AGRONOMIC AND ECONOMIC EVALUATION OF PHOSPHATE FERTILIZER USE IN MAIZE -BEAN CROPPING SYSTEMS IN WESTERN KENYA

BY

DORCUS OTSOWA OFUYO

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

SCHOOL OF AGRICULTURE AND FOOD SECURITY

MASENO UNIVERSITY

DECLARATION

Declaration by candidate

This thesis is my original work and has not been presented for a degree or any other award in any university.

Dorcus Otsowa Ofuyo

Department of Applied Plant Sciences	____________________	________________
MSc/AF/00148/2014	Signature	Date

Declaration by supervisors

Prof. Peter A. Opala (PhD)

Department of Soil Science,	____________________	________________
Maseno University	Signature	Date

Prof. George D. Odhiambo (PhD)

Department of Applied Plant	____________________	________________
Sciences, Maseno University	Signature	Date

DEDICATION

This work is dedicated to God and my family for their unwavering support, love, and inspiration during my entire studies.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to everyone who assisted me in realizing the objectives for this study. I especially appreciate the dedicated support and guidance I got from my supervisors Prof. Peter A. Opala and Prof. George D. Odhiambo. Thank you for your patience, guidance and for critiquing my research work. I also offer great gratitude to KARI Kibos, field officer, Charles Okara for his technical assistance throughout my field research. My appreciation also goes to the farmers, Joseph Ouma, John Owiti and Reuben Obingo for providing land for the field experiments. Thanks to Samuel Osieyo, my classmate and the late Justo Munala my nephew, for the moral support and encouragement offered during the period of my work. My greatest thanks go to Humid Tropics Projects through Prof. George D. Odhiambo for technical and financial support during my field work. I would also like to express my sincere appreciation to MEA- Nakuru and KARI Kibos for allowing me to use their laboratories and personnel during soil analysis. I thank Mr. Herbert Chamwada from Geography department at Maseno University for his support with study area maps. God bless you all. Finally I wish to thank my family for their moral support and prayers that I was able to complete this assignment. I thank the Almighty God for his grace.

ABSTRACT

Maize and beans are commonly grown as intercrops in western Kenya to maximize the utilization of the small land sizes per household, but their yields are low mainly due to deficiencies of nitrogen (N) and phosphorus (P) and inappropriate crop arrangements. A study was conducted at Bugeng'i and Malanga sub locations in Busia and Siaya Counties respectively during the short rains (SR) of 2015, and Bugeng'i and Ebusakami (Vihiga County) in long rains (LR) of 2016 to determine the effect of P fertilizer rate and cropping arrangement in maize-bean cropping systems on yields of the component crops and accruing economic benefits. The experiment was arranged as factorial in a split-plot design with 15 treatments replicated three times. The main plots consisted of five levels of maize-bean cropping arrangements (i) one row of maize alternating with one row of beans (conventional), (ii) maize planted in the same hole with beans, (iii) two rows of maize alternating with two rows of beans (Mbili), (iv) sole maize and (v) sole beans. The subplots consisted of three P fertilizer levels i.e. 0, 30, and 60 kg P ha^{-1}. Leaf area index (LAI) of both crops and available soil P were determined at 6 weeks after planting (WAP) while maize height was measured at 8 WAP. Grain yield of the crops was determined at physiological maturity. All data were subjected to analysis of variance (ANOVA) and treatment means separated using least significance difference of means ($p < 0.05$). Land equivalent ratio (LER) was used to determine yield advantage of intercropping while benefit cost ratio (BCR) was used in economic evaluation. The available soil P generally increased with increasing P rate at all sites. The LAI of maize and beans was not significantly affected by crop arrangement at all sites. The LAI of beans was also not affected by P rate at all sites. However, LAI of maize significantly increased with increasing P rate at Bugeng'i during the SR season but there was no significant effect of P rate at the same site in the LR and at Malanga (SR) and Ebusakami (LR). The LAI in all cases was however very low with the highest at 1.51 for beans and 1.93 for maize. Maize plant heights as affected by P rate at all sites followed the order 60 > 30 > 0 kg P ha^{-1}. There was no significant effect of P rate on maize yields at Bugeng'i and Ebusakami in the LR season. The available P was also not significantly related to maize yields at these sites in the LR. This lack of response to P is attributed mainly to the lower than average rainfall and therefore water became a more limiting factor than P for maize growth. This is in contrast to the SR season at Bugeng'i when with adequate rainfall, significant effects of crop arrangement were observed with the mean yields for conventional and Mbili arrangements being statistically similar, but significantly higher than those of maize planted in the same hole with beans. Significant effects of P rates were also observed at the same site with maize yields increasing with P rate. The available P was significantly related to both LAI and maize yields at Bugeng'i in the wetter SR and not the drier LR season. The highest beans yields were obtained in the sole bean crops mainly because of their higher plant population compared to the intercrops. The bean yields of the other crop arrangements did not generally differ significantly. The total LERs were >1 at all sites and therefore showed yield advantage of intercropping maize and beans, irrespective of crop arrangement, over sole crops apart from the Bugeng'i site in the LR. Rainfall was very low in the LR at this site and therefore sole crops performed better under the water stress than the intercrops. Therefore intercropping should only be recommended in areas with adequate rainfall. Financial returns were low because of high input costs and low output prices and none of the treatments therefore met the threshold BCR > 2 suggesting that none of them is likely to be adopted by farmers under conditions similar to those of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS / ABBREVIATIONS

ANOVA **:** Analysis Of Variance

BCR **:** Benefit-Cost Ratio

BNF **:** Biological Nitrogen Fixation

CAN **:** Calcium Ammonium Nitrate

DAP **:** Diammonium Phosphate

FYM **:** Farmyard Manure

ISFM : Integrated Soil Fertility Management

KARI **:** Kenya Agricultural Research Institute

LAI **:** Leaf Area Index

LER **:** Land Equivalent Ratio

LSD **:** Least Significant Differences of means

LR **:** Long Rains

N **:** Nitrogen

P **:** Phosphate

SR **:** Short Rains

TSP **:** Triple Superphosphate

WAP **:** Weeks After Planting

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Maize (*Zea Mays* L.) and common beans (*Phaseolus vulgaris* L.) are grown widely by smallholder farmers in western Kenya for subsistence and commercial purposes. Maize originated in Central America and is an important cereal crop in the family poaceae (Vavilov, 1992). It is now the predominant source of carbohydrate in human diet in the developing world (Undie et al., 2012) and is the staple food with the highest per capita consumption in Kenya, averaging 103 kg person^{-1} year^{-1} (Pingali, 2001). Common bean (*Phaseolus vulgaris* L.) has its origin in Central western Mexico (Vavilov, 1992) and is in the family fabaceae. The legume is an important protein source and is ranked second only to maize in the quantity consumed by humans in Kenya (Ndung'u et al., 2005). The yields of these crops on smallholder farms are, however, low despite the generally favourable climatic conditions in western Kenya. Maize yields of less than 1 t ha^{-1} are common (Nekesa, 2007), against the potential yield of 6 – 8 t ha^{-1} while yields of beans average only 0.5 t ha^{-1} against a potential of 3 t ha^{-1} under optimal production conditions (Namugwanya et al., 2014).

Soil fertility depletion, especially of N and P, has been identified as the fundamental root cause of the low yields of these crops (Sanchez et al., 1997). Continuous farming with no fertilizer inputs by subsistence farmers has contributed to the depletion of soil nutrients. In addition, most soils in western Kenya are dominated by of high aluminium and iron which increase P-fixation thus exacerbating P deficiencies (Kisinyo et al., 2014). Furthermore, these soils are characterized by low organic matter levels, low cation exchange capacity and high nutrient leaching (Opala et al., 2014). In western Kenya, deficiencies of N and P often occur simultaneously on most farms (Kisinyo et al., 2014). In order to increase and sustain crop production, replenishment of soil P must therefore be accompanied with that of soil N (Giller et al., 1997).

Although N and P deficiencies can be overcome by use of fertilizers, most resource poor smallholder farmers cannot afford them (Opala et al., 2010; Odendo et al., 2007). Consequently, there has been increased interest on biological nitrogen fixation (BNF) in intercropping systems as a cost-effective method of addressing N deficiencies (Attar et al., 2012). However, for efficient BNF by the legume, adequate P must be supplied because nitrogen fixing bacteria require high energy inform of Adenosine tri-phosphate (ATP) (Attar et al., 2012; Opala et al., 2010).

Maize and beans in western Kenya are planted as either monocrops or intercrops (Sullivan, 2003) but intercropping is the predominant way of producing these crops (Beebe et al., 2012). Intercropping systems have a potential of enhancing food security because two or more crops are grown simultaneously on the same field. This poly-culture cropping system is therefore a strategy for enhancing crop output per unit area in developing countries (Mucheru-Muna et al., 2010; Tsubo et al., 2003). Maize-bean intercropping systems are also beneficial to smallholder farmers mainly because they improve water, nutrient and radiation use efficiency (Woomer et al., 2004). In addition, these intercrops enhance, profit maximization, risk minimization, soil conservation and improvement of soil fertility. They also enhance weed, pest and disease control and balanced human nutrition (Matusso et al., 2014; Tsubo et al., 2003). However, because of high plant densities, intercropping systems have higher labour requirements than sole cropping. High interspecies competition between the crops in the intercrops may also have negative effects on the yield of the component crops (Silwana et al., 2007).

Advantages of intercropping can be adequately achieved if farmers adopt better spacing and appropriate crop spatial arrangements (Matusso et al., 2014). There are four intercropping patterns practiced by farmers in western Kenya i.e. row intercropping, strip intercropping, mixed intercropping, and relay intercropping (Sullivan, 2003); but most of them mainly practice mixed intercropping of maize and beans and also plant both crops in the same hole. However, due to high competition for growth resources, planting of maize and beans in the same hole arrangement is characterized by low yields (Broughton et al., 2003). To improve resource use efficiency by the component crops within the intercrop other crop arrangements have been proposed. These include (i) Conventional maize-bean row arrangement in a 1:1 ratio. This arrangement however gives low yields due to high competition and poor utilization of growth resources such as light, water and nutrients (Mucheru-Muna et al., 2010). (ii) Two rows of maize followed by two rows of beans (known as Mbili system in Kiswahili). This arrangement has been reported to increase productivity compared to the other crop arrangements although the practice is yet to be widely accepted by farmers (Woomer et al., 2004). Farmers will only adopt use of a technology if they perceive the returns on inputs are above alternative investments (Tungani et al., 2003). There is therefore need to determine interactive effects of cropping systems and P fertilizer rates on yields of maize-beans and their economic benefits that accrue in this study; since previous studies have looked at the economics of the two aspects separately.

1.2 Statement of the Problem

Land scarcity is a major problem in western Kenya due to high population growth rate with most smallholder farmers owning < 0.2 ha of land (Vanlauwe et al., 2011). Intercropping legumes with cereals is among the copping strategies adopted by farmers in the region as a means of maximizing land use (Matusso et al., 2014). Although intercropping is a norm, there has been an increased interest in bettering productivity of such systems in tropical agriculture

(Ghosh et al., 2009; Mal´ezieux, 2009). Because of their ability to fix significant atmospheric nitrogen, legumes offer an alternative to use of expensive fertilizers for increasing nitrogen input in cropping systems. Nitrogen fixation by beans in western Kenya is however low because of P deficiencies (Okalebo et al., 2007), thus negating nitrogens' usefulness as a component of maize-bean intercropping systems (Giller, 2001). For efficient BNF by the legume, adequate P must be supplied in form of fertilizers because nitrogen fixing bacteria require high energy in form of adenosine tri-phosphate (ATP) (Attar et al., 2012). There is however paucity of information on the appropriate P rates to be used in maize-bean intercropping systems because the current fertilizer recommendations were developed for maize monocrops (Tungani et al., 2003). There is therefore need to determine appropriate rates of P fertilizer to be used in maize-bean intercrops for optimum productivity.

One aspect that has received little attention in intercropping research is the spatial arrangements of crops within the cropping system. Crop arrangements may create different micro climate in the stands and influence the efficiency with which the growth resources are utilized by the intercrops for yield production. There is however little understanding on how crop arrangements interact with fertilizer inputs to affect crop yield in intercropping systems (Mal´ezieux, 2009). There are also concerns that even when biophysical aspects of certain technologies are well understood and their agronomic effectiveness established, adoption of such technologies by farmers has been dismal (Opala et al., 2010). A fact that is often overlooked by most researchers is that, adoption of any technology by a farmer is not only based on yield returns, but also on economic benefits that accrue (Tungani et al., 2003). Most agronomic studies on cereal-legume integration in the region however lack information on economic aspects that consider farmers' production environment (Odendo et al., 2007). The study therefore integrated agronomic and economic evaluation of maize-bean cropping systems under different P fertilizer rates.

1.3 Objectives of the Study

1.3.1 General Objective

To determine effects of phosphate fertilizer rate and crop arrangements in maize-bean intercropping systems on available P, yields of component crops and economic benefits in Busia, Siaya and Vihiga Counties in western Kenya.

1.3.2 Specific Objectives

1. To determine the effect of phosphate fertilizer rate and crop arrangement on available P, yields and yield components of maize and beans in maize-bean cropping systems.
2. To determine economic benefits of phosphate fertilizer rate and crop arrangement in maize-bean cropping systems in Busia, Siaya and Vihiga Counties.

1.4 Hypotheses (Null)

1. Phosphate fertilizer rate and crop arrangement have no effect on available P, yields and yield components of maize and beans in maize-bean cropping systems in Busia, Siaya and Vihiga Counties.

2. Phosphate fertilizer use and crop arrangements have no economic benefits in maize-bean cropping systems in Busia, Siaya and Vihiga Counties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Nitrogen and Phosphorus Constraints and their Management in Western Kenya

Phosphorus is essential for root growth and energy transfer processes in plants e.g. cell division, photosynthesis, respiration, BNF, and the mineral is also vital in flowering and seed formation hence in yield production in legumes such as beans (Beebe et al., 2012). Its deficiency therefore reduces the rate of metabolic processes mentioned above (Shepherd et al., 1996). It occurs in the soil in both organic and inorganic forms, the latter being the most important for crop nutrition. Inorganic P occurs as various salts of Ca, Fe and Al in solution, surface films, solid state or exchangeable phosphate anions held by positive charges (Buresh et al., 1997). Generally plants absorb P from the soil solution as primary orthophosphate ($H_2P0_4^-$) and to a small extent as secondary orthophosphate ($HP0_4^{2-}$) ions (Opala et al., 2010).

Smallholder farmers in western Kenya continuously cultivate their soils with no fertilizer inputs leading to mining of nutrients especially N and P (Vanlauwe et al., 2011; Okalebo et al., 2007). Farm scale studies reveal negative nutrient balances in soil phosphorus in most countries in sub Saharan Africa (Shepherd et al., 1996), including Kenya. There is also widespread evidence of P deficiencies in arable soils that are highly weathered and leached in the western Kenya region (Woomer et al., 2004; Okalebo et al., 2007). Phosphorus deficiency in many of the soils is largely due to low occurrence of P-containing minerals and P-fixation (Okalebo et al., 2007; Opala et al., 2010).

Methods for replenishment of phosphorus on P deficient soils in Kenya include application of inorganic P fertilizers such as, single superphosphate (SSP) and triple superphosphate (TSP), and use of phosphate rock (PR). However, some researchers have reported low responses by crops to application of inorganic P fertilizer because of high soil acidity and low soil organic matter content in western Kenya (Okalebo et al., 2007; Opala et al., 2014). Use of phosphate rocks, has been reported to increase crop yields though their reaction is slow in releasing available P (Gudu et al., 2005). Organic sources e.g. tithonia and farmyard manure (FYM) have been used to enhance soil P although they are low in P and should be supplemented with inorganic P sources (Opala et al., 2010). Efforts to address P deficiency have also focused on application of lime, to raise soil pH, reduce Al levels hence increase available P but this practice is not common among smallholder farmers in western Kenya (Kisinyo et al., 2014).

Nitrogen inputs used in the region consist of inorganic fertilizers, biomass transfers, BNF mainly by legumes, animal manures or composts, and nitrate captured from subsoil depths, beyond the reach of crop roots and trees (Giller et al., 2001). Manure application improves chemical, physical and biological properties of soil. The use of manure is however limited by their low nutrient content, inadequate amounts and high costs of transportation for the material due to the large volumes needed (Okalebo et al., 2007). The common inorganic nitrogenous fertilizers available to farmers in western Kenya are urea (46% N) and Calcium ammonium nitrate (C.A.N) (26 % N) (Opala et al., 2014). However, the use of inorganic N fertilizers by small holder farmers in western Kenya is constrained by lack of adequate finances to buy these inputs (Odendo et al., 2007). Integrated soil fertility management (ISFM) which involves combined use organic and inorganic sources of nutrients has therefore been proposed to mitigate the challenges that are encountered while using sole inorganic fertilizers or organic inputs (Nandwa et al., 2011; Mugendi et al., 2011; Sanginga and Woomer, 2009; Mugwe et al. 2009).

2.2 Cropping Systems

Cropping systems that are mainly practised in western Kenya include monocropping and intercropping. Monocropping involves planting one type of crop e.g. sole maize or sole beans at a time. Reported disadvantages for this system include; poor soil cover hence soil prone to soil erosion, build up of pests, diseases and weeds, exhaustion of soil nutrients and damage to the soil structure due to repeated ploughing at the same soil depth (Sullivan, 2003). Intercropping is a soil fertility management practice consisting of cultivating two or more crops in the same space at the same time (Matusso et al., 2014). The major types of intercropping systems include: row intercropping, strip intercropping, mixed intercropping, and relay intercropping. Relay intercropping is the planting a second crop into a standing crop when the standing crop is at its reproductive stage but before harvesting (Vanlauwe et al., 2011). This avoids competition between the main crop and the intercrop.

Strip intercropping involves planting broad strips of cereals and legumes in the field (Broughton et al., 2003). The legume improves soil fertility and rotation of the component crops helps reduce pest and weed problems (Woomer et al., 2004). In addition, managing a single crop within the strip is easy, and interspecies competition between the crops is reduced. Mixed intercropping involves planting of crops together without any particular cropping arrangement (Tamiru Hirpa, 2014). The method is easy to carry out though it makes weeding, fertilization and harvesting difficult and crops have high competition for growth resources (Prasad and Brook, 2005). Row intercropping is planting of crops in rows and it makes weeding and harvesting easier than mixed intercropping (Sullivan, 2003). Traditionally, beans were intercropped with maize, banana, cassava, rice, sorghum or with rice in the tropics (Broughton et al., 2003). The reported advantages of these cereal-legume intercropping systems to smallholder farmers are flexibility in carrying out field operations since labour requirement is minimised, water, nutrient and radiation use efficiency because of different nutrient requirement levels and growth patterns, profit maximization, risk is spread on more than one crop, soil conservation and improvement of soil fertility since most legumes acts as cover crops and can also fix some atmospheric nitrogen (Matusso et al., 2014; Tsubo et al., 2003). In addition, these systems help in management of weeds, pests and diseases and contribute to balanced nutrition (Tsubo et al., 2003). These advantages occur when the component crops have different requirements for resources hence minimizing competition for growth resources (Mattuso et al., 2014).

Intercropping systems are also beneficial in risk-minimization in case of total failure in one crop. The ability of the legume to act as a soil cover helps to cope with soil erosion and addressing declining levels of soil fertility through BNF (Beebe et al., 2012). The amount of N transferred to associated non-leguminous crops determines the extent of benefits of intercropping (Cardoso et al., 2007). Intercropping ensures that there is more efficient use of space and labour hence an increased and diverse productivity per unit area of production compared to sole cropping (Seran and Brintha, 2010; Woomer et al., 2004). Intercropping, however has several disadvantages such as; high labour requirements than in the sole cropping, slower pace of cultural practices such as weeding and harvesting due to high plant densities, and interspecific competition between the crops (Silwana et al., 2007). For instance, Mucheru-Muna et al. (2010) reported that intercropping may accelerate soil nutrient depletion due to high plant population densities, high competition hence low crop yields and poor financial returns.

The interactive effects of intercropping cereals and legumes on the yields of component crops have been reported widely (Seran and Brintha, 2010; Nekesa, 2007). For example, Morgado and Willey (2008) observed that grain yields of beans were suppressed by the intercrop maize, at the highest maize plant population because of poor light interception by the under storey legume. In the same study above, application of nitrogen fertilizer to maize rows mitigated the negative intercropping effect on maize at higher population while at lower maize plant population the associated bean increased grain yields because of better light interception by the legumes. Silwana et al. (2007) reported that intercropping of beans and maize reduced yield of each component crop and attributed this to competition for growth resources. Other studies have, however, reported that intercropping enhances nutrient use efficiency (Mattuso et al., 2014*)* due to different levels of nutrient uptake by roots of the different crop species that explore different soil depths. Although competition for light is considered one of the major factors contributing towards reduction in growth and yield of crops in intercropping systems, Kitonyo et al. (2013) observed increased grain production and monetary value per unit area from intercropping attributed to optimized utilization of solar radiation, soil water and growth nutrients, and space. Intercropping between high and low canopy crops can improve light interception and hence yields of the shorter crops (Tsubo et al., 2003). This therefore requires that the shorter intercrops be planted between sufficiently wider rows of the taller ones (Matusso et al., 2014). This concept was one of the drivers for the staggered spacing of the Mbili intercropping system of maize and beans (Woomer et al., 2004; Tungani et al., 2002) which has been tested with varying degrees of success in western Kenya.

2.3 Crop arrangement in Maize-Bean Intercropping Systems

Maize-bean cropping systems in western Kenya are often arranged in five different cropping patterns. They include; 1. Sole maize 2. Sole beans 3. Conventional 4. Mbili and 5. Maize and beans planted in the same hole. In the conventional method, one row of maize is alternated with one row of beans. In the Mbili system, double rows of maize are alternated with two rows of beans. Mbili is thought to be an improvement on the conventional system (Tungani et al., 2002). Competition and complementarities are the two most important interactions in intercropping. Under competition more than one species of crop require the same element in large amounts to complete a major physiological growth process like biomass production, while under complimentarity more than one species of crops growing together co exist in the same environment in a mutual interaction to complete physiological growth cycle. Intercropping largely depends on the competitive abilities of the component crops and their respective plant populations (Woomer et al., 2004).

Selection of the right crop combination is important in intercropping systems (Ndung'u et al 2005; Tsubo et al., 2001). Crops which mature at different times such as maize and beans have separate periods of maximum demand for nutrients, moisture, aerial space and light and can therefore be suitably intercropped (Liebman, 1995). In addition, optimum plant populations with proper row arrangements enables a more efficient utilisation of available resources (sunlight, moisture and soil nutrients) and can therefore result in relatively higher yields than when crops are grown separately, as pure stands (Mucheru-Muna et al., 2010; Woomer et al., 2004). In ecological terms, resource complementarities minimize the niche overlap and the competition between crop species, and allow crops to capture a greater range of nutrient resources than the sole crops (Brintha and Seran, 2009). When nodulated legume plants such as beans are shaded or kept under low light for several days by a tall canopy crop, the rate of biological N_2 fixation and biomass accumulation is reduced since the nitrogen fixing bacteria require exposure to optimum sunlight temperatures for nitrification process to take place (Attar et al., 2011). A proper crop arrangement that enhances light interception by the below canopy legume crop could mitigate this problem (Kitonyo et al., 2013; Tsubo et al., 2001).

2.4 Leaf Area Index

Leaf area index (LAI) refers to the leaf area (one side) per unit area of ground cover (Blanco and Folegatti, 2003). Leaf area index in intercropping affects interception of light by the component crops for the process of photosynthesis. In addition, LAI is highly correlated with other processes such as evapotranspiration, and hence highly influences biomass accumulation and crop yields. Rain interception and reduced soil erosion is also determined by crop LAI (Tsubo et al., 2003). Crop LAI should be >1 for optimum light interception hence better rates of physiological processes.

2.5 Measures of Effectiveness of Intercropping Systems

Indices used for assessment of efficiency of intercropping over monocropping systems include, (i) Land equivalent ratio (LER), (ii) Area time equivalent ratio (ATER), (iii) Competitive ratio (CR), and (iv) Actual yield Loss (AYL). Land equivalent ratio is the most commonly used method to indicate the yield per unit area of land for intercropping compared to mono-cropping system (Willey and Rao, 1980). Area time equivalent ratio (ATER) provides a comparison of the yield advantage of intercropping over monocropping in terms of time taken by component crops in the intercropping systems (Hiebsch, 1980). It is not an effective method because crops are harvested at physiological maturity which highly varies with environmental conditions. Competitive ratio (CR) gives a measure of competitive ability of the crops rather than the yield advantage. The Actual yield Loss (AYL) is the proportionate yield loss or gain of intercrops compared to sole crop (Willey and Rao, 1980). Land equivalent ratio is considered to be one of the most appropriate indices to evaluate the efficiency of intercropping system (Mead and Willey, 1980) since LER verifies the effectiveness of intercropping in using the resources of the environment compared to sole cropping (Odhiambo and Ariga, 2001; Mead and Willey, 1980). When LER is greater than 1, the intercropping arrangement favours the growth and yield of the intercrop species. In contrast, when LER is lower than 1, the intercropping arrangement negatively affects the growth and yield of plants grown in mixture (Odhiambo and Ariga, 2001).

2.6 Economics of Fertilizer Use in Intercropping Systems

Application of a unit of input is economical, if the value of increase in the crop yield due to the quantity of input added is greater than the cost of input used. Some of the approaches used to calculate economic advantage in intercropping systems include: (i) monetary advantage index (MAI), which is an indicator of the economic feasibility of intercropping systems as compared to sole cropping. (ii) Partial budgeting, which is a method of organizing data and information about the costs and benefits of various alternative treatments. (iii)

Marginal analysis using benefit cost analysis which gives a direct measure of the cost of production relative to the value of returns of a production enterprise (Willey and Rao, 1980). The benefit-cost ratio (BCR) has been used in various studies to determine which farming technologies are likely to be adopted by farmers (Mucheru-Muna et al., 2010; Opala et al., 2010). The benefit-cost ratio (BCR) shows the cost of production relative to the value of returns of a production enterprise unlike the MAI which combines the profits of both intercrops hence you cannot evaluate individual crop performances and responses to inputs applied. Benefit-cost ratio of ≥ 2 implies that the technology in use is feasible in terms of returns on input investments while a BCR < 2 shows infeasibility of the crop production technology (CIMMYT, 1988). Farmers will adopt improved technologies if they perceive a clear return on their direct costs and from labour and inputs (Tungani et al., 2003). Odendo et al. (2007) however observed that there has been lack of economic evaluation of crop production technologies in many studies in Africa, thus farmers make poor choices on the technologies to adopt due to lack of appropriate economic information.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

The study was conducted on three farmers' fields at Bugeng'i, Malanga, and Ebusakami sub locations in Busia, Siaya, and Vihiga Counties respectively in western Kenya. These sites were chosen on the basis of contrasting agro ecological zonations to evaluate responses of the crops to the treatments under different environmental conditions. At all the sites, intercropping of a variety of food crops especially cereals and the pulses is practiced, usually with minimal amounts of fertilizer inputs. Maize is the most dominant food crop, followed by sorghum, finger millet and cassava. The dominant legume crop is the common bean (Jaetzold et al., 2009; Jaetzold et al., 2005). Busia and Siaya sites were used in the first season (2015 SR), but only Busia site was retained for the second season (2016 LR) while Siaya site was replaced with Vihiga site in this season. This was because of striga weed problem at Malanga during the first season.

Bugeng'i has two rainy seasons with long rains from March to May, while short rains are in August to October. Mean annual rainfall ranges between 1,270 mm and 1,790 mm. Soils are highly weathered ferrasols. The mean annual maximum temperatures range from 26 ^{0}C to 30 ^{0}C while the mean annual minimum temperatures vary between 14 ^{0}C and 18 ^{0}C. The site lies at an altitude of 1298 m above sea level and at longitude N00.42745 and latitude E034.1709 (Jaetzold et al., 2009).

Malanga in Siaya County is geographically positioned at longitude N00.13808 and latitude E034.423884 (Jaetzold et al., 2009). It receives a bimodal rainfall that ranges between 1500 mm and 1900 mm per annum, with the long rains in (February – July) and short rains (August – November). Malanga lies at an altitude of 1524 m above sea level, with mean annual temperatures of 21 ^{0}C. Soils at this site are rhodic ferrasols. Ebusakami lies at a latitude

34.579550 and longitude 0.004556 and at an altitude of 1329 m above sea level. This site receives a mean annual rainfall of 1750 mm with a bimodal distribution, the long rains from February to July and the short rains from August to November and mean annual temperatures of 28.7 ^{0}C. Soils at the site are classified as acrisols (Jaetzold et al., 2009).

3.2 Soil Characterisation

Soils for site characterization at the beginning of the study were obtained at a depth of 0 - 20 cm by randomly auguring eight spots in every field and then bulking the soil to get one composite sample to ensure homogeneity of the sample (Okalebo et al., 2002). The soils were kept in polythene bags and taken to KARI- Kibos for processing before analysis. The soils were air dried under a shade, crushed and sieved through a 2 mm sieve. A representative sample of 250 g was retained for analysis. The soils were analysed using standard laboratory procedures (Okalebo et al., 2002). Soil pH was determined in a soil-water (1:2.5) suspension with a pH meter as follows: 20 g of soil was put in a 60 ml plastic bottle and 50 ml of distilled water added and the mixture stirred for 10 minutes. It was allowed to stand for 30 minutes and stirred again for 2 minutes and the pH meter immersed into 60 ml bottle and pH reading recorded. Organic carbon was determined by Walkley-Black method. All organic C in the soil sample was oxidized by acidified dichromate under controlled conditions. The excess chromic acid used, was titrated against ferrous ammonium sulphate solution.

Exchangeable calcium, magnesium and potassium were determined by Mehlich double acid method. Air-dry soil samples were extracted with a mixture of 0.1 N, HCl and 0.025 N H_2S0_4. Calcium and magnesium in the extract were determined using atomic absorption spectrophotometer while potassium was determined using a flame spectrophotometer. Extractable soil phosphorous was determined by Mehlich double acid method: 5 g of air dry soil pulverized to pass through 10 mesh sieve (< 2.0 mm) was added into 25.0 mL of M1 extracting solution (0.1 N HCl and 0.025 N H_2SO4) into a plastic flask. The mixture was placed on reciprocating mechanical shaker for five minutes. The solution was filtered using Whatman filter papers No.2 into clean labelled test tubes. Phosphorus in solution was determined using inductively couple plasma emission mass spectroscopy (ICPE 900). Total soil N was determined by Kjeldahl acid digestion method (Okalebo et al., 2002) as follows: soil samples were digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at 360 ^{0}C. Total N was determined by distillation followed by titration with $H_2S0_{4.}$ The hydrometer method was used to determine soil particle size.

3.3 Experimental Design and Treatments

The study was conducted over two consecutive cropping seasons; the short rains (SR) in September 2015 and long rains (LR) in March 2016. The experiment was laid out as a 5 × 3 factorial arranged in a split-plot design with 15 treatments replicated three times (Table 1; Figure 1). The main plots consisted of 5 types of crop arrangements in maize-beans cropping systems’ 1. Two rows of maize alternating with two rows of beans (Mbili) (Figure 2a) 2. Maize planted in the same hill with beans (Figure 2b), 3. One row of maize alternating with one row of beans (conventional) (Figure 2c), 4. Sole maize and 5. Sole beans. Sub-plots consisted of three phosphate fertilizer levels i.e. 0, 30 and 60 kg P ha $^{-1}$.

Table 1: Experimental Treatments

The 15 treatments included**:**

Treatment number	Cropping system	P rates kg P ha $^{-1}$
1.	Sole bean	0
2.	Sole bean	30
3.	Sole bean	60
4.	Maize, bean (SH)	0
5.	Maize, bean (SH)	30
6.	Maize, bean (SH)	60
7.	Conventional	0
8.	Conventional	30
9.	Conventional	60
10.	Maize, bean (Mbili)	0
11.	Maize, bean (Mbili)	30
12.	Maize, bean (Mbili)	60
13.	Sole maize	0
14.	Sole maize	30
15.	Sole maize	60

SH= same hole; Conventional= One row of maize alternating with one row of beans; Mbili = Two rows of maize alternating with two rows of beans

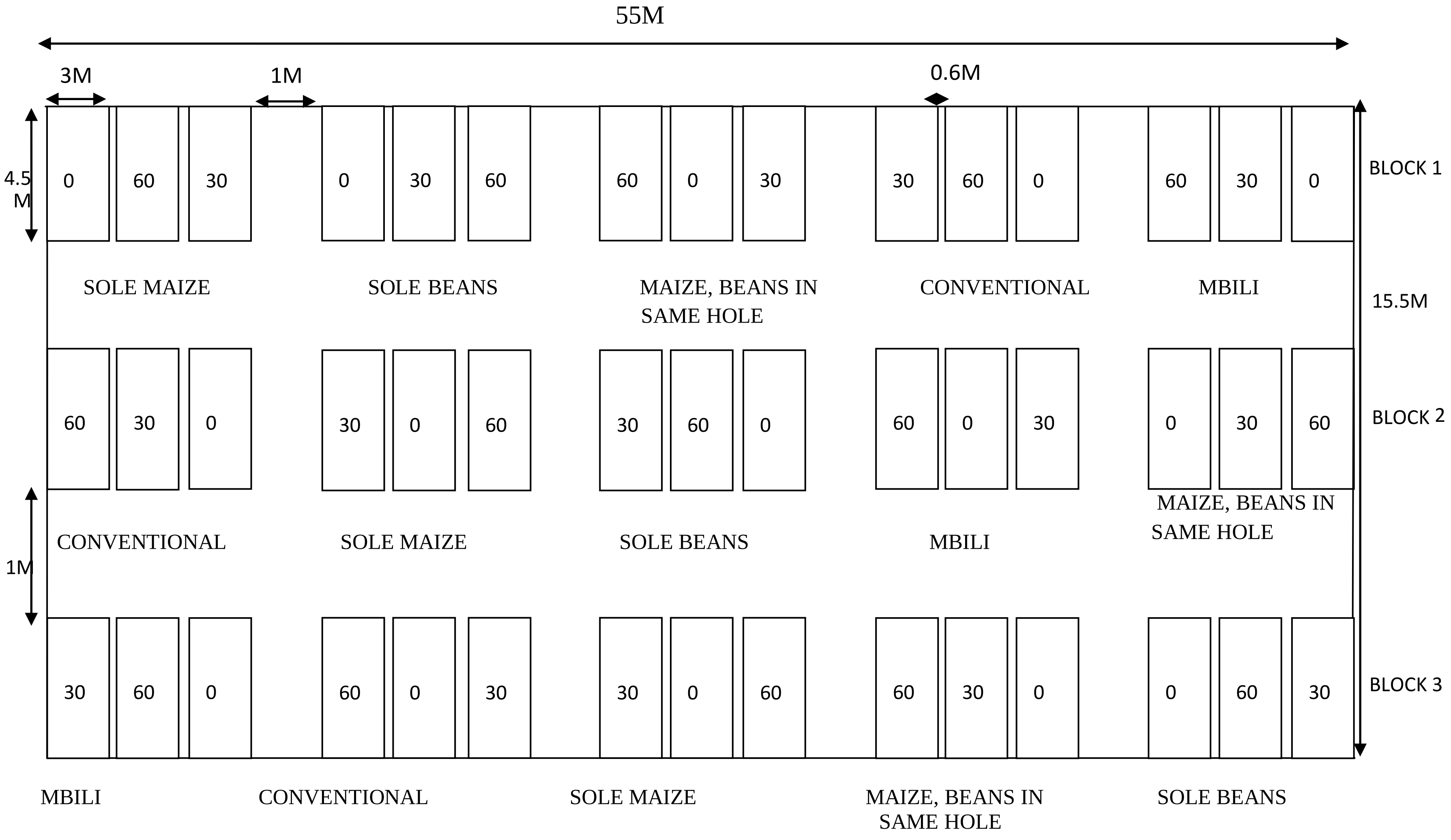

Figure 1.0: Experimental layout

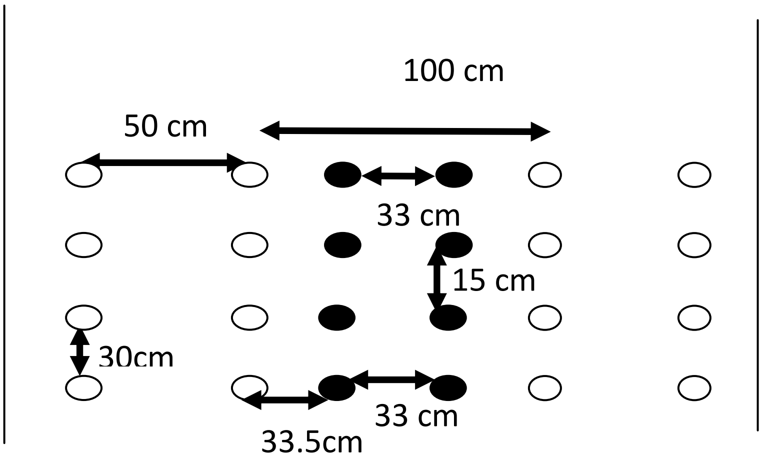

Figure 2a: Mbili cropping system arrangement

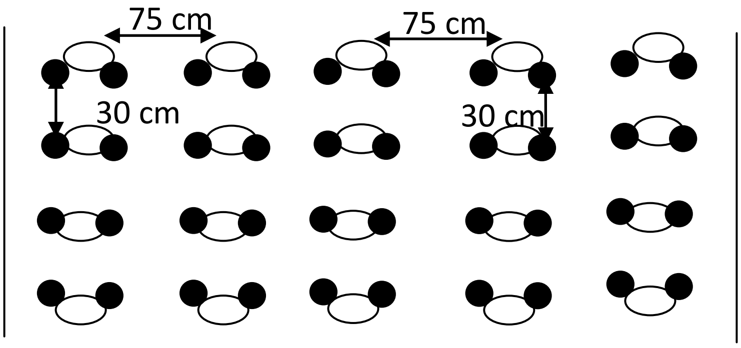

Figure 2b: maize + beans in the same hole cropping system arrangement

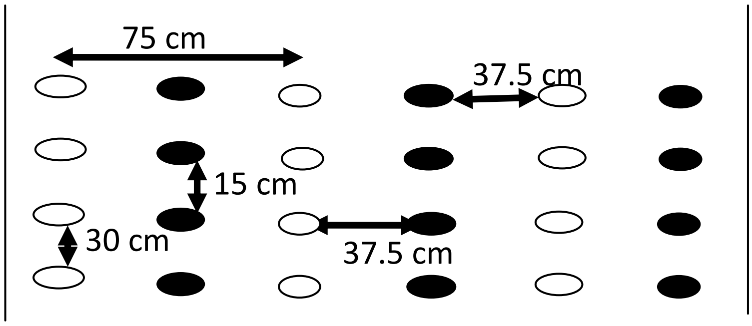

Figure 2c: Conventional cropping system arrangement

Key

○ — Maize

● — Beans

3.4 Crop Establishment and Management

Prior to the experiment, fields at all sites were under a two month natural fallow period. Land was prepared to a medium seedbed tilth. Plots measuring 4.5 m x 3 m were marked before planting. Pathways measuring 1.0 m were left between blocks and main plots, while 0.6 m was left between subplots as illustrated in Figure 1. Sole maize and beans were planted at 75 cm by 30 cm and 30 x 15 cm respectively. Maize variety Western Hybrid 505 was planted it grows well at pH (5-8), altitude 1000-1800 m.a.s.l. minimum rainfall 450 mm and maximum 700 mm per year (Jaetzold et al., 2005). An inoculated hybrid variety of common beans Rose coco, commonly grown in the study areas for its early maturity was used. It grows well at altitude 2000 m.a.s.l. minimum rainfall 250mm and maximum 450mm per year (Jaetzold et al., 2009). The three intercropping arrangements (Figures 2a, 2b and 2c) were planted at a plant population of 44, 444 plants ha^{-1} (maize) and 88, 888 plants ha^{-1} (beans). 44,444 plants ha^{-1} was maintained in sole maize, while sole beans were increased to 202,020 plants ha^{-1}.

Triple superphosphate and CAN were evenly broadcast in the appropriate plots and incorporated into the soil at planting, a third of N fertilizer (20 kg N ha $^{-1}$) applied at planting. The rest 40 kg N ha^{-1} was applied using spot application to all maize treatments at 6 WAP. Sole bean treatments were not top dressed with N fertilizer because the beans were inoculated and were therefore expected to fix N for their growth. In all cropping arrangements, except maize and beans planted in the same hole, maize and beans were each planted at a rate of 2 seeds per hill and later thinned to 1 plant at 2 WAP. Where maize and beans were planted in the same hole, three beans were planted and thinned to two at 2 WAP but maize was planted and thinned as described earlier for the other arrangements. The crops were weeded twice by cultivation with hand hoes. Plants were harvested at physiological maturity by excluding one border row on each side of the harvested area to eliminate edge effect.

3.5 Data Collection

3.5.1 Available Phosphorus

Soil samples were obtained at 0-20 cm depth from every plot at 6 WAP by auguring eight spots and bulking the soil to get one composite sample of 500 g per plot. The soils were kept in polythene bags and taken to KARI Kibos and processed and analysed for available soil P as already described in section 3.3.

3.5.2 Crop Data

3.5.2.1 Plant Leaf Area Index and Height

Ten maize plants were randomly sampled in each plot and tagged. The LAI of these plants were determined at 6 WAP. The heights of these plants were measured using a standard metre rule from the base of the plant to the shoot apex at 8 WAP. Maize Leaf area was estimated by direct measurements on single leaves for cross-sectional lengths and widths using a standard metre rule and calculation of means of repeated cross-sectional leaf areas using the formulae:

$$Leaf\ area(m^2) = Length\ (L)\ in\ meters\ x\ Width\ (W)\ in\ meters$$

(Blanco and Folegatti, 2003).

Leaf area index for beans was determined at 6 WAP: Ten fully expanded leaves were obtained from a sample of three bean plants randomly selected from 5 sample plants from each sub-plot of maize-bean intercrops. Leaf area was determined using graphical method of tracing the leaves on graph papers and counting the total number of squares to find area in cm^2 which was converted into m^2. Leaf area index for the two crops was calculated using the following formulae of Blanco and Folegatti, (2003);

$$LAI = \frac{Leaf\ area\ (m^2)}{Total\ ground\ area\ (m^2) of\ sampled\ plants}$$

3.5.2.2 Biomass and Grain Yield

Maize and beans were harvested at physiological maturity. The maize plant were cut at the ground level and weighed to determine total fresh biomass weight. Maize ears were recovered, the cobs separated from the stover and total fresh weight of the stover and cobs determined using a field weighing balance. Maize cobs were sun-dried, shelled and grain yield was then determined using a standard weighing balance. Beans were harvested by uprooting the plants. The plants were then processed by sun-drying, shattering the pods, collecting and cleaning seeds, and then sun-drying to a constant weight. The yields of both crops were determined at moisture content of 13.5%.

3.5.3 Land Equivalent Ratio

Land Equivalent Ratio was used to compare yield advantage obtained from different cropping systems. LER was calculated according to Mead and Willey (1980) as follows:

LER= Partial LER maize + Partial LER beans i.e.

$$LER = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

$$Partial\ LER\ Maize = LER = \frac{Yab}{Yaa}$$

$$Partial\ LER\ Beans = \frac{Yba}{Ybb}$$

Where *Y*aa and *Y*bb are yields as sole crops and *Y*ab and *Y*ba are yields in intercrops.

3.5.4 Economic Analysis

Data for cost-benefit analysis was collected at a specific time for each activity at each site and season. Labour was measured in terms of person-days by observing how long it took to perform specific activities and coasted them using the mean prevailing market wage rates within the study areas. Economic benefits were calculated by multiplying the crop yields with prevailing market prices. Prices of farming inputs, maize grain and stover and common bean were determined by carrying out a survey of the prevailing market prices of the study areas.

Total production costs can be classified into fixed costs and variable costs. There were no fixed costs except land which was common to all systems. Land was assumed to be owned by the farmer and not rented. The only costs calculated were the variable costs which were considered to make up the total production cost. Variable costs consisted of costs of farming inputs such as fertilizers, seeds and labour.

Benefit-cost analysis was performed using the procedure of CIMMYT (1988) as follows:

$$NB = GFb - TC,$$

$$BCR = \frac{NB}{TC}$$

Where, NB = net benefit, TC = total costs= Fixed costs +Variable costs. BCR = Benefit-cost ratio, GFb = gross field benefits which is the product of mean yield and farm gate price.

TR = A product of crop yields at harvest and prevailing market prices.

3.6 Data Analysis

Analysis of variance (ANOVA) was performed for crop agronomic data and LER values using GenStat software (Genstat Release 7.22, 2010). Statistically significant treatment means were separated by Least Significant Differences of means (LSD) at $p < 0.05$. Correlation analysis was used to determine the quantitative relationships between available soil P at 6 WAP and plant heights, leaf area index and crop yields.

CHAPTER FOUR

RESULTS

4.1 Introduction

In this chapter results of all the data analyzed are presented under the following sub-sections: Rainfall data, changes in soil properties during the two seasons, growth parameters and grain yields of maize and bean, relationships between soil available P and yield and yield components and economic evaluation of the different treatments are also presented. A test for homogeneity of error variance was performed to compare effects of treatments between the sites in each season and between seasons at Bugeng'i, where the study was conducted for two seasons. Results indicated there was lack of homogeneity ($p < 0.05$) for all parameters under consideration, indicating that there were differences in responses to treatments across sites and seasons. The results are therefore presented per site and season.

4.2 Rainfall

Figures 3a, 3b and 3c represent the amount and distribution of rainfall during crop growth periods and long-term monthly rainfall mean trends generated using New_LocClim climate database and interpolation software (FAO, 2006a) for the three sites. Total rainfall amount that was received was as follows: Ebusakami LR- 792 mm, Malanga SR- 820 mm, Bugeng'i SR and LR at 1065 mm and 529 mm respectively. The SR in 2015 season recorded higher amounts of rain than the long term monthly means at Malanga and Bugeng'i, while the LR season recorded lower amounts of rain than the long term monthly means at Ebusakami and Bugeng'i.

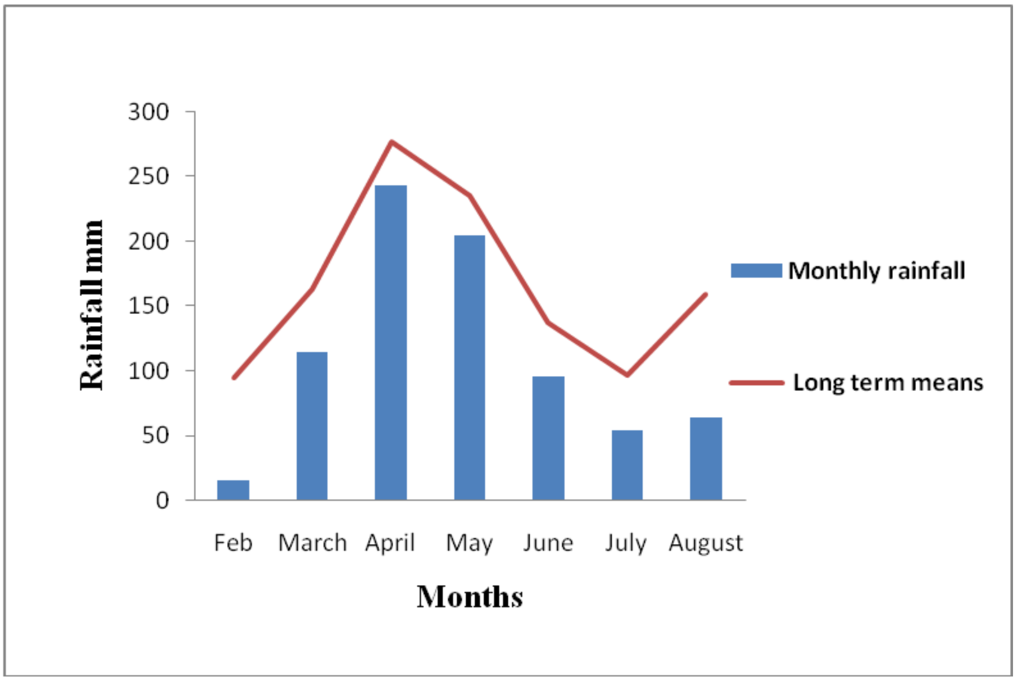

Figure 3a: Ebusakami rainfall pattern in 2016 long rains (CIAT Maseno, 2016).

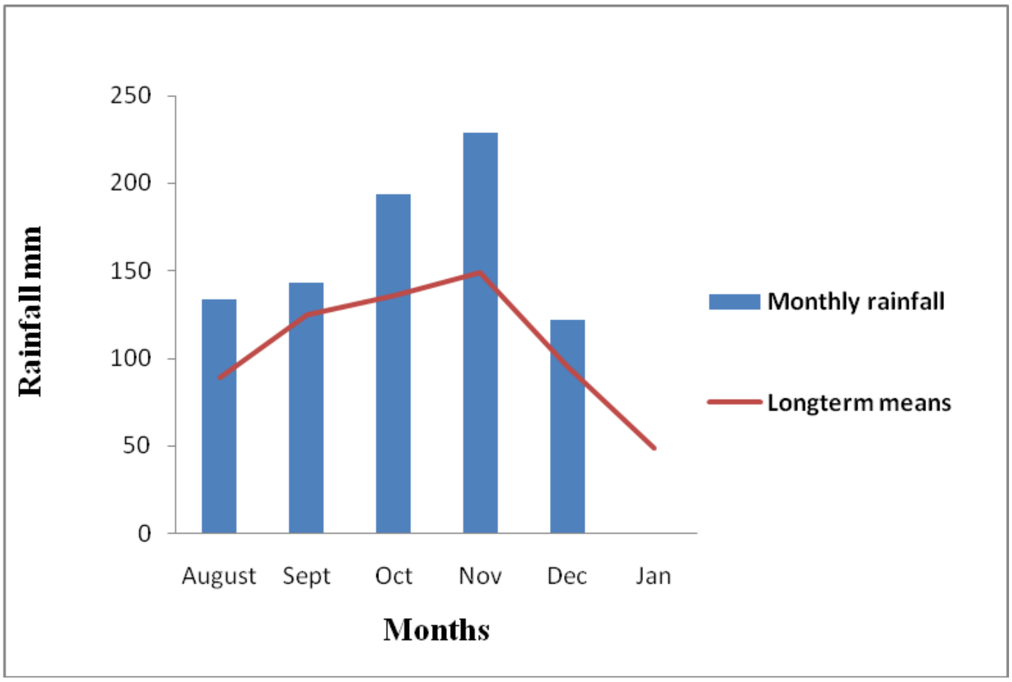

Figure 3b: Malanga rainfall pattern in 2015 short rains **(**CIAT Maseno, 2015)

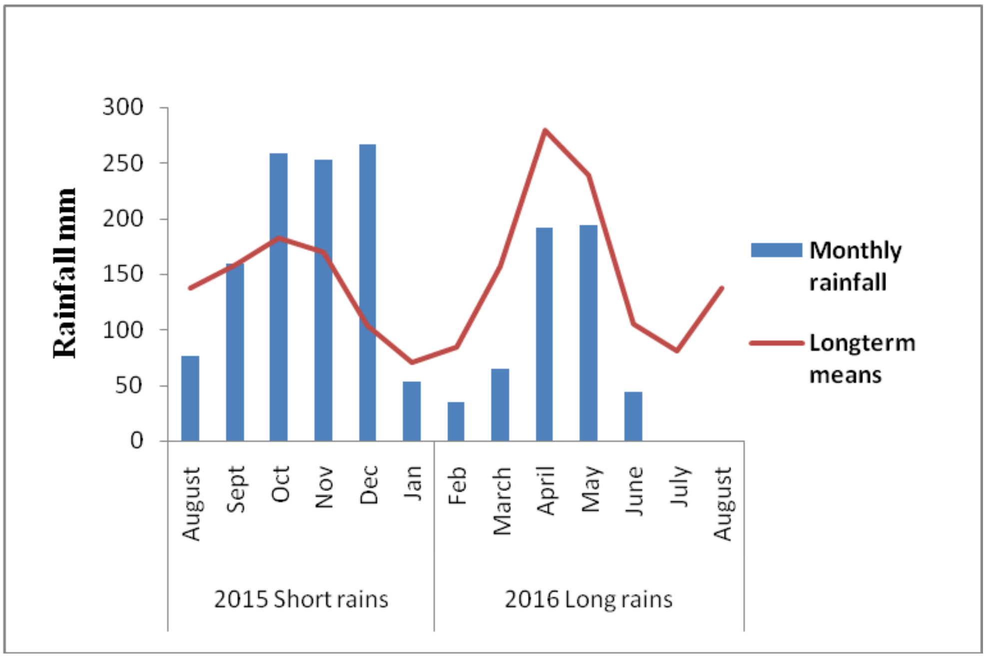

Figure 3c: Bugeng'i rainfall patterns in 2015 short rains and 2016 long rains **(**CIAT Maseno, 2016**)**

4.3 Initial Soil Properties

Soil properties prior to establishment of the experiments at the sites are presented in Table 2. The soils were acidic with a pH of 5.0, 4.8 and 5.3 at Malanga, Ebusakami and Bugeng'i respectively. The available P at all sites was below the critical value of 20 mg kg^{-1}. Among the exchangeable bases, Mg and K were low at all sites but Ca was not limiting at any of the sites. Organic C and N were below the optimum values of 2 and 0.2 % respectively (Okalebo et al., 2002).

Table 2: Soil properties of three sites (0-20 cm) Malanga and Bugeng'i at the beginning of SR season 2015 and at Ebusakami beginning of LR 2016

Soil property	**Critical values**	**Malanga**	**Bugeng'i**	**Ebusakami**
pH (1:2.5 Soil:H_2O)	5.5	5.00	4.80	5.30
Total Organic Carbon (%)	2	0.63	1.10	1.50
Total Nitrogen (%)	0.2	0.10	0.12	0.17
Available P (mg kg^{-1})	20	8.00	8.00	10.40
Exchangeable Ca (Cmol kg^{-1})	2	5.30	4.22	5.80
Exchangeable Mg(Cmol kg^{-1})	1	0.24	0.01	0.12
Exchangeable K(Cmol kg^{-1})	0.2	0.66	0.29	0.13
Sand (%)		30.00	34.00	26.00
Silt (%)		10.00	40.00	14.00
Clay (%)		60.00	26.00	60.00
Textural class		Clay	Clay loam	Clay

4.4 Available Soil Phosphorus

Table 3 illustrates effects of treatments on soil available P at 6 WAP at all the sites. There was no interaction between P fertilizer rate and crop arrangement on soil available P at all sites in both seasons. At Malanga during SR season, soil available P ranged between 6.7 mg kg^{-1} and 30 mg kg^{-1} under maize and beans planted in the same hole at 0 kg P ha^{-1} and sole maize at 60 kg P ha^{-1} respectively. The effect of P fertilizer rate on soil available P was not significant at this site but crop arrangement had a significant effect. Sole maize and sole bean crop arrangements had significantly higher soil available P than other crop arrangements, although sole beans and Mbili had no significant differences in soil available P. At Bugeng'i, soil available P ranged between 10 mg kg^{-1} and 12.87 mg kg^{-1} under conventional at 0 kg P ha^{-1} and sole maize at 60 kg P ha^{-1} respectively in the SR season. During this season, soil available P was not affected by crop arrangements, although there was a significant effect ($p < 0.001$) of P fertilizer rates on soil available P. In general soil available P increased with increasing P rate across all crop arrangements in the SR. In the LR season, at the same site, soil available P ranged from 7.33 mg kg^{-1} under sole maize at 0 kg P ha^{-1} fertilizer to 26 mg kg^{-1} under sole beans at 60 kg P ha^{-1}.

Table 3: Soil available P at Bugeng’i, Malanga and Ebusakami

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng’i 2015 SR				Bugeng’i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	8.0	12.7	15.3	12.0	10.47	11.33	12.43	11.41	12.00	17.33	21.33	16.89	9.57	10.47	11.17	10.40
Mbili	7.3	16.3	24.0	15.9	11.13	12.03	12.60	11.92	13.00	18.00	24.67	18.56	10.77	11.60	11.80	11.39
Maize+ beans (SH)	6.7	11.3	17.3	11.8	10.57	11.23	11.80	11.20	11.33	14.67	15.67	13.89	9.47	10.27	11.10	10.28
Sole beans	20.0	22.7	29.3	20.7	11.30	11.97	12.23	11.83	25.33	25.33	26.00	25.56	10.80	11.03	11.07	10.97
Sole maize	20.0	26.7	30.0	25.6	11.53	11.90	12.87	12.10	7.33	9.33	12.00	9.55	10.93	10.97	11.30	11.07
Means	12.4	17.94	23.18	17.2	11.00	11.69	12.39	11.69	13.80	16.93	19.93	16.89	10.43	10.87	11.16	10.82
Probabilities of the F test for the ANOVA for system and P rate																
CA	0.001				NS				0.004				<0.001			
P rate	NS				<0.001				0.009				0.002			
CA × P rate	NS				NS				NS				NS			
LSD																
CA	5.230				NS				6.3				0.35			
P rate	NS				0.29				3.69				0.37			
CA × P rate	NS				NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; NS = not significant; CA = Crop Arrangement

During the same season at this site, effect of crop arrangements and P rate on soil available P were significant. Sole beans had significantly higher soil available P than other crop arrangements. Averaged across crop arrangements, soil available P followed the order 60 > 30 > 0 kg P ha^{-1} although the differences between 60 and 30 kg P ha^{-1} and 0 and 30 kg P ha^{-1} did not attain statistical significance. Averaged across P rates, sole maize had significantly lower soil available P than all other crop arrangements apart from maize and beans planted in the same hole. The conventional, Mbili and maize and beans planted in the same hole recorded soil available values that did not significantly differ.

At Ebusakami in the LR season, soil available P ranged between 9.47 to 11.80 mg kg^{-1} under maize and beans planted in the same hole at 0 kg P ha^{-1} and Mbili at 60 kg P ha^{-1} respectively. Effect of crop arrangements on soil available P was significant. Mbili and sole maize arrangements had similar amount of soil available P which was significantly higher than that of other crop arrangements. Averaged across crop arrangements, the soil available P of 60 kg P ha^{-1} was significantly higher than of 0 kg P ha^{-1} but not 30 kg P ha^{-1}. However soil available P at 30 kg P ha^{-1} was significantly higher than at of 0 kg P ha^{-1}.

4.5 Beans Performance

4.5.1 Leaf area Index of Beans

The LAI of beans was very low and ranged from 0.29 to 1.51. There was no interaction between P fertilizer rates and crop arrangements on LAI of beans during both seasons at all sites (Table 4). Effects of crop arrangements and P rates on LAI of beans were also not significant at all sites in all seasons.

Table 4: Bean Leaf Area Index at Bugeng’i, Malanga, and Ebusakami

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng’i 2015 SR				Bugeng’i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	1.03	0.99	1.51	1.18	0.49	0’49	0.51	0.50	0.47	0.48	0.66	0.54	0.29	0.67	0.86	0.64
Mbili	0.76	0.79	1.27	0.94	0.48	0’48	0.54	0.50	0.52	0.69	0.79	0.67	0.42	0.74	0.88	0.68
Maize+ beans (SH)	0.78	1.32	1.42	1.17	0.50	0.52	0.56	0.52	0.35	0.77	1.01	0.71	0.40	0.64	0.67	0.57
Sole beans	0.80	0.92	1.22	0.98	0.47	0.52	0.61	0.53	0.79	0.90	0.96	0.88	0.38	0.49	0.76	0.54
Means	0.84	1.01	1.36	1.07	0.48	0.51	0.55	0.51	0.53	0.71	0.86	0.70	0.37	0.64	0.79	0.61
Probabilities of the F test for the ANOVA for system and P rate																
CA	NS				NS				NS				NS			
P rate	NS				NS				NS				NS			
CA× P rate	NS				NS				NS				NS			
LSD																
CA	NS				NS				NS				NS			
P rate	NS				NS				NS				NS			
CA× P rate	NS				NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; N.S = not significant; CA= Crop Arrangement

4.5.2 Bean Yields

Effects of treatments on bean grain yields are presented in Table 5. There was no interaction between P fertilizer rate and crop arrangement on grain yields of beans at all sites in both seasons. At Malanga, effect of crop arrangements on grain yields of beans was not significant in the SR. Bean yields, however significantly increased with increasing P rate in this season at the site. At Bugeng'i during the SR season, conventional arrangement at 0 kg P ha^{-1} had the least (0.09 t ha^{-1}) while sole beans at 60 kg P ha^{-1} had the highest (1.8 t ha^{-1}) bean grain yields. In the LR season at the same site, bean grain yields ranged between 0.17 t ha^{-1} and 0.99 t ha^{-1} under maize and beans planted in the same hole at 0 kg P ha^{-1} and sole beans at 60 kg P ha^{-1} arrangements respectively. Effect of crop arrangement on bean grain yields was not significant in the LR season but was significant during the SR season. In the SR season, when averaged across all P rates, sole bean crop had significantly higher bean grain yields than the other crop arrangements. Effect of P fertilizer on bean grain yields was significant during both seasons at Bugeng'i. Bean grain yields during the SR, at application of 60 kg P ha^{-1} was significantly higher than at 0 and 30 kg P ha^{-1} while in the LR bean yields at application of 30 and 60 kg P ha^{-1} did not differ significantly but were however significantly higher than at 0 kg P ha^{-1}.

In the LR season at Ebusakami, bean grain yields ranged from 0.02 t ha^{-1} to 0.22 t ha^{-1} under conventional at 0 kg P ha^{-1} and sole beans at 60 kg P ha^{-1} respectively. Effect of P fertilizer on beans grain yields was not significant at this site but the effect of crop arrangement was significant ($p < 0.001$) with sole beans and Mbili arrangements having significantly higher bean yields than other crop arrangements.

Table 5: Bean grain yields (t ha^{-1}) at Bugeng’i, Malanga and Ebusakami

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng’i 2015 SR				Bugeng’i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	0.24	0.30	0.38	0.31	0.09	0.14	0.22	0.15	0.18	0.33	0.34	0.28	0.04	0.05	0.06	0.05
Mbili	0.21	0.28	0.35	0.28	0.14	0.17	0.25	0.19	0.23	0.40	0.42	0.35	0.06	0.18	0.21	0.15
Maize+ beans (SH)	0.22	0.28	0.39	0.30	0.13	0.13	1.23	0.50	0.17	0.34	034	0.28	0.02	0.03	0.04	0.03
Sole beans	0.48	0.54	0.81	0.60	0.42	0.60	1.80	0.94	0.50	0.88	0.99	0.79	0.15	0.18	0.22	0.18
Means	0.29	0.35	0.48	0.37	0.20	0.26	0.87	0.45	0.27	0.49	0.52	0.43	0.09	0.11	0.11	0.10
	Probabilities of the F test for the ANOVA for system and P rate															
CA	NS				0.010				NS				<0.001			
P rate	<0.001				0.001				0.03				NS			
CA× P rate	NS				NS				NS				NS			
LSD																
CA	NS				0.240				NS				0.04			
P rate	0.054				0.070				0.16				NS			
CA × P rate	NS				NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; N.S = not significant; CA= crop Arrangement

4.6 Maize Performance

4.6.1 Leaf Area Index of Maize

There was no interaction between P fertilizer rate and crop arrangement on LAI of maize at all sites in both seasons (Table 6). LAI of maize was also not significantly affected by crop arrangement at all sites in both seasons. Leaf area index of maize at Malanga ranged from 1.09 under sole maize at 0 kg P ha^{-1} to 1.80 under Mbili at 60 kg P ha^{-1}. Averaged across all crop arrangements, the LAI increased significantly with increasing rate of P fertilizer applied apart from Ebusakami in the long rain season. At Bugeng'i during the SR season, LAI of maize ranged between 0.10 under maize and beans planted in the same hole at 0 kg P ha^{-1} and 1.93 under conventional at 60 kg P ha^{-1}. In the LR season at the same site, LAI of maize ranged from 0.25 under maize and beans planted in the same hole at 0 kg P ha^{-1} and 1.15 under Mbili at 60 kg P ha^{-1}. Effect of P fertilizer on LAI of maize was significant at Bugeng'i during both seasons. In the SR season, the LAI due to application of 60 and 30 kg P ha^{-1} did not differ significantly but both had significantly higher LAI than 0 kg P ha^{-1}. In the LR season, LAI of maize increased significantly with increasing P fertilizer rate. At Ebusakami, there was no significant effect of treatments on LAI of maize.

4.6.2 Maize Height

Maize plant heights at all sites are presented in Table 7. There was no significant interaction between P rate and crop arrangement on plant height nor were the effects of crop arrangement on plant height significant at all sites in both seasons. Effects of P fertilizer on maize plant height were however significant at all sites during both seasons. At Ebusakami (LR), Malanga (SR) and Bugeng'i (LR), plant heights due to application of 30 and 60 kg P ha^{-1} did not significantly differ but were significantly higher than at 0 kg ha^{-1}. At Bugeng'i during the SR season, plant heights increased significantly with increasing P fertilizer rates.

Table 6: Leaf Area Index of Maize

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng’i 2015 SR				Bugeng’i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	1.27	1.54	1.70	1.50	0.93	1.80	1.93	1.55	0.26	0.33	0.78	0.32	0.38	0.43	0.45	0.42
Mbili	1.40	1.59	1.80	1.60	1.13	1.32	1.33	1.26	0.27	0.31	1.15	0.33	0.38	0.39	0.44	0.41
Maize+ beans (SH)	1.30	1.49	1.67	1.49	0.10	1.17	1.22	0.83	0.25	0.41	0.54	0.32	0.36	0.38	0.41	0.38
Sole maize	1.09	1.24	1.74	1.36	1.18	1.45	1.57	1.40	0.33	0.41	0.73	0.40	0.34	0.39	0.40	0.39
Means	1.27	1.47	1.73	1.49	0.84	1.43	1.51	1.26	0.28	0.36	0.80	0.34	0.37	0.40	0.43	0.40
	Probabilities of the F test for the ANOVA for system and P rate															
CA	NS				NS				NS				NS			
P rate	<0.001				0.01				0.01				NS			
CA× P rate	NS				NS				NS				NS			
LSD																
CA	NS				NS				NS				NS			
P rate	0.170				0.16				0.06				NS			
CA× P rate	NS				NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; N.S = not significant; SR=Short rains; LR=Long rains; CA= Crop Arrangement

Table7: Maize height (cm) at (8 WAP) at Bugeng’i, Malanga and Ebusakami

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng’i 2015 SR				Bugeng’i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	75.7	95.7	105.3	92.2	114.9	142.1	151.6	136.2	123.9	140.8	144.6	136.4	139.1	149.1	149. 1	145.8
Mbili	79.1	97.1	97.5	91.2	124.8	146.2	151.9	141.0	121.0	145.4	146.1	137.7	147.0	151.8	161.6	153.5
Maize+ beans (SH)	79.2	96.8	97.5	91.2	110.0	137.1	141.8	129.6	131.0	146.6	155.3	144.4	129.0	136.7	146.4	137.4
Sole maize	72.4	82.9	85.5	80.3	128.6	154.4	160.2	147.7	132.5	142 .5	150.7	141.9	131.6	156.8	159.4	149.3
Means	76.6	93.1	96.5	88.7	119.6	145.0	151.3	139.0	127.3	143.8	149.4	140.1	136.7	149.0	154.0	147.0
Probabilities of the F test for the ANOVA for system and P rate																
CA	NS				NS				NS				NS			
P rate	0.002				<0.001				<0.001				0.003			
CA× P rate	NS				NS				NS				NS			
LSD																
CA	NS				NS				NS				NS			
P rate	9.140				5.990				9.460				10.06			
CA × P rate	NS				NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; N.S = not significant; CA= Crop Arrangement

4.6.3 Maize Grain Yields

Maize grain yields are presented in Table 8. There was no interaction between P fertilizer rate and crop arrangement on maize grain yields at Malanga during the SR season. The effect of crop arrangement was also not significant in this season. Maize grain yields ranged between 0.27 t ha^{-1} under maize and beans planted in the same hole at 0 kg P ha^{-1} and 0.69 t ha^{-1} under conventional at 60 kg P ha^{-1}. Application of 60 kg P ha^{-1} had significantly higher maize grain yields than 0 and 30 kg P ha^{-1} at Malanga during the SR season. The difference in yield between at 0 and 30 kg P ha^{-1} was however not significant.

At Bugeng'i during the SR season, maize grain yields ranged between 1.55 t ha^{-1} under sole maize at 0 kg P ha^{-1} and 5.84 t ha^{-1} under conventional at 60 kg P ha^{-1}. In the LR season, maize grain yields ranged between 0.18 t ha^{-1} and 0.78 t ha^{-1} under Mbili at 0 kg P ha^{-1} and sole maize at 60 kg P ha^{-1} respectively. There was a significant interaction between P rate and crop arrangement on maize grain yields at this site during the SR season. Averaged across crop arrangements, maize grain yields statistically followed the order 60 > 30 > 0 kg P ha^{-1} except under Mbili arrangement. Grain yields for Mbili arrangement at 0 kg P ha^{-1} were significantly lower than those at 30 kg P ha^{-1} which were however not significantly different with the yields at 60 kg P ha^{-1}. Averaged across P rates, application of 0 kg P ha^{-1} had equal amounts of maize yields across all crop arrangements, at 30 kg P ha^{-1} Mbili arrangement had the highest maize grain yields than other crop arrangements, while at 60 kg P ha^{-1} Mbili and conventional arrangements had significantly higher maize yields than sole maize and maize planted in the same hole with beans. Crop arrangement did not significantly affect maize yields at all sites except at Bugeng'i in the SR season where the mean yields for conventional and Mbili arrangements were statistically similar but were significantly higher than those of maize planted in the same hole with beans and sole maize. In the LR season, there were no significant treatment effects' on maize grain yields at this site and at Ebusakami (Table 8).

Table 8: Maize grain yields (t ha^{-1}) at Bugeng’i, Malanga and Ebusakami

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng’i 2015 SR				Bugeng’i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	0.40	0.41	0.69	0.50	2.43	4.13	5.84	4.02	0.26	0.55	0.59	0.46	3.25	3.83	4.33	3.80
Mbili	0.36	0.45	0.55	0.45	2.13	5.40	5.50	4.35	0.18	0.49	0.51	0.39	4.20	4.28	4.45	4.31
Maize+ beans (SH)	0.27	0.32	0.45	0.35	1.82	2.32	3.33	2.49	0.40	0.46	0.49	0.45	3.54	3.74	3.93	3.74
Sole maize	0.37	0.43	0.45	0.42	1.55	2.24	3.18	2.32	0.67	0.77	0.78	0.74	2.67	3.08	3.74	3.16
Means	0.35	0.40	0.54	0.43	1.98	3.52	4.37	3.29	0.41	0.56	0.57	0.51	3.42	3.75	3.82	3.75
Probabilities of the F test for the ANOVA for system and P rate																
CA	NS				0.001				NS				NS			
P rate	0.004				<0.001				NS				NS			
CA × P rate	NS				0.005				NS				NS			
LSD																
CA	NS				0.75				NS				NS			
P rate	0.10				0.46				NS				NS			
CA × P rate	NS				0.98				NS				NS			

SH = Same hole; LSD = Least significant difference of means; N.S = not significant; CA= Crop arrangement

4.6.4 Maize Biomass Yields

At Malanga maize biomass yields ranged between 3.61 t ha^{-1} under sole maize at 0 kg P ha^{-1}, and 21.11 t ha^{-1} under Mbili at 60 kg P ha^{-1} (Table 9). There was no significant interaction between P fertilizer rate and crop arrangement on maize biomass yields at this site. There was however a significant effect of crop arrangement on maize biomass yields. Mbili arrangement had significantly higher biomass yields than maize and beans planted in the same hole and sole maize. There was no significant differences in yields between Mbili and conventional arrangements. Application of 60 kg P ha^{-1} gave significantly higher maize biomass yields than 0 and 30 kg P ha^{-1} across all crop arrangements, but there was no significant difference in yields at 0 and 30 kg P ha^{-1}.

At Bugeng'i during the SR season, maize biomass yields ranged between 5.94 t ha^{-1} under sole maize at 0 kg P ha^{-1} and 36.46 t ha^{-1} under Mbili at 60 kg P ha^{-1}. There was a significant interaction between P fertilizer rate and crop arrangement on maize biomass yields during this season (Table 9). Maize biomass yields significantly increased at an increasing P rate under Mbili, while under sole maize, conventional and maize and beans planted in the same hole arrangements, application of 30 kg P ha^{-1} had no significant effect on maize biomass yields compared to 0 kg P ha^{-1} but application of 60 kg P ha^{-1} had significantly higher maize biomass yields than 30 kg P ha^{-1} under the conventional arrangement only.

At Bugeng'i in the LR season, maize biomass yields ranged between 1.18 t ha^{-1} under conventional at 0 kg P ha^{-1} and 3.72 t ha^{-1} under sole maize at 60 kg P ha^{-1}. Effect of crop arrangement on maize biomass yields was significant. Sole maize had significantly higher biomass yields than other crop arrangements. Effect of P fertilizer on maize biomass yield was not significant in this season. At Ebusakami in the LR season, the effects of P fertilizer rate and crop arrangement on maize biomass yields were not significant.

Table 9: Maize biomass yields (t ha^{-1}) at Bugeng'i, Malanga and Ebusakami

	Phosphate fertilizer rate kg ha^{-1}															
Crop	Malanga 2015 SR				Bugeng'i 2015 SR				Bugeng'i 2016 LR				Ebusakami 2016 LR			
Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	14.17	14.25	16.02	14.81	24.06	24.58	28.63	25.76	1.18	1.59	2.15	1.64	17.26	17.35	18.21	17.60
Mbili	14.02	14.64	21.11	15.92	22.10	27.52	36.46	28.69	1.24	2.61	2.97	2.27	17.55	18.16	18.38	18.03
Maize+ beans (SH)	11.53	11.00	12.94	11.82	19.52	20.34	23.99	21.28	2.16	2.46	2.56	2.39	21.42	22.67	23.67	22.59
Sole maize	3.61	4.72	7.80	5.38	5.94	7.89	10.84	8.22	3.19	3.82	4.14	3.72	19.57	20.64	21.09	20.43
Means	10.33	11.15	14.47	11.79	18.39	20.08	24.98	20.98	1.94	2.51	2.96	2.51	18.95	19.71	20.34	19.67
Probabilities of the F test for the ANOVA for system and P rate																
CA	0.002				0.001				0.004				NS			
P rate	0.010				<0.001				NS				NS			
CA × P rate	NS				0.002				NS				NS			
LSD																
CA	3.13				3.02				0.81				NS			
P rate	1.99				1.61				NS				NS			
CA × P rate	NS				3.69				NS				NS			

SH = same hole; LSD = Least significant difference of means; N.S = not significant; CA= Crop Arrangement

4.7 Relationships

4.7.1 Relationships between Available Soil P and LAI of Maize and Beans

There was a significant positive linear relationship (r = 0.75) between available soil P and LAI of maize at Bugeng’i during the SR season only but no significant relations were observed at Bugeng’i in the LR and at Malanga and Ebusakami sites in the SR and LR seasons respectively (Table 10). There was a significant positive linear relationship between soil available P and LAI of beans at Bugeng’i (r = 0.66) in the LR and at Ebusakami (r = 0.73) in the LR seasons. The relationship between these parameters was not significant at Bugeng’i and Malanga during the SR.

4.7.2 Relationships between Available Soil P and Maize Height

There was a significant positive linear relationship between available soil P and maize plant heights at Bugeng’i (r= 0.93) in SR and Ebusakami (r = 0.68) in the LR season (Table 10). The relationship between available soil P and maize plant heights at Bugeng’i in the LR and Malanga during the SR season was not significant.

4.7.3 Relationships between Available Soil P and Bean and Maize Yields

There was a significant positive linear relationship between available soil P and bean grain yields at Ebusakami (r = 0.7) in the LR and Malanga (r = 0.86) during the SR season (Table 10). However, there was no significant relationship between available soil P and bean grain yields at Bugeng’i during both seasons. There was a significant positive linear relationship (r = 0.74) between available soil P and maize grain yields at Bugeng’i during the SR season only. All other relationships between available soil P and maize grain yields at Bugeng’i, Ebusakami, and Malanga were not significant.

Table 10: Coefficients of correlation and regression equations relating soil available phosphorus to yield and yield components of maize and beans in maize-beans cropping systems

Relationship variable	R	Regression equation
Maize LAI at 6 WAP (Bugeng'i SR)	0.75*	Maize LAI = 1.7 (available P) + 9.9
Maize LAI at 6 WAP (Bugeng'i LR)	0.45 NS	Maize LAI = 12.2 (available P) +9.4
Maize LAI at 6 WAP (Ebusakami LR)	0.49 NS	Maize LAI = 10.6 (available P) +6.6
Maize LAI at 6 WAP (Malanga SR)	0.22 NS	Maize LAI = 7.5 (available P) + 5.0
Bean LAI at 6 WAP (Bugeng'i SR)	0.51 NS	Maize height = 20.2 (available P) - 96.2
Bean LAI at 6 WAP (Bugeng'i LR)	0.66*	Maize height = 1.1 (available P) + 123.4
Bean LAI at 6 WAP (Ebusakami LR)	0.73*	Maize height = 11.2 (available P) + 26.28
Bean LAI at 6 WAP (Malanga SR)	0.38 NS	Maize height = 0.2 (available P) + 86.2
Maize height at 8 WAP (Bugeng'i SR)	0.93*	Bean LAI = 8.8 (available P) + 7.1
Maize height at 8 WAP (Bugeng'i LR)	0.49 NS	Bean LAI = 17.6 (available P) + 6.4
Maize height at 8 WAP (Ebusakami LR)	0.68*	Bean LAI = 2.6 (available P) + 9.2
Maize height at 8 WAP (Malanga SR)	0.15 NS	Bean LAI = 8.8 (available P) + 6.7
Bean grain yields (Bugeng'i SR)	0.45 NS	Bean Yields = 139.7 (available P) -1337
Bean grain yields (Bugeng'i LR)	0.56 NS	Bean Yields = 20.4 (available P) - 40.1
Bean grain yields (Ebusakami LR)	0.70*	Bean Yields = 75.9 (available P) -713.4
Bean grain yields (Malanga SR)	0.86*	Bean Yields = 20.2 (available P) + 55.2
Maize grain yields (Bugeng'i SR)	0.74*	Maize Yields = 1.7 (available P) - 16.7
Maize grain yields (Bugeng'i LR)	0.09 NS	Maize Yields = - 0.003(available P) + 0.6
Maize grain yields (Ebusakami LR)	0.36 NS	Maize Yields = 0.03 (available P) + 0.8
Maize grain yields (Malanga SR)	0.39 NS	Maize Yields = 0.01 (available P) + 0.4

Where * = Significant relationship between available P and the variable at $p < 0.05$

NS = Not significant relationship

LA I= Leaf Area Index

WAP = Weeks after planting

SR = Short rains

LR = Long rains

4.8 Land Equivalent Ratio

The results of LERs are presented in (Tables 11a to 11d). Total LERs obtained across all seasons were > 1 for all the maize-beans crop arrangements at Malanga (Tables 11a) and Ebusakami (Tables 11d). Total LERs obtained at Bugeng'i were also > 1 for all the maize-beans crop arrangements in the SR apart from maize and beans planted in the same hole at 0 kg P ha^{-1} (Tables 11b). However at Bugeng'i in the LR, LERs were < 1 (Table 11c) apart from conventional and Mbili arrangements at application of 60 kg P ha^{-1}. The total LERs among the various crop arrangements did not significantly differ. Similarly the partial LERs among the various crop arrangements did not significantly differ apart from Ebusakami where the partial LERs for maize increased with increasing P rate across the crop arrangements.

Table 11a: LER at Malanga 2015 Short rains

Malanga 2015 Short rains												
	Phosphate fertilizer rate kg ha^{-1}											
	Partial LER maize				Partial LER beans				Total LER			
Crop Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	1.01	1.08	1.89	1.33	0.73	0.78	0.53	0.68	1.79	1.81	2.41	2.00
Mbili	0.95	1.43	1.52	1.30	0.64	0.73	0.70	0.69	1.23	1.64	2.22	1.58
Maize+ beans (SH	0.70	0.93	1.05	0.89	0.77	0.69	0.55	0.67	1.47	1.59	1.62	1.56
Means	0.89	1.15	1.49	0.85	0.71	0.73	0.59	0.68	1.50	1.68	1.96	1.71
Probabilities of the F test for the ANOVA for system and P rate												
C A			NS				NS			NS		
P rate			NS				NS			NS		
C A × P rate			NS				NS			NS		
LSD												
C A			NS				NS			NS		
P rate			NS				NS			NS		
CA × P rate			NS				NS			NS		

SH = same hole; LSD = Least significant difference of means; NS = not significant;
CA = Crop Arrangement

Table 11b: LER at Bugeng'i 2015 Short rains

	Bugeng'i 2015 Short rains											
	Phosphate fertilizer rate kg ha^{-1}											
	Partial LER maize				Partial LER beans				Total LER			
Crop Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	0.99	1.08	1.82	1.30	0.24	0.25	0.27	0.25	1.25	1.31	2.09	1.55
Mbili	0.91	1.35	1.44	1.23	0.27	0.41	0.61	0.43	1.18	1.63	1.85	1.55
Maize+ beans (SH	0.65	0.92	1.03	0.87	0.23	0.30	0.35	0.29	0.88	1.15	1.33	1.16
Means	0.85	1.12	1.43	1.13	0.25	0.32	0.41	0.32	1.10	1.36	1.76	1.42
Probabilities of the F test for the ANOVA for system and P rate												
CA	NS				NS				NS			
P rate	NS				NS				NS			
C A × P rate	NS				NS				NS			
LSD												
C A	NS				NS				NS			
P rate	NS				NS				NS			
CA × P rate	NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; NS = not significant; CA = Crop Arrangement

Table 11c: LER at Bugeng'i 2016 Long rains

	Bugeng'i 2016 long rains											
	Phosphate fertilizer rate kg ha^{-1}											
	Partial LER maize				Partial LER beans				Total LER			
Cropping Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	0.33	0.72	0.78	0.61	0.48	0.49	0.63	0.53	0.92	0.96	1.27	1.05
Mbili	0.28	0.43	1.65	0.79	0.43	0.47	0.50	0.47	0.63	0.76	1.15	0.85
Maize+ beans (SH	0.51	0.63	0.70	0.61	0.26	0.32	0.35	0.31	0.67	0.86	0.89	0.81
Means	0.37	0.59	1.04	0.67	0.39	0.43	0.49	0.44	0.74	0.86	1.10	0.90
Probabilities of the F test for the ANOVA for system and P rate												
C A	NS				NS				NS			
P rate	NS				NS				NS			
C A × P rate	NS				NS				NS			
LSD												
C A	NS				NS				NS			
P rate	NS				NS				NS			
CA × P rate	NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; NS = not significant; CA = Crop Arrangement

Table 11d: LER at Ebusakami 2016 Long rains

	Ebusakami 2016 long rains											
	Phosphate fertilizer rate kg ha^{-1}											
	Partial LER maize				Partial LER beans				Total LER			
Crop Arrangement	0	30	60	Means	0	30	60	Means	0	30	60	Means
Conventional	0.96	1.18	1.28	1.14	0.29	0.40	0.39	0.36	1.26	1.42	1.57	1.42
Mbili	1.03	1.06	1.26	1.12	0.04	0.22	1.32	0.53	1.09	1.24	2.58	1.66
Maize+ beans (SH	0.97	1.03	1.09	1.03	0.25	0.50	1.00	0.60	1.13	1.36	2.09	1.53
Means	0.99	1.09	1.21	1.10	0.19	0.37	0.92	0.50	1.16	1.34	2.08	1.54
Probabilities of the F test for the ANOVA for system and P rate												
CA	NS				NS				NS			
P rate	0.04				NS				NS			
CA × P rate	NS				NS				NS			
LSD												
CA	NS				NS				NS			
P rate	0.04				NS				NS			
CA × P rate	NS				NS				NS			

SH = same hole; LSD = Least significant difference of means; NS = not significant; CA = Crop Arrangement

4.9 Cost - Benefit Analysis

Results of cost-benefit analysis are shown in Tables 12a to 12d. The costs across all the sites are similar because the same treatments were repeated at all the sites. Across all the sites sole maize at 0 kg P ha^{-1} recorded the least cost (Ksh 69,333) while conventional and Mbili both at 60 kg P ha^{-1} recorded the highest costs (Ksh 119,718). There were negative financial returns across all the treatments at Malanga (Table 12a), Ebusakami (Table 12b), and Bugeng'i in the LR season (Table 12d). However positive financial returns were recorded in the SR at Bugeng'i with Mbili arrangement at 60 kg P ha^{-1} recording the highest financial returns (Ksh 161,760). All treatments recorded BCR values of < 2 with the highest BCR (1.27) obtained with Mbili at 30 kg P ha^{-1}.

Table 12a: Cost, benefits and cost - benefit ratios of treatments at Malanga 2015 short rains

Treatment		Costs /ha (KSh/ha)	Gross benefits (KSh/ha)	Net benefits (KSh/ha)	BCR
1. Sole bean	0P	84069.33	36000	-48069.3	-0.57
2. Sole bean	30P	94520.33	40500	-54020.3	-0.57
3. Sole bean	60P	104971.30	60750	-44221.3	-0.42
4. Maize, bean	0P	94566.00	51750	-42816.0	-0.45
5. Maize, bean	30P	105017.00	55140	-49877.0	-0.47
6. Maize, bean	60P	115468.00	71850	-43618.0	-0.38
7. Conventional	0P	98816.00	73310	-25506.0	-0.26
8. Conventional	30P	109276.00	78370	-30897.0	-0.28
9. Conventional	60P	119718.00	95640	-24078.0	-0.20
10. Mbili	0P	98816.00	61530	-37286.0	-0.38
11. Mbili	30P	109267.00	79050	-30217.0	-1.28
12. Mbili	60P	119718.00	104870	-14848.0	-0.12
13. Sole maize	0P	69333.00	22670	-46663.0	-0.67
14. Sole maize	30P	79784.00	27570	-52214.0	-0.65
15. Sole maize	60P	90235.00	34580	-55655.0	-0.62

Table 12b: Cost, benefits and cost - benefit ratios of treatments at Ebusakami 2016 long rains

Treatment		Costs/ha (Ksh./ha)	Gross benefits (Ksh./ha)	Net benefits (Ksh./ha)	BCR
1. Sole Beans	0P	84069.33	11250.0	-72819.3	-0.87
2. Sole Beans	30P	94520.33	13500.0	-81020.3	-0.86
3. Sole Beans	60P	104971.30	16500.0	-88471.3	-0.84
4. Maize, bean	0P	94566.00	55638.9	-38927.1	-0.41
5. Maize, bean	30P	105017.00	58750.9	-46266.1	-0.44
6. Maize, bean	60P	115468.00	62552.6	-52915.5	-0.46
7. Conventional	0P	98816.00	55733.8	-43082.3	-0.44
8. Conventional	30P	109276.00	57824.1	-51443.0	-0.47
9. Conventional	60P	119718.00	59746.6	-59971.5	-0.50
10. Mbili	0P	98816.00	55664.8	-43151.2	-0.44
11. Mbili	30P	109267.00	68909.8	-40357.2	-0.37
12. Mbili	60P	119718.00	72245.8	-47472.3	-0.40
13. Sole maize	0P	69333.00	50772.1	-18560.9	-0.27
14. Sole maize	30P	79784.00	52157.8	-27626.2	-0.35
15. Sole maize	60P	90235.00	52810.9	-37424.1	-0.41

Table 12c: Cost, benefits and cost - benefit ratios of treatments at Bugeng'i 2015 short rains

Treatment	Costs /ha (Ksh./ha)	Gross benefits (Ksh./ha)	Net benefits (Ksh./ha)	BCR
1. Sole bean 0P	84069.33	31500	-52069.3	-0.62
2. Sole bean 30P	94520.33	45000	-59471.3	-0.57
3. Sole bean 60P	104971.30	60000	-65373.3	-0.52
4. Maize, bean 0P	94566.00	126550	32484.0	0.35
5. Maize, bean 30P	105017.00	145010	30042.0	0.26
6. Maize, bean 60P	115468.00	195780	59910.0	0.44
7. Conventional 0P	98816.00	156690	58374.0	0.59
8. Conventional 30P	109276.00	216400	97182.0	0.82
9. Conventional 60P	119718.00	288520	148400.0	1.06
10. Mbili 0P	98816.00	150210	51894.0	0.53
11. Mbili 30P	109267.00	271110	151892.0	1.27
12. Mbili 60P	119718.00	301880	161760.0	1.15
13. Sole maize 0P	69333.00	73270	4437.0	0.06
14. Sole maize 30P	79784.00	89500	-235.0	-0.00
15. Sole maize 60P	90235.00	134280	23643.0	0.21

Table 12d: Cost, benefits and cost - benefit ratios of treatments at Bugeng'i 2016 long rains

Treatment	Costs /ha (Ksh./ha)	Gross benefits (Ksh./ha)	Net benefits (Ksh./ha)	BCR
1. Sole bean 0P	84069.33	7500	-76569.3	-0.91
2. Sole bean 30P	94520.33	37500	-57020.3	-0.60
3. Sole bean 60P	104971.30	66000	-38971.3	-0.37
4. Maize, bean 0P	94566.00	31730	-62836.0	-0.66
5. Maize, bean 30P	105017.00	37130	-67887.0	-0.64
6. Maize, bean 60P	115468.00	43700	-71768.0	-0.62
7. Conventional 0P	98816.00	31270	-67546.0	-0.68
8. Conventional 30P	109276.00	46250	-63017.0	-0.58
9. Conventional 60P	119718.00	51850	-67868.0	-0.57
10. Mbili 0P	98816.00	25710	-73106.0	-0.74
11. Mbili 30P	109267.00	53180	-56087.0	-0.51
12. Mbili 60P	119718.00	56790	-62928.0	-0.53
13. Sole maize 0P	69333.00	31580	-37753.0	-0.54
14. Sole maize 30P	79784.00	36070	-43714.0	-0.55
15.Sole maize 60P	90235.00	37380	-52855.0	-0.59

CHAPTER FIVE

DISCUSSION

5.1 Available Soil Phosphorus

The available P levels were generally low (Table 3). Most of the treatments did not achieve the critical P level of 20 mg kg^{-1} that is considered adequate for most crops in Kenya (Okalebo et al., 2002). These low P levels, despite application of P fertilizers, are attributable to P-fixation which is common in the soils of western Kenya (Nziguheba et al., 2016). In these acid soils (Table 2), soluble P applied as fertilizer is precipitated by reactions with Al and Fe thus rendering most of it unavailable (Kisinyo et al., 2014). The available soil P at all sites during the SR and LR seasons at 6 WAP generally increased with increasing P rates applied at all the sites (Table 3). These results are to be expected because triple superphosphate, which was used as the P source in this study, is very soluble and therefore released phosphorus in the soil within a short time (Opala et al., 2010). Higher rates of fertilizer released higher quantities of P in solution hence enhancing available soil P. Similar findings of increased available soil P with increasing P rate were reported by Opala et al. (2012).

Sole maize generally recorded significantly higher soil available P levels than other crop arrangements apart from the Bugeng'i site in the SR (Table 3). The higher available P under sole maize compared to intercrops was due to lower uptake of P in the sole crops where the plant population was lower than in the intercrops where competition and therefore uptake of P was higher. The mean values of available soil P at Bugeng'i were generally higher in the LR than SR season (Table 3) likely because of droughts during the LR season (Figure 3c) that led to reduced uptake of available P by plants. Therefore high amounts of P were retained in the soils. In addition, P fertilizer is known to have a high residual effect in soils (Sanchez and Uehara, 1980). Therefore, some of the P applied in the SR was still in the soil when fresh additions were applied in the LR and consequently cumulatively gave higher available P in the LR.

5.2 Bean Performance

5.2.1 Leaf Area Index of Beans

The LAI of beans was not significantly affected by crop arrangement and P rates at all sites in both seasons (Table 4). This is likely due the fact that maize growth was very poor with low LAI < 1(Table 6) and hence did not shade the beans. Competition for light was therefore not a major factor among the crop arrangements as would have been expected. The observed LAIs in all cases were however very low with the highest at 1.51 while the optimum for beans is approximately 4 (Mengel et al., 2001). High bean LAI is responsible for higher absorption rates of solar radiation due to larger leaf surface area thus highly influence biomass accumulation (Tsubo et al., 2001). The low LAI in this study therefore adversely affected the final yields. These low LAIs are attributed to the generally heavy rains that physically damaged the bean leaves.

5.2.2 Bean Yields

The average bean yields (0.37 t ha^{-1} at Malanga, 0.45 and 0.42 t ha^{-1} at Bugeng'i in the SR and LR respectively and 0.10 t ha^{-1} at Ebusakami) were lower than the potential yield of 3 t ha^{-1} (Namugwanya et al., 2014). These poor yields, as earlier explained for the low LAIs, are attributed to the generally adverse weather conditions during the study period. In the SR season, heavy rain physically damaged the bean leaves and in addition the excess rain could have led to poor aeration around the beans root zones due to water-logging hence poor utilization of nutrients. In the LR severe drought limited plant growth. It was assumed that they would be able to fix their own N to support their growth but due to high acidity of these soils, the generally low soil P levels coupled with the fact that beans are inherently poor N fixers (Beebe et al., 2012) the beans are unlikely to have fixed enough N for their use (Attar et al., 2012).

The highest bean yields were obtained in the sole bean crops mainly because of their higher plant population (202,020 plants ha^{-1}) compared the intercrops (88, 888 plants ha^{-1}) but also due to reduction in yields per plant due to competition, in the intercrops. Other crop arrangements did not generally differ significantly in bean yields. This is consistent with the lack of significant differences in LAI observed earlier. Effect of P fertilizer on bean grain yields was significant during both seasons at Bugeng'i and at Malanga with higher P rates generally giving higher yields. This response to P application confirms that the initial available soil P at these sites (8 mg kg^{-1}) was deficient. These results are consistent with those of Kajumula and Muhamba, (2012) in Tanzania who observed that under low P availability, beans suffer from reduced photosynthesis rate thus leading to low grain yield, unlike for those at high P levels.

There was a significant positive linear relationship between available soil P and bean grain yields at Ebusakami (r = 0.7) in the LR and Malanga (r = 0.86) during the SR season (Table 10) which indicates that P was important in determining yields at these sites. However, there was no significant relationship between available soil P and bean grain yields at Bugeng'i during both seasons indicating factors other than P were more limiting to bean growth at this site.

5.3 Maize Performance

5.3.1 Leaf area Index of Maize

Crop arrangements had no effect on maize LAI at all sites during both seasons (Table 6). This is consistent with the fact that maize, which was the main crop in the intercrop, was taller than the beans and therefore was not affected by the beans in competing for light. Worku (2008) reported that bean arrangement didn't influence growth of maize in Ethiopia and attributed this to the less aggressive nature of bean over maize. The observed LAIs in all cases were however very low with the highest at 1.93 while the optimum for maize is approximately 5 (Mengel et al., 2001). This again is attributed to adverse weather conditions and other constraints that prevailed during the study period (Figures 3a-3c). The trends on the effect of P rates on LAI of maize were similar to those of beans with generally LAI increasing with P rate. There was also a significant positive linear relationship between soil available P and LAI of maize at Bugeng'i during the SR season only (Table 10) probably because the pH was lowest at this site (Table 2) which reinforces the fact that P was more limiting at these sites due to soil acidity. Similar responses to P fertilizer have been demonstrated by several studies in western Kenya (Opala et al., 2012; Nyambati and Opala, 2014, Nziguheba et al., 2002).

5.3.2 Maize Plant Heights

Crop arrangement had no significant effect on maize plant heights at all sites during both seasons (Table 7). As explained for LAI, maize was the main crop and being taller than beans was not expected to be adversely affected by presence of beans. These results are consistent with those by Matusso (2011) in Central Kenya who reported that crop arrangement in a maize-soybean intercrop did not affect maize plants. Maize plant heights at all sites in both seasons significantly followed the order 60 = 30 > 0 kg P ha^{-1} across all cropping systems (Table 7). There was also a significant positive linear correlation between soil available P at 6 WAP and maize plant heights (Table 10) at Bugeng'i in the SR and Ebusakami during LR seasons which is an indicator that application of phosphate fertilizer enhances maize physiological processes and hence vegetative growth (Shepherd et al., 1996).

5.3.3 Maize Yields

Maize grain yields were higher in the SR (mean of 3.29 t ha^{-1}) than the LR (mean of 0.51 t ha^{-1}) at Bugeng'i (Table 8). The variation in grain yield observed between the two consecutive seasons at Bugeng'i is attributed mainly to the differences in rainfall. In the SR season, the rainfall was unusually high (1065 mm) and well distributed during the growing period of maize and the uptake of nutrients by the crop was thus not inhibited. However, in the LR season at this site, the rainfall was low and poorly distributed (Figure 3c). Only 529 mm of rainfall was recorded in this season, with only 30 mm being received in June, at the critical stage when the crop was tasselling and no rainfall was recorded in July. Uptake of nutrients was therefore very likely constrained by low available moisture in the LR season at Bugeng'i leading to very low yields.

At Ebusakami, rain was much higher (792 mm) (Figure 3a) than at Bugeng'i in the LR and was well distributed hence the mean yields were also higher (3.75 t ha^{-1}). At Malanga, the rainfall received was adequate for maize growth but the mean maize yields were very low (0.43 t ha^{-1}) because this site was infested with the parasitic striga weed. Striga has been reported to decrease yields of maize by as much as 100% in western Kenya (Atera, et al., 2013; Vanlauwe et al., 2008). In addition, soil acidity (Malanga pH =5.0, Bugeng'i pH =4.8 and Ebusakami pH =5.3) is likely to have been a problem at all the sites. Under such low pH levels (pH < 5.5), Al toxicity limits root growth and crops may not adequately respond to applied fertiliser inputs (Kisinyo et al., 2014; Marschner, 1985).

Crop arrangement did not significantly affect maize yields at all sites except at Bugeng'i in the SR season where the mean yields for conventional and Mbili arrangements were statistically similar but significantly higher than those of sole maize and maize planted in the same hole with beans arrangements. This was attributed to the advantages of appropriate crop arrangements in these systems, hence reduced interspecies competition between maize and beans. This led to better nutrient absorption and utilisation. Similar results were reported by Mattuso et al. (2014), Mucheru-Muna et al. (2010) in the central highlands of Kenya and Woomer et al. (2004) in western Kenya.

Application of 60 kg P ha^{-1} had significantly higher maize grain yields than at 0 and 30 kg P ha^{-1}at Malanga and Bugeng'i during the SR season for most crop arrangements confirming the need to apply higher rates of P at these sites. Similar increases in maize yield have been demonstrated in many other studies in western Kenya (Nziguheba et al., 2016; Opala et al., 2012; Okalebo et al., 2007; Nziguheba et al., 2002). There was no significant effect of P rate on maize yields at Bugeng'i and Ebusakami in the LR season. The available P was also not significantly related to maize yields at these sites (Table 10). Phosphorus was limiting at these sites and hence response to P was expected. The lack of response is attributed mainly to lower than average rainfall and therefore water became a more limiting factor than P for maize growth especially at Bugeng'i and this confounded the treatment effects.

5.4 Total Land Equivalent Ratio of Maize and Beans

The total LER at all sites showed yield advantage (LER >1) of intercropping maize and beans irrespective of crop arrangement, over component sole crops apart from the Bugeng'i site in the LR (Table 11c). The better performance of the intercrop is attributed to more efficient resource use and resource complementarity hence an increased and diverse productivity per unit area of production compared to sole cropping (Matusso et al., 2014). Tsubo et al. (2001) and Tungani et al. (2002) have reported that intercrops intercept more photosynthetic active radiation than sole crops due to higher LAI of the intercrops. The low LERs (< 1) at Bugeng'i in the LR are attributed to possible competition for water by the component crops. The intercrops had higher plant water requirements and hence consumed more water than sole crops (section 3.4). The sole crops therefore performed better under the water stress than the intercrops in this season that received below average rainfall hence the possible better nutrient utilization under these systems.

5.5 Benefit-Cost Analysis

Cost-benefit analysis indicated that there were negative financial returns accrued for all treatments at all sites, excluding Bugeng'i in the SR seasons (Tables 12a -12d). The negative returns were mainly due to high costs of production that could not be compensated through the sale of the low yields of maize and bean (Table 5 and 8). Some positive financial returns were however obtained at Bugeng'i in the SR with Mbili arrangement at 60 kg P ha^{-1} recording the highest financial returns (Table 12c). This was attributed to better yields that were achieved by this crop arrangement in this season. Similar results were reported by Mucheru-Muna et al. (2010) and Nekesa et al. (2005) in Central Kenya. Sole maize at 0 kg P ha^{-1} had the least costs (Tables 12a -12d), because of lower inputs costs (no fertilizer was used) and less time that was needed to perform field operations. Conventional and Mbili, both at 60 kg P ha^{-1}, recorded the highest costs because of high fertilizer and labour costs in these crop arrangements. Mucheru-Muna et al. (2010) pointed out that Mbili arrangement requires more careful planting and weeding operations, which necessitate more time and labour.

All treatments recorded BCR values of < 2 (Tables 12a -12d) because of low yields and low prices offered for the crops against high costs of production. Thus although the LER analysis generally showed advantage of the intercrop over the monocrops, economic evaluation painted a different picture. The general rule is that a BCR of at least 2 is attractive to farmers (FAO, 2006b). None of the treatments in the present study met this threshold and therefore none of them is likely to be adopted by farmers. Similar results that showed technologies having agronomic effectiveness but being economically unattractive have been reported by other workers in western Kenya (e.g. Opala et al. 2010; Jama et al., 1997).

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1 Summary of Main Findings

The available P levels were generally low at all the sites therefore making them ideal for replenishment with phosphate fertilizers because crops respond to P in such soils. The available P in the soils generally increased with increasing P rate at all the sites but the increase did not achieve the critical level of 20 mg kg^{-1} for most of the treatments likely due to P fixation in the soils and this could be one of the factors that contributed to the low maize and bean yields.

The LAI of beans was not significantly affected by crop arrangement and P rate at all sites in both seasons. Leaf area index of maize was also not significantly affected by crop arrangement at all sites in both seasons but it increased significantly with increasing rate of P fertilizer applied at Bugeng'i in the LR. The observed LAIs in all cases were very low with the highest at only 1.51 and 1.93 for beans and maize respectively. This could have contributed to the low yields of the crops because LAI is positively correlated to yields. Constraints such as drought, soil acidity and deficiencies of other nutrients are likely to have been responsible for the low LAI of both maize and beans.

The yields of both crops were below their potential. The poor yields of beans are attributed to the generally adverse weather conditions during the study period. In the SR season heavy rain led to poor nutrient absorption by the beans due to water-logging and reduced LAI due to physical damage on leaves while in the LR, severe drought limited plant growth. In addition, the beans could have been affected by low levels of soil N at all sites given that they were not top-dressed. The highest beans yields were obtained in the sole bean crops mainly because of their higher plant population compared to the intercrops but also likely due to reduction in yields per plant due to competition in the intercrops. Drought adversely affected maize growth mainly in the LR at Bugeng'i. In addition, soil acidity (pH < 5.5) is likely to have been a problem at all the sites. In acidic soils, Al toxicity limits root growth and crops may not adequately respond to applied fertiliser inputs. Striga weed also adversely affected maize growth at Malanga.

There was no significant effect of P rate on maize yields at Bugeng'i and Ebusakami in the LR season. The available P was also not significantly related to maize yields at these sites. Phosphorus was limiting at these sites and hence response to P was expected. The lack of response is attributed mainly to lower than average rainfall and therefore water became a more limiting factor than P for maize growth. This is in contrast to the SR season at Bugeng'i when with adequate rainfall, there were significant effects of crop arrangement and the mean yields for conventional and Mbili arrangements were statistically similar but were significantly higher than those of maize planted in the same hole as beans. Significant effects of P rates were also observed with yields increasing with P rate. In addition, the available P was significantly related to the LAI and yields of maize in the SR season unlike in the drier LR season at the same site. This further buttresses the fact that when rainfall was adequate, uptake of nutrients such as P was not limited unlike under drier conditions.

The total LER at all sites showed yield advantage (LER >1) of intercropping maize and beans, irrespective of crop arrangement, over component sole crops apart from the LER at Bugeng'i in the LR. The better performance of the intercrop is attributed to more efficient resource use and resource complementarily. The low LERs (< 1) at Bugeng'i in the LR are attributed to competition for water by the component crops. The intercrops had higher plant population and hence consumed more water than sole maize crops. The sole crops therefore performed better under the water stress than the intercrops in this season that received below average rainfall. Although the LER analysis generally showed advantage for the intercrop over the monocrops, economic evaluation using BCR painted a different picture. None of the treatments met the threshold BCR of at least 2 to be economically attractive and therefore none of them is likely to be adopted by farmers.

6.2 Conclusion and Recommendations

1. The yields of component crops did not significantly differ among crop arrangements under drought conditions or when constraints such as striga weed limited maize growth. However, when conditions were more favourable e.g. in the SR at Bugeng'i, conventional and Mbili arrangements had similar yields but were superior to maize and beans planted in the same hole. Arrangements such as Mbili may however not be easily accepted by farmers unless its superiority in agronomic terms is unequivocally demonstrated.
2. Intercropping was beneficial in the SR when rain was generally good but not in the LR especially at Bugeng'i when rain was limiting. Therefore, intercropping should only be recommended in areas with adequate rainfall.
3. Several factors, such as acidity, striga and drought contributed to low yields of maize and beans crops at specific sites and seasons. Unless such stresses are removed, then the crops are unlikely to respond to applied nutrients as was demonstrated by lack of significant relationships between available P and most parameters of growth in this study.
4. Financial returns were generally low because of high input costs and low output prices. The returns could be improved if fertilizer inputs are subsidized by the Kenya Government. Government should also consider increasing output prices of the maize it buy through the National Cereals and Produce Board.

5. Since none of the tested technologies achieved a BCR of > 2, they should not be upscaled to farmers especially under conditions similar to those of this study. Indeed, this study reflects the most challenging issue currently facing farmers in Kenya i.e. climate change. That the short rains, which are traditionally lower the long rains, were in this study higher reflects the unpredictable nature of the farming conditions that farmers face. To

mitigate this, climate smart agriculture with drought tolerant crops such as sorghum is being proposed for the region.

6. For further research, the following are recommended;
    - Studies should be carried out to determine the effects of the treatments in the present study under controlled conditions to take care of unpredictable environmental conditions.
    - Sensitivity analyses should, as part of economic analyses be conducted to determine the minimum yields of maize and beans that should be obtained and at what phosphate fertilizer rate, in order to break even economically for each of the tested technologies.

REFERENCES

Atera, E.A., T., Ishii, J.C., Onyango, K., Itoh, T., Azuma (2013). Striga Infestation in Kenya: Status, Distribution and Management Options. Sustainable Agriculture Research. 2:99-108.

Attar, H.A., D., Blavet, E.M., Selim, M.T., Abdelhamid, J.J., Drevon (2012). Relationship between Phosphorus and nitrogen fixation by common beans (Phaseolus vulgaris L.). Under drip irrigation.Int.J.Environ.Sci.Technol. 9:1-13.

Beebe, S., I., Rao, C., Mukankusi, R., Buruchara (2012). Improving Resource Use Efficiency and Reducing Risk of Common Bean Production in Africa, Latin America, and the Caribbean A. 8: 118-134.

Blanco, F.F., M.V., Folegatti (2003). A new method for estimating the leaf area index of cucumber and tomato plants. Horticultura Brasileira, Brasília. 21, 4:666-669.

Brintha, I., T.H., Seran (2009). Effect of paired row planting of radish (*Raphanus sativus*L.) intercropped with vegetable amaranthus (*Amaranthus tricolor* L.) on yield components of radish in sandy regosol. Journal of Agricultural Science. 4, 19-28.

Buresh, R.J., P.C., Smithson, D.T., Hellums (1997). Building soil phosphorus capital in Africa. In: Buresh et al. (Eds). Replenishing soil fertility in Africa. Soil Science society of America, SSSA Special Publication No 51. Madison Wisconsin, USA, pp.111-149.

Broughton, W. J., G., Hern´andez, M., Blair, S., Beebe, P., Gepts, J., Vanderleyden (2003). Beans (Phaseolus spp) - model food legumes. Plant and soil science. 252:55-128.

Cardooso, E.J.B.N., M.A., Nogueira, S.M.G., Febraz (2007). Biological N Fixation and mineral N in Common Bean-Maize intercropping or sole cropping in South Eastern Brazil. Expl Agric. 43:319-330.

CIAT. (2015). Centre for International Tropical Agricultural Research, Maseno, Kenya. Annual environmental weather reports.

CIAT. (2016). Centre for International Tropical Agricultural Research, Maseno, Kenya. Annual environmental weather reports.

CIMMYT. (1988). From Agronomic Data to Farmer Recommendations. An Economic Training Manual Completely Revised Edition, Mexico D.F.

FAO (2006a). New_LocClim climate database and interpolation software. Available at: ftp: //ext-ftp.fao.org/SD/Reserved/Agromet/New_LocClim/ (accessed 22 November 2017).

FAO (2006b). Plant nutrition for food security: A guide for integrated nutrient management. Fertilizer and Plant Nutrition Bulletin no. 16. Rome, Italy.

GenStat (2010). The GenStat Teaching Edition. GenStat Release 7.22 TE. Copyright (2008), VSN International Ltd.

Ghosh, P.K., A.K., Tripathi, K.K., Bandyopadhyay, M.C., Manna (2009). Assessment of nutrient competition and nutrient requirement in soybean/sorghum intercropping system. Europ. J. Agronomy. 31:43–50.

Giller, K.E. (2001). Nitrogen fixation in tropical cropping systems. Wallingford, CABI International, Wallingford, UK. 2nd ed.

Giller, K.E., G., Cadisch, C., Ehaliotis, E., Adams (1997). Building Soil Nitrogen Capitalin Africa.

Gudu, S.O., J.R., Okalebo, C.O., Othieno, P.A., Obura, D.O., Ligeyo, D., Schulze, C., Johnson (2005). Response of five maize genotypes to nitrogen, phosphorous and lime on acid soils of western Kenya. African Crop Science Conference Proceedings. 7, 1109-1115.

Hiebsch, C.K. (1980). Principles of Intercropping. Effect of N Fertilization and Crop Duration on Equivalency Ratios in Intercrops versus Monoculture Comparisons. PhD thesis, North Carolina State University, Raleigh.

Jama, B., R.A., Swinkels, R.J., Buresh (1997). Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. Agron. J. 89:597-604.

Jaetzold, R., H., Schimdt, B., Hornetz, C., Shisanya (2009). Farm management handbook of Kenya Volume II. Natural conditions and farm management information. 2nd Edition, part A West Kenya, subpart A2 Nyanza Province. Ministry of Agriculture, Nairobi, Kenya.

Jaetzold, R., H., Schmidt, B., Hornetz, C., Shisanya (2005). Farm management handbook of Kenya Volume I. Natural conditions and farm management information. 2nd Edition, part A West Kenya, subpart A1 Western Province. Ministry of Agriculture, Nairobi, Kenya.

Kajumula, S.M., and G.T., Muhamba (2012). Evaluation of Common Bean (Phaseolus vulgaris L.) Genotypes for Adaptation to Low Phosphorus. ISRN Agronomy Volume 2012, 9 pages doi:10.5402/2012/309614.

Kisinyo, P.O., P.A., Opala, S.O., Gudu, C.O., Othieno, J.R., Okalebo, V., Palapala, A.N., Otinga (2014). Recent advances towards understanding and managing Kenyan acid soils for improved crop production. African Journal and Agricultural Research. 9:2397-2408.

Kitonyo, O.M., G.N., Chemining’ wa, J.W., Muthomi (2013). Productivity of farmer-preferred maize varieties intercropped with beans in semi-arid Kenya. International Journal of Agronomy and Agricultural Research (IJAAR). 3:6-16.

Liebman, M. (1995). Polyculture cropping systems in agro ecology: The science of sustainable agriculture. In: M. A. Altieri (eds.). Intermediate Technology Publications, London. pp. 205-218.

Marschner, H. (1995). Mineral Nutrition of Higher Plants, Academic Press, London, UK,

Mal´ezieux, E., Y., Crozat, C., Dupraz, M., Laurans, D., Makowski, H., Ozier-Lafontaine, B., Rapidel, S., de Tourdonnet, M.,Valantin-Morison (2009). Mixing plant species in cropping systems: Concepts, tools and models. A review Agron. Sustain. Dev. 29 43–62.

Matusso, J.M.M., J.N., Mugwe, M., Mucheru-Muna **(**2014). Potential role of cereal-legume ntercropping systems in integrated soil fertility management in smallholder farming systems of Sub-Saharan Africa. Research Journal of Agriculture and Environmental Management. 3: 162-174.

Matusso, J. M.M. (2011). Effects of Different Maize (*Zea mays L.*) – Soybean *(Glycine max (L.)* Merrill). Intercropping on yields and soil properties in two contrasting sites of Embu and Meru counties, KENYA. A Thesis Submitted in Partial Fulfilment of the Requirements for the Award of the degree of Master of Science (Integrated Soil Fertility Management) in the School of Agriculture and Enterprise Development of Kenyatta University.

Mead, R., and R.W., Willey (1980). The Concept of a Land Equivalent Ratio and advantages in yields from Intercropping. Exp. Agric. 16:217-228.

Mengel, K., E.A., Kirkby, H., Kosegarten, T., Appel (2001). Principles of plant nutrition. Dordrecht. Kluwer Academic.

Morgado, L.B., and R.W.,Willey (2008). Optimum plant population for maize-bean intercropping system in the Brazilian semi-arid region. Sci. Agric. (Piracicaba, Braz.). 5: 474-480.

Mugendi, D. N., B.S., Waswa, M.W., Mucheru-Muna, J. M., Kimetu (2011). Strategies to Adapt, Disseminate and Scale Out Legume Based Technologies. In: A. Bationo *et al.* (eds.), Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management. DOI 10.1007/978-94-007-1536-3_3, Springer Science+Business Media B.V. 2011, pp 85-116.

Mucheru-Muna, M., P., Pypers, D., Mugendi, J., Kungu, J., Mugwe, R., Merckx, B., Vanlauwe (2010). A staggered maize-legume intercrop arrangement robustly increases yields and economic returns in the highlands of Central Kenya. Field Crops Research. 115:132-139.

Mugwe, J., D., Mugendi, M., Mucheru-Muna, R., Merckx, J., Chianu, B., Vanlauwe (2009). Determinants of the Decision to Adopt Integrated Soil Fertility Management Practices by Smallholder Farmers in the Central Highlands of Kenya. Expl Agric. (2009), volume 45, pp. 61–75.

Nandwa, S. M., A., Bationo, S. N., Obanyi, I. M., Rao, N., Sanginga, B., Vanlauwe (2011). Inter and Intra-Specific Variation of Legumes and Mechanisms to Access and Adapt to Less Available Soil Phosphorus and Rock Phosphate. In: A. Bationo et al. (eds.), Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management. DOI 10.1007/978-94-007-1536-3_3, Springer Science+Business Media B.V. 2011, pp 47-83.

Namugwanya, M., S.T., John, O., Erasmus, N.M., Drake, A.B., Twaha (2014). Development of Common Bean (*Phaseolus Vulgaris* L.) Production under Low Soil Phosphorus and Drought in Sub-Saharan Africa. Journal of Sustainable Development. Vol. 7: 5.

Nyambati R.O., and P.A., Opala (2014). An agronomic and economic evaluation of integrated use of Calliandra callothyrsus and maize stover with urea in western Kenya. Am. J. Exp.Agric.4 (1):80-89.

Nekesa, A.O. (2007). Effect of minjingu phosphate rock and agricultural lime on maize, groundnut and soybean yields on acid soils of western Kenya. M. Phil. Thesis, Moi University, Eldoret, Kenya.

Nekesa, A. O., C.O., Okalebo, M.N., Othieno, M., Thuita, M.J., Kipsat, A., Bationo, N., Sanginga, J., Kimettu, B., Vanlauwe (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. Vol. 7. pp.1121-1128.

Ndung'u, K.W., T.K., Kwambai, J., Barkutwo, P., Omollo, M., Kamidi, J., Mulati (2005). Effect of maize and bean spatial arrangements on bean yields in north rift Kenya. African Crop Science Conference Proceedings. 7: 1211-1215.

Nziguheba, G., S., Zingore, J. Kihara (2016). "Phosphorus in smallholder farming systems of sub-Saharan Africa: implications foragricultural intensification," Nutrient Cycling in Agroecosystems. 104:321–340.

Nziguheba, G., R., Merckx, C.A., Palm, P., Mutuo (2002). Combining Tithonia diversifolia and fertilizers for maize production in phosphorus deficient soil in Kenya.Agrofor. Syst. 55: 165-174.

Odendo, M., J., Ojiem, A., Batiano, M., Mudeheri (2007). On-farm evaluation and scaling-up of soil fertility management in Western Kenya pp 969- 978. In Batiano, A., B. Waswa, J. Kihara, and J. Kimetu (eds.) Advances in integrated soil fertility Management in sub-Sahara Africa: Challenges and opportunities. Springer. A.A. Dordrecht, the Netherlands.

Odhiambo, G.D., and E.S., Ariga (2001). Effect of intercropping maize and beans on striga incidence and grain yield. Proceedings of the Eastern/ Southern Africa Regional Maize conference, 7: 183-186.

Okalebo, J.R., P.L., Woomer, C.O., Othieno, N.K., Karanja, S., Ikerra, A.O., Esilaba, A.O., Nekesa, E.C., Ruto, M.N., Thuita, K.W., Ndung‘u, M.N., Kifuko, A., Bationo (2007). The potential of underutilized phosphate rocks for soil fertility replenishment in Africa: case studies in western Kenya. African Crop Science Conference Proceedings. 8: 1589-1598.

Okalebo, J.R., K.W., Gathua, P.L., Woomer (2002). Laboratory methods of soil and plant analysis, pp 128. A Working manual, 2nd edition, TSBF-CIAT, SSSEA, KARI, Sacred Africa, Moi University.

Opala, P.A., R.O., Nyambati, P.O., Kisinyo (2014). Response of maize to organic and inorganic sources of nutrients in acid soils of Kericho County, Kenya Am. J Exp. Agric. 6:713-723.

Opala, P. A., J.R., Okalebo, C.O., Othieno (2012). Comparison of effects of phosphorus sources on soil acidity, available phosphorus and maize yields at two sites in western Kenya. Archives of Agronomy and Soil Science. 59:327– 339.

Opala, P.A., C.O., Othieno, J.R., Okalebo, P.O., Kisinyo (2010). Effects of combining organic materials with inorganic phosphorus sources on maize yield and financial benefits in Western Kenya. Expl agric 46: 23-34.

Pingali, P.L. (2001). World Maize: Facts and Trends. Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector. CIMMYT 1999 - 2000. CIMMYT. Mexico. D.F.

Prasad, R.B., R.M., Brook (2005). Effect of varying maize densities on intercropped maize and soybean in Nepal. Expl Agric. 41: 365-382.

Sanchez, P. A., and G., Uehara (1980). “Management considerations for acid soils with high phosphorus fixation capacity,” in The role of P in agriculture, F. E., Khasawneh, C.

R., Dinauer, E. C., Sample, and E. J., Kamprath, Eds., pp. 471–514, American Society of Agronomy, Madison,Wis, USA, 1980.

Sanchez, P.A., K., Shepherd, M.J., Soule, F.M., Place, R., Buresh, A.M., Izac (1997). Soil fertility replenishment in Africa: an investment in natural resource capital pp. 1–46. In: Buresh, R.J., Sanchez, P.A. and Cahoun, F. (eds.). Replenishing soil fertility in Africa. SSA Special Publication No 51, SSA, Madison, Wisconsin, USA.

Sanginga, N., and P.L., Woomer (Eds.) (2009). In ‘‘Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process’’. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture, Nairobi.

Seran, T.H., and I., Brintha (2010). Review on Maize Based Intercropping. Journal of Agronomy. 9: 135–145.

Shepherd, K.D., E., Ohllson, J.R., Okalebo, J.K., Udifu (1996). Potential impact of Agroforestry on soil nutrient balances at farm scale in the East Africa highlands. Fertility Resources. 44: 87-89.

Silwana, T.T., E.O., Lucas, A.B., Olaniyan (2007). The effects of inorganic and organic fertilizers on the growth and development of component crops in maize/bean intercrop in Eastern Cape of South Africa. Journal of Food, Agriculture and Environment. 1:267-272.

Sullivan, P. (2003). Intercropping principles and production practices, pp.1-12. In Williams, P. (ed.). Appropriate Technology Transfer for Rural Areas (ATTRA). Fayetteville: Arkansas.

Tamiru Hirpa. (2014). Effect of Intercrop Row Arrangement on Maize and Haricot Bean Productivity and the Residual Soil. Global Journal of Science Frontier Research: D. Agriculture and Veterinary, 14:27-34.

Tittonell, P., B., Vanlauwe, P.A., Leffelaar, E.C., Rowe, K.E., Giller (2005). Exploring diversity in soil fertility management of smallholder farms in Western Kenya: L. Heterogeneity at region and farm scale, agric. Ecosyst. Environ. 110:149−165.

Tsubo, M., E., Mukhala, H.O., Ogindo, S., Walker (2003). Productivity of maize bean intercropping in a semi-arid region of South Africa. Department of Soil, Crop and Climate Sciences, University of the Free State. The concept of LER and advantages in yield from intercropping. 29: 381-388.

Tsubo, M., S., Walker, E., Mukhala (2001). Comparison of Radiation Use Efficiency of Mono-/Inter-Cropping Systems with Different Row orientations. Field Crop Research. 71: 17 – 29.

Tungani, J.O., P.L., Woomer, E.J., Mukhwana (2003). Strategies of applying mineral fertilizers to an innovative maize-legume intercrop in western Kenya. African Crop Science Conference Proceedings, 6: 394-399.

Tungani, J.O., E., Mukhwana, P.L., Woomer (2002). Mbili is Number 1: A Handbook for Innovative Maize–Legume Intercropping. SACRED Africa, Bungoma, Kenya.

Undie, U. L., D.F., Uwah, E. E., Attoe (2012). Effect of Intercropping and crop arrangement on yield and productivity of late season maize/soybean mixtures in the humid environment of southern Nigeria. Journal of Agricultural Science, 4: 37-50.

Vanlauwe B., F., Kanampiu, G.D., Odhiambo, H., De Groote, L.J., Wadhams, Z.R., Khan (2008). Integrated management of *Striga hermonthica*, stemborers, and declining soil fertility in western Kenya. Field Crops Research. 107: 102-115.

Vanlauwe, B., A., Bationo, J., Chianu, K.E., Giller, R., Merckx, U., Mokwunye, O., Ohiokpehai, P., Pypers, R., Tabo, K., Shepherd, E., Smaling, P.L., Woomer, N., Sanginga (2011). Integrated soil fertility management: operational definition and consequences for implementation and dissemination. Outlook on Agriculture 39:17–24.

Vavilov, N.I. (1992). Origin and Geography of Cultivated Plants (V.F. Dorofeev, ed.). Cambridge University Press, Cambridge, UK.

Woomer, P.L., M., Langat, J.O., Tungani (2004). Innovative maize-legume intercropping results in above- and below-ground competitive advantages for understorey legumes.West African Journal of Applied Ecology 6:85-94.

Worku, W. (2008). Evaluation of common bean genotypes of diverse growth habit under sole and intercropping with maize in southern Ethiopia. J. Agron. 7: 306-313.

Willey, R.W., M.R., Rao (1980). A Competitive Ratio for Quantifying Competition between Intercrops. Expl. Agric, 16.117-125.

APPENDICES

Appendix I: Bugeng'i maize and beans agronomic seasonal comparison

Seasonal Means	Maize height 8WAP	Maize LAI	Maize grain yields (t ha^{-1})	Maize biomass yields (t ha^{-1})	Beans LAI	Beans grain yields (t ha^{-1})	Available P 6WAP
Season1	139.04	1.21	3.29	21.18	0.51	0.28	11.69
Season 2	140.92	0.34	0.80	3.03	0.70	0.42	16.90
Probabilities for F test ($p \leq 0.05$)	NS	<0.001	<0.0001	<0.0001	0.005	0.015	<0.0001
LSD	NS	0.08	0.24	0.95	0.13	0.11	1.53

LSD = Least significant difference of means; N.S = not significant; LAI= Leaf area index; WAP=Weeks after planting

Appendix II: High Striga infestation at Malanga site

Appendix III: Values used for cost- benefit analysis during the year 2015 short rains and 2016 long rains

Parameter	Actual value
Input costs	**Ksh / Kg**
Rose cocoa grains: Sole beans	250
WH 505 maize grains	400
TSP fertilizer	70
CAN fertilizer	60
Bio fix	5000
Labour costs	**Ksh / Ha**
Ploughing	9000
Harrowing	6000
1st and 2nd weeding sole maize	@10000
1st & 2nd weeding sole beans & intercrops	@15000
Top-dressing	2000
Harvesting sole crops	7500
Harvesting intercrops	12500
Output prices	**Ksh / Kg**
Maize grain	35
Bean grain	75
Maize stover	03