, J.**, Vanlauwe, B., Waswa, B., Kimetu, J.M., Chianu, J, and Bationo, A., (2010). Strategic phosphorus application in legume-cereal rotations increases land productivity and profitability in western Kenya. *Experimental Agriculture*, 46: 35–52.
- Kihara, J** and Njoroge, S. (2013). Phosphorous agronomic efficiency in maize - based cropping systems: a focus on western Kenya. *Field Crops Research*, 150: 1-8.
- Kimetu, J. M.**, Lehmann, J. Ngoze, S.O., Mugendi, D. N., Kinyangi, J. M., Riha, S. and Pell, N., (2008). Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. *Ecosystems*, 11: 726-739.
- Kinyangi, J.** (2008) Soil degradation, thresholds and dynamics of long-term cultivation: from landscape biogeochemistry to nanoscale biogeocomplexity. PhD dissertation, Cornell University, Ithaca, NY, USA, p 161.
- Kisinyo, P. O.**, Ng'etich, W. K., Othieno, C.O., Okalebo, J. R., and Opile, W.R., (2011). Phosphorus depletion- Current issues for future research and policy. Department of Soil Science, Chepkoilel University College. Eldoret Kenya.

- Kpomblekou, K.** and Tabatabai, M .A., (1994). Effect of organic acids on release of phosphorus from phosphate rocks. *Jornal Soil Science*, 158: 442-453.
- Lampkin, N. H.,** (2000). Organic farming. In: S. Padel, (Ed.). Soil sickness and soil fertility. Cab publisher, Wallingford, USA.
- Lekasi, J. K.,** Ndungu, K.W., and Kifuko, M. N (2003). A Scientific Perspective on composting: Organic resource management in Kenya. The forum for organic resource management and technologies, Nairobi, Kenya, Pp; 65-70.
- Levy, S. J.,** and Taylor. B. R., (2003). Effects of pulp mill solids and three composts on early growth of tomatoes. *Bioresource Technology*, 89:297-305.
- Li, S. M., Li, L., Zhang, F. S. and Tang, C.** (2004). Acid Phosphatase Role in Chickpea/ Maize Intercropping. *Annals of Botany*, 94: 297-303.
- Li, S. X., Wang, Z. H. and Stewart, B. A.** (2011). Differences of some leguminous and non leguminous crops in utilization of soil phosphorus and responses to phosphate fertilizers. *Advances in Agronomy*, 110: 130- 202.
- Mahimairaja, S.** Bolan, N. S., and Hedley, M. J., (1995). Dissolution of phosphate rock during the composting of poultry manure: an incubation experiment. *Fertilizer Research* 40, 93–104.
- Makokha, S., Kimani, S. K., Mwangi, W., Verkuijl, and Musembi, F.** (2001). Determinants of fertilizer and manure use for maize production in Kiambu District Kenya. International maize and wheat improvement centre (CIMMYT), Mexico, D.F. and Kenya Agricultural Research Institute (KARI-NARL), Nairobi.
- Manna, M.** Hazra, J. N., Sinha, B. N., and Ganguly, T. (2001). Enrichment of compost by bioinoculant and mineral amendments. *Journal Indian Society of Soil Science*, 45: 831-833.

- Marenya, P. P., and Barrett, C. B.** (2009). State-conditional fertilizer yield response on western Kenyan farms. *American Journal of Agricultural Economics*, 96: 991-1006
- Marschner, H.**, (1995) Mineral nutrition of higher plants, 2nd ed. *Academic Press*, London, UK.
- Misra, R. V., Roy, R.N., and Hiraoka, H.**, (2003). On-farm composting methods; Land and Water Discussion paper No. 2, Food and Agriculture Organization of the United Nations, Rome, p 34.
- Muhammad, S. B., Tanvir, W., Fazli, A., and Khan,** (2011). Effect of Rock Phosphate composted with organic materials on yield and phosphorous uptake of wheat and mung bean crops; *Pakistan Journal in Botany*, 45: 1349-1356.
- Muhawish, N. M., and I.B. Razaq.** (2009). Agronomic Effectiveness of a New Formula of phosphate Fertilizer I- Initial Agronomic Effectiveness. *Journal of Tikrit University for Agricultural Sciences*. 9: 617 – 625.
- Murage, E. W., Karanja, N. K., Smithson, P.C., and Woomer, P. L.,** (2000). Diagnostic indicators of soil quality in productive and non-productive smallholder fields of Kenya's Central highlands. *Agriculture, Ecosystem and Environment*, 79: 1–8.
- Ndung'u, K. W., Kifuko, M. N., and Okalebo, J. R.** (2007). Producing fortified compost from Crop residues. In: Organic resource management in Kenya; Perspectives and Guidelines. Savala, E. N., Omare, M. N., and Woomer P. L, (Eds). Format, Nairobi, Kenya, Pp 71-74.
- Ndung'u, K.W., Okalebo J.R., Othieno C.O., Kifuko M.N., Kipkoech, A. K., and Kimenye, L. N.,** (2006). Residual effectiveness of Minjingu Phosphate Rock and fallow biomass on crop yields and financial returns in western Kenya. *Africa Crops Science Conference* 42: 323-336.

- Ndungu, K.W.** Kifuko M. N. and Okalebo, J.R. (2003). Producing Fortified Compost from Crop Residues: Organic Resource Management in Kenya: Perspectives and Guidelines. Savala, E. N., Omare, M. N., and Woomer (Eds). FORMAT Nairobi, Kenya pp. 71-74.
- Nekesa, A. O.,** Okalebo, J. R., Othieno, C. O., Thuita, M. N., Bationo, A., Sanginga, N., Kimettu J.A, and Vanlauwe, B. (2005). The potential of Minjingu phosphate rock from Tanzania as a liming material: Effect on maize and bean intercrop on acid soils of western Kenya. *African Crop Science Conference Proceedings*, 7: 1121-1128.
- Nekesa, P.,** Maritim, H. K., Okalebo, J. R. and Woomer, P. L. (1999). Economic analysis of maize-bean production using a soil fertility replenishment product (PREP-PAC) in western Kenya. *African Crop Science Journal*, 7: 423-437.
- Ngome, A.F.,** Becker, M., Mtei, M.K., and Mussnug, F.,(2012). Management options and soil types differentially affect weeds in maize fields of Kakamega, Western Kenya. *Journal Agriculture Science and. Technology*, 2: 104-114.
- Nishanth, D.** and Biswas, D.R. (2008). Kinetics of phosphorus and potassium release from rock phosphate and waste mica enriched compost and their effect on yield and nutrient uptake by wheat (*Triticum aestivum*). *Bioresource. Technology*, 99: 3342–3353.
- Nuruzzaman, M.H.** Bolland, M.D., and Veneklaas, E.J. (2005) Phosphorus uptake by grain legumes and subsequently grown wheat at different levels of residual phosphorus fertilizer. *Australian Journal of Agriculture Research*, 56:1041–1047.
- Nziguheba, G.** Merckx, R., Palm, C. A., and Rao, M. (2000). Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. *Biology, Fertilizer and. Soils*, 32: 328-339.

- Ojiem, J. O.,** and Odendo, M. (1997). Farmers' perceptions of spatial heterogeneity and its influence on soil management in small scale farms in Kenya. *African Crop Science Journal*, 3: 283-287.
- Okalebo, J. R.,** Gathua, K.W., and Woomer, P. L., (2002). Laboratory methods of soil and plant analysis: A working manual. TSBF, Nairobi, Kenya.
- Okalebo, J.R.,** Othieno, C.O., Woomer, P.L., Karanja, N.K., Semoka, J.R.M., Bekunda, M.A., Mugendi, D.N., Muasya, R.M., Bationo, A., and Mukhwana, E.J., (2006). Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling. Agroecosystems*, 76: 153-170.
- Oldeman, L. R.,** Hakkeling, R.T.A., and Sombrock, W.G. (1991). World Map of the Status of Human-induced soil degradation: An Explanatory Note second revised edition. ISRIC Wageningen and UNEP, Nairobi.
- Onwonga, R.N.,** Lelei JJ, Freyer B, Friedel JK, Mwonga SM, and Wandahwa P. (2008). Low cost techniques for enhancing N and P availability and maize (*Zea mays L.*) performance on acid soils. *World Journal of Agricultural Sciences*, 4:862-873.
- Otinga, A. N.,** Pypers, P., Okalebo, J. R., Njoroge, R., Emongole, M., Six, L., Vanlauwe, B. and Merckx, R. (2013). Partial substitution of phosphorus fertilizer by farmyard manure and its localized application increases agronomic efficiency and profitability of maize production. *Field Crops Research* 140: 32- 43.
- Palaniappan, S. P.,** and Natarajan, K. (1993). Practical aspects of organic matter maintenance in soil. In P.K. Thampan, (Ed). *Organics in soil health and crop production*, Pp. 24-41.
- Palm, C. A.,** Myers, R. J .K. and Nandwa, S. M. (1997). Combined Use of Organic and Inorganic Nutrient Sources for Soil Fertility Maintenance and Replenishment. In: *Replenishing Soil Fertility in Africa*, Buresh, R.J., P.A. Sanchez and F. Calhoun

(Eds.). *America Society of Agronomy and Soil Science Society of America*, Madison WI., USA. pp: 193-217.

- Paredes, C. J. C., Bernal, M. P., and Roi, A.** (2005). Influence of olive mill wastewater in composting and impact of the compost on a Swiss Chard crop and soil properties. *Environment International*, 31:305-312. ..
- Park, J. H., Bolana, N., Megharaja, M. and Naidua, R.** (2011). Isolation of phosphate solubilizing bacteria and their potential for lead immobilization in soil. *Journal of Hazardous Materials*, 185: 829- 836.
- Pohlman, A. A., and McColl, J.G.** (1986). Kinetics of metal distribution from forest soils by soluble organic acids. *Journal of Environment Quality*, 15:86–92.
- Quansah, C. and Yeboah, O.** (2000). Composting Land and Water Management Extension Bulletin. University Press; Kumasi, Ghana. Pp. 3-12.
- Rivaie, A. A., Loganathan, P. Graham, J. D. Tillman, R. W., and Payn, T. W.** (2008). Effect of phosphate rock and triple superphosphate on soil phosphorus fractions and their plant-availability and downward movement in two volcanic ash soils under *Pinus radiata* plantations in New Zealand. *Nutrient Cycling in Agroecosystems*, 82; 75–88.
- Savala, C. E. N., Omare, M. N. and Woomer, P. L. (Eds)** (2003). Organic resource management in Kenya: Perspective and Guidelines. Forum for Organic Resource Management and Agricultural Technologies, Nairobi, Kenya. p 184.
- Sanchez, P. A.,** (2002) Ecology soil fertility and hunger in Africa. *Science*, 295: 2019–2020.
- Sanchez, P. A, Shepherd, K.D., and Soule, M.J.** (1997). Soil fertility replenishment in Africa: an investment in natural resource capital. In: Replenishing Soil Fertility in Africa (Eds Buresh RJ, Sanchez PA), Pp. 1–46 SSSA and ASA, Madison, WI, USA.

- Sarwar, G.** Schmeisky, H. Hussain, N. Muhammad, S. Ibrahim, M. and Safdar, E. (2008) Improvement of soil physical and chemical properties with compost application in Rice-Wheat cropping system. *Pakistan Journal of Botany*, 40: 275-282.
- Scheffe, C. R.**, Patti, A. F., Clune, T. S., and Jackson, W. R. (2008). Organic amendment addition enhances phosphate fertiliser uptake and wheat growth in an acid soil. *Australian Journal of Soil Research*, 46: 686-693.
- Shapiro, A. C.**, and Francis, D. (2006). Using a chlorophyll meter to improve Nitrogen management. Neb Guide G.I 632.
- Sharpley, A.** and Moyer, B. (2001) Phosphorus forms in manure and compost and their release during simulated rainfall. *Journal of Environmental Quality*, 29:1462-1469.
- Sheida, Z.**, Sattaria, I. Alexander, F., Bouwmanb, C., Ken, E. Gillera, and Martin, K. (2012). Residual soil phosphorous as the missing piece in the global phosphorous crisis puzzle. *Netherland Journal of Agriculture Science*, 109: 6353.
- Shisanya, C. A.** (2003). A note on the response by smallholder farmers to soil nutrient depletion in the East African highlands. *Food, Agriculture and Environment*, 4: 247-250.
- Singh, H.** and Reddy, M. S. (2011). Effect of inoculation with phosphate solubilizing fungus on growth and nutrient uptake of wheat and maize plants fertilized with phosphate rock in alkaline soils. *European Journal of Soil Biology* 47: 30- 34.
- Smaling, E.** (1993). Soil nutrient depletion in sub-Saharan Africa. In: Van Reuler, H. and Prins, W., (Eds). The role of plant nutrients for sustainable food crop production in sub-Saharan Africa. VKP, Leidschendam.

- Smaling, E. M. A.**, Stoorvogel, J. J., and de Jager, A. (2002). Decision making on integrated nutrient management through the eyes of the scientist, the land user and the policy maker. In: vanlauwe, B. Diels, J. Sanginga N, Merckx, R. editors. Integrated plant nutrient management in sub-Saharan Africa. Pp 265-284.
- Smaling, E. M. A.**, Toure, E. De Ridder, N. Sanginga, N., and Breman, H. (2006) Fertilizer use and the environment in Africa: Friends or foes? Proceedings of the African Fertilizer Summit, Abuja, Nigeria, Pp 9–13.
- Srikanth, K.** and Organics, G. (2006). Effect of enriched compost on crop growth and soil properties; Organic farming advantages and disadvantages for soils, water quality and sustainability. *Journal Indian Society of Soil Science*, 78: 162–168.
- Syers, J. K.**, Johnston, A. E., and Curtin, D. (2008). Efficiency of soil and fertilizer phosphorus: Reconciling changing concepts of soil phosphorus behaviour with agronomic information. *Fertilizer and Plant Nutrition Bulletin*, 18:108.
- Taiwo, L. B.** and B. A. Oso. 2004. Influence of composting techniques on microbial succession, temperature and pH in a composting municipal solid waste. *African Journal of Biotechnology*, 3:239-243.
- Tittonell, P.** Vanlauwe, B. Leffelaar, P.A., Rowe, E.C., and Giller, K.E., (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya. Heterogeneity at region and farm scale. *Journal of Agriculture Ecosystem and Environment*, 110:149-165.
- United States Department of Agriculture**, (2013). Crop production report. National Agricultural Statistics Service.
- Van den Bergh, H.**, and Rijlaarsdam, G. (1996). The dynamics of composing: Modeling writing process data. In: C. M. Levy, and S. Ransdell (Eds). *The Science of Writing*:

Theories, Methods, Individual Differences and Applications (Pp. 207-232). Hillsdale, NJ: Erlbaum.

- Van den Bosch, H.** Ogara, V.N., Maobe, S. and Vlaming, J. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON). III. Monitoring nutrient flows and balances in three districts in Kenya. *Journal of Agriculture, Ecosystem and Environment*, 71:63-80.
- Van Straaten, P.** (2002). Rocks for crops: Agro minerals of sub-Saharan Africa. ICRAF, Nairobi, Kenya, p 338.
- Vanlauwe, B. J.,** Diels, N. and Sanginga, R. (2002). Integrated plant nutrient management in sub-Saharan Africa: From Concept to Practice. CABI, Wallingford, UK, p 352.
- Vanlauwe, B. J.,** Titttonell, P. and Mukulama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertilizer application in Western Kenya. Nutrition. Cycle Agro forestry. In: Batiano, A. (Eds). Advances in integrated soil fertility management in sub-Sahara Africa: Challenges and opportunities. 76: 171-182.
- Vanlauwe, B. J** Titttonel, P. Batiano, A., Kihara, J., and Kimetu, J. M., (2007). Within-farm fertility gradient affects response of maize to fertilizer application in Western Kenya. In; Batiano, A. (Eds.) advances in integrated soil fertility management in sub-Sahara Africa: Challenges and opportunities. 96: 121-132.
- Walkley, A.** and Black, C. A. (1934). An estimation of the Degjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Socience*, 37: 29-38.
- Warren, G.P.,** (1994). Influence of soil properties on the response to phosphorous in some tropical soils: 11: Response to fertilizer P residues. *European Journal Soil Science*, 45:345-351.

- Yu, X.,** Liu, X., Zhu, T. H., Liu, G. H. and Mao, C. (2012). Co-inoculation with phosphate-solubilizing and nitrogen-fixing bacteria on solubilization of phosphate rock and their effect on growth promotion and nutrient uptake by walnut. *European Journal of Soil Biology*, 112:117- 50:
- Zayed, G.** and Motaal, (2005). Bio-production of compost with low, pH and high soluble phosphorous from sugar cane bagasse enriched with rock phosphate. *World Journal Microbiology and Biotechnology*, 21: 747-752.
- Zingore, S.** Murwira, H. K., Delve, R. J., and Giller, K .E., (2007). Soil type, management history and current resource allocation: three dimensions regulating variability in crop productivity on African smallholder farms. *Journal of Field Crops Research*, 101: 296–305.

APPENDICES

Appendix 1: Fertilizer calculations

Quantity of the fertilizer applied in the experiment.

Straight inorganic fertilizer of P sources TSP (46% P_2O_5) and RP (29% P_2O_5) were applied.

- 1) Quantity of TSP (Triple super phosphate applied)

$$\text{Plot size} = 3.6 \text{ m} \times 3.75 \text{ m} = 13.5 \text{ m}^2$$

$$60/46 \times 100 = 130.4 \text{ kg/ha}$$

$$13.5/10000 \times 130.4 = 0.176 \text{ kg/plot} = 176 \text{ gms/plot.}$$

- 2) Quantity of RP (Rock phosphate)

$$60/29 \times 100 = 206.9 \text{ kg/ha}$$

$$13.5/10000 \times 206.9 = 0.2793 \text{ kg/plot} = 279.3 \text{ g/plot}$$

- 3) Compost application rate = 2.25 kg/row (4.5m row)

- Based on CRSP application of 1.5 x 2 kg per 6m row
- Rates calculates to 6.67tons/ha (Rates is what CRSP project used according to info by James)
- Total amount of compost for experiment (3/6 plots to receive compost)
- $3/6 \times 18 \text{ plots/site} \times 3 \text{ sites} \times (1.8 \text{ kg/row} \times 5 \text{ rows/plot}) = 243 \text{ kg compost.}$
- Hence for two seasons $(243 \text{ kg} \times 2) = 486 \text{ kg compost.}$

- 4) Fortified compost half rate (Amount of RP to be used)

Amount of material prepared = 0.5 tons, RP analysis = 29% P_2O_5

Amount of P required = $0.5 \text{ ton} / 6.7 \text{ tons} \times 30 \text{ kg } P_2O_5 \times 100 / 29 = 7.72 \text{ kg RP}$

Amount per layer (Assume 3 layer) = $7.72 / 3 = 2.57 \text{ kg RP approximately}$
1.3 kg RP/layer based on 250 kg output.

- 5) Fortified compost full rate (Amount of RP to be used):

Amount of material prepared = 0.5 tons, RP analysis = 29% P_2O_5

Amount of P required = $0.5 \text{ ton} / 6.7 \text{ tons} \times 60 \text{ kg } P_2O_5 \times 100 / 29 = 15.44 \text{ kg RP}$

Amount per layer (assume 3 layer) = $15.44 / 3 = 5.15 \text{ kg RP approx}$
2.58 kg RP/layer based on 250 kg output.

Appendix 2: Analysis of variance (ANOVA) for plant height, leaf area index, chlorophyll content, hundred seed weight, and yields for Kiobem long rain season (Sept- Feb, 2011-2012)

Means squares					
Source of variation	DF	PH	LAI	CC	YLD
Treatment	5	333.288889*	0.11389889*	89.4240000*	1.87111222*
Rep	2	5.722222	0.00723889	3.2150000	0.04517222
Model	7	239.698413*	0.08342460*	64.7928571*	1.34938651*
Error	10	18.655556	0.00573889	4.6730000	0.02045222
Total	17				

KEY: PH-plant height, LAI-Leaf area index, CC- Chlorophyll content, 100SW- 100 seed weight, YLD- Yield, *significant at 0.05 probability level

Appendix 3: Analysis of variance (ANOVA) for plant height, leaf area index, chlorophyll content, hundred seed weight, and yields for Kiptaruswo long rain season (Sept- Feb, 2011-2012)

Means squares					
Source of variation	DF	PH	LAI	CC	YLD
Treatment	5	306.189333*	0.10032556*	56.0813333*	1.82799222*
Rep	2	20.615000	0.01362222	43.1816667	0.21908889
Model	7	224.596667*	0.07555317*	52.3957143*	1.36830556*
Error	10	7.766333	0.00998222	4.4010000	0.07643556
Total	17				

KEY: PH-plant height, LAI-Leaf area index, CC- Chlorophyll content, 100SW- 100 seed weight, YLD- Yield, *significant at 0.05 probability level

Appendix 4: Analysis of variance (ANOVA) for plant height, leaf area index, chlorophyll content, hundred seed weight, and yields for Kapkerer long rain season (Sept- Feb, 2011-2012)

Source of variation	Means squares				
	DF	PH	LAI	CC	YLD
Treatment	5	652.488889*	0.10583556*	37.1330000*	1.31491556*
Rep	2	8.222222	0.00737222	7.8650000	0.13393889
Model	7	468.412698*	0.07770317*	28.7707143*	0.977493665*
Error	10	103.822222	0.0065889	4.1970000	0.01981222
Total	17				

KEY: PH-plant height, LAI-Leaf area index, CC- Chlorophyll content, 100SW- 100 seed weight, YLD- Yield, *significant at 0.05 probability level

