EFFECT OF CHICKPEA (*Cicer arietinum* L.) AND WHITE LUPIN (*Lupinus albus* L.) ON PHOSPHORUS MOBILIZATION FROM MINJINGU PHOSPHATE ROCK, SOIL AVAILABLE N AND SORGHUM YIELDS IN VARIOUS CROPPING SYSTEMS

TUNYA BELDINA ALONA

Thesis Submitted in Partial Fulfillment for the Requirements of the degree of Master of Science in Soil Science in the Department of Crops, Horticulture and Soils, Egerton University

EGERTON UNIVERSITY

MARCH 2015

DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and has not been shared, presented or submitted wholly or in part for any award in any other Institution.

Signature...Date..

Tunya Beldina Alona

KM13/3273/12

Recommendation

We confirm that this thesis was prepared under our supervision and has our approval to be submitted for examination as per the Egerton University regulations.

Signature...Date..

Dr. Joyce J. Ndemo

Department of Crops, Horticulture and Soils

Egerton University

Signature...Date..

Prof. Josephine P. Ouma

Department of Crops, Horticulture and Soils

Egerton University

DEDICATION

This work is dedicated to my loving parents Mr. and Mrs. Tunya for their financial, moral and spiritual support throughout my study.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to God for enabling me to go through my course of study successfully through His continued favors and graces. I greatly appreciate Egerton University, and the department of Crops, Horticulture and soils, for providing the experimental field and laboratory facilities. I also appreciate the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for funding this research work. I am greatly indebted to my supervisors Dr. Joyce J. Ndemo and Prof Josephine P. Ouma for their efforts, advice, guidance, and patient supervision during the carrying out of this project and preparation of this thesis. I also extend my sincere thanks to Mr. Ombui, Chief technician Department of Crops, Horticulture and Soils, for his unflagging support during laboratory analysis. I sincerely thank Mr. Karanja for his great support during the field work. I appreciate my course mates Korir, Joseph and Alex for their moral support. I am also grateful to my parents for their continued prayers and support to ensure that I was always comfortable.

ABSTRACT

Smallholder farming systems in Njoro are characterized by the application of sub- optimal rates or non-utilization of inorganic fertilizers due to their exorbitant prices vis-à-vis low financial returns from crops. Efficient application of natural materials in agro ecosystems, viz. the use of Minjingu phosphate rock (MPR) as a fertilizer is an attractive alternative to inorganic fertilizers, however, releases phosphorous slowly due to its low solubility. The use of the legumes apart from fixing nitrogen (N) can enhance MPR solubility through the release of citrate. The objective of the present work was to enhance phosphorus release from MPR and increase soil available N content using white lupin and chickpea for increased sorghum yields. The study was carried out at the Egerton University agricultural field experimental site during the long and short rain seasons of 2012 and Long rain season (LRS) of 2013. The experimental design was split plot arranged in a randomized complete block design. The main plots were three cropping systems; sorghum monocrop, legume- sorghum rotation and legume- sorghum intercrop. The subplots comprised two P sources; triple super phosphate (TSP) and MPR both applied at the rate of 60 kg P ha^{-1}. Soil samples were collected at seedling, flowering and maturity stages of sorghum and analyzed for pH, organic C, and available P and N. Plant samples were also collected at the same time periods as for soils and analyzed for total N and P. Sorghum grain and dry matter yield were determined at maturity. N and P balances were also measured at the end of the experiment. Results on soil pH indicated a lower plant and soil response with the use of MPR at a pH greater than 5.5. The use of MPR also led to a rise in soil pH due to its liming effect. The use of TSP resulted in a decrease in pH in the long run to below 4 and this impaired N fixation. TSP application resulted in significantly higher P concentrations in the soil and plant tissues than MPR addition in the first season since the latter has low solubility in water. Comparison of the two legumes showed that both were competitive in enhancing MPR solubilization, with a greater potential in lupin. Higher soil available P led to higher levels of soil and plant available N and also to higher accumulation of dry matter and grain yield and upon incorporation of crop residues in to the soil and their decomposition, high levels of organic C was realized. Higher levels of plant N and P was also realized with the use of MPR. N, P and K nutrient balances showed a negative balance. All the cropping systems showed significant results but intercropping systems was the most effective for this research by the end of the LRS 2013. There is a need for

more research to improve the poor performance of MPR in the first season and to identify other mechanisms of P mobilization from MPR. Thus MPR could be a viable alternative to TSP in supplying P to both soil and plants.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ATP	Adenosine Triple Phosphate
Ca-P	Calcium Bound Phosphate
Fe-P	Iron bound Phosphate
MPR	Minjingu Phosphate Rock
NB	Nutrient Balances
NUTMON	Nutrient Monitoring.
PR	Phosphate Rock
RUFORUM	Regional Forum for Capacity Building in Agriculture
SAN	Soil Available Nitrogen
SAP	Soil Available Phosphorus
SOC	Soil Organic Carbon
SSA	Sub Saharan Africa

CHAPTER 1

INTRODUCTION

1.1 Background Information

Sorghum (*Sorghum bicolor* L. Moench) is considered the fifth most important cereal after wheat, rice, maize and barley (Buchanan *et al.*, 2005). It is grown on approximately seven million hectares annually in Eastern Africa and is the second most important cereal crop after maize (FAO, 2010). It is one of the most versatile crops in terms of its importance as a food grain in the dry regions of the semi-arid tropics (Rai *et al.*, 1999; Mutisya *et al*., 2010).

Adequate supply of phosphorus (P), the second most critical plant nutrient element, is required for optimum sorghum growth and reproduction (Yu *et al*., 2012). The macronutrient is an integral part of energy metabolism and major biological processes including photosynthesis, respiration, and membrane transportation (Li *et al*., 2011). Continuous cereal mono cropping coupled with application of sub-optimal rates of inorganic fertilizers has led to soil nutrient depletion and subsequently low crop yields in small holder farms. Modern agriculture is mainly dependent on regular inputs of the mineral P in water soluble chemical fertilizers for continuous agricultural production (Shrivastava *et al*., 2011). The use of inorganic fertilizers on a regular basis has however become a costly affair for small holder farmers and is also environmentally undesirable. The resultant soil fertility depletion is the fundamental biophysical root cause of declining per capita food production in sub Saharan Africa (Sanchez et al., 1997).

There is therefore an obvious necessity to develop sustainable, economical and eco-friendly technologies with greater resource use efficiency (Jayasinghearachchi *et al*., 2006). The efficient application of natural materials in agro ecosystems, such as phosphate rocks (PRs) are regarded as a valuable alternative for P fertilizers for a sustainable agriculture system (Jain *et al*., 2010), because they are cheaper sources of P (Vanlauwe and Giller., 2006). A promising PR is Minjingu phosphate rock (MPR) from Tanzania, a sedimentary/biogenic deposit which contains about 13% total P and 3% neutral ammonium citrate (NAC) soluble P. Besides MPR, *Busumbu* Phosphate Rock from Uganda (BPR), *Tilemsi* from Mali, and *Matam* from Senegal are other potential sources of P (Jama and Straaten, 2006). The P in these rocks is however, not readily available to plants (Park *et al* ., 2011). Solubility of phosphorus in these hard phosphate rocks may be increased by grinding, applying it in acidic soils and by use of certain plant species (Kifuko *et al*., 2007; Aria *et al*., 2010).

Evidences indicate that plants can solubilize P from PRs by releasing enzymes like phosphatases, phytase and carboxylates under P deficiency, allowing mobilization and utilization of P in soil under P deficiency stress (Li *et al*., 2011). Rhizosphere concentrations of carboxylic acids at a level high enough to mediate desorption of significant amounts of soil phosphorus have been reported only for a limited number of plant species, mainly cluster-rooted plants such as white lupin (*Lupinus albus*) and members of the *Proteaceae* (Shane and Lambers, 2006). Some carboxylic acids (carboxylates), for example citrate and malate, can mobilize inorganic phosphorus into the soil solution (Gerke *et al*., 2000). Chickpea (*Cicer arietinum* L.), like lupin, exudes carboxylates from its roots (Veneklaas *et al*., 2003) and can thus mobilize calcium-bound phosphate (Ca-P).

The incorporation of these legumes in association with sorghum in rotation or intercropping systems with application of MPR can address soil fertility problems in farmers' fields (Groote *et al*., 2010; Bayala et al., 2012). The legumes provide an alternative means of improving soil N fertility through their ability to fix atmospheric nitrogen, increase soil organic matter and improve general soil structure. Nitrogen is a key component of enzymes and other proteins essential to all growth functions (Christiansen and Graham, 2002).

A nutrient balance is a land quality indicator that describes the rate at which soil fertility changes under actual management (Segala *et al*., 2010). NUTMON; a Nutrient Monitoring tool, can be used to track nutrient input and output from production systems. It plays an important role in monitoring impact of applied technologies (Vlaming et al., 2001).

1.2 Statement of the Problem

Phosphorus (P) is the second most critical plant nutrient after nitrogen (N). Adequate P and N nutrition enhances many aspects of plant development including flowering, fruiting and root growth. P is a non-renewable resource, unlike N, which can be assimilated from N_2 into NH_3 by free-living and symbiotic N_2-fixing micro-organisms or converted into NH_3, NO_3^- or urea industrially. Worldwide soils are supplemented with inorganic P as chemical fertilizers to support crop production but repeated use of fertilizers deteriorates soil quality. Smallholder farming systems in Njoro use of suboptimal inorganic fertilizers doses in crop production due to their exorbitant prices vis-à-vis low financial return from crops. This has resulted in deterioration of soil fertility and declined crop yields leading to unsustainable crop production. MPR is envisaged to be a viable option to the expensive inorganic P fertilizers and additionally can build the soil capital P through its residual effect. The greatest challenge in its use is however the low solubility hence low uptake by plants. The phosphorus from phosphate needs to be released into the solution before any residual phosphorus can manifest itself. There is thus an urgent need to test and promote crops and cropping systems that can enhance P release from MPR. This will in turn provide sustainable approaches of managing soil fertility and crop productivity. Chickpea, like lupin, exudes carboxylates from its roots (Veneklaas *et al*., 2003) and can thus enhance the solubility of phosphate rock. However, minimum research has been done on the dissolution of MPR by use of lupin and chickpea for enhanced availability of phosphorus to sorghum for improved yield.

1.3 Objectives

1.3.1 General Objective

The overall objective was to enhance P release from MPR and increase soil available N by use of white lupin and chickpea (legumes) for increased sorghum yields.

1.3.2 Specific Objectives

The specific objectives were to:

1. To determine soil available P, N, organic C and pH at seedling, flowering and harvest stages of sorghum in different cropping systems.
2. To determine plant P and N at seedling, flowering and harvest stages of sorghum in different cropping systems.
3. To determine sorghum grain and dry matter yields following integration of white lupin and chick pea with application of MRP and TSP.
4. To calculate N and P balances in soil using NUTMON following integration of legumes with application of MRP and TSP.

1.4 Hypotheses

1. There are no differences in soil available N, P, C and pH across all sampling periods in the different cropping systems.
2. There are no differences in plant N and P contents across all sampling periods in the different cropping systems.
3. There are no differences in sorghum grain and dry matter yields with integration of legumes and application of TSP and MRP.

4. There are no differences in P and N balances in the soil in lupin and chickpea treatments with the application of TSP and MRP.

1.5 Justification

Sorghum is an important grain crop grown in many developing countries as a food, feed and energy crop. It can grow in marginal lands that do not support other cereal crops and also in tropical climates because of its efficiency in water usage and tolerance to drought as well as waterlogged and saliferous soils.

Adequate supply of P to sorghum is required for optimum plant growth and reproduction. Phosphate fertilizers, such as single superphosphate (SSP), di- ammonium phosphate (DAP) and triple superphosphate (TSP) have the potential to supply phosphorus to plants immediately after application but they are expensive due to high cost of production and therefore beyond the reach of many small scale farmers. Besides production of these fertilizers requires the use of sulphuric acid that gets slowly released in to the soil which is also environmentally undesirable as it results in ground and surface water pollution.

Direct application of phosphate rock (PR) is an environmentally-friendly and foreign-currency saving way to alleviate P deficiency. MPR has high phosphate content lasts long in the soil and can release locked minerals and thus increase the P level in soils. In addition phosphate rocks build the P capital of the soil and can be considered an investment in the natural resource capital since it can be released over a long period. The legumes chickpea and white lupin, exude carboxylates from their roots (Veneklaas *et al*., 2003) and can thus enhance the solubility of phosphate rock and consequently enhance P fertility of soil.

The leguminous crops also have nodules and can accumulate N as NH_3 through symbiosis with Rhizobium micro-organisms and thus biologically fix N from the atmosphere. This results in an increase in N fertility of soil. Solubility and uptake of P in rhizosphere of phosphate rock can be enhanced by intercropping of legumes with cereals. Intercropping offers farmers the opportunity to exploit nature’s principle of diversity on their farms and greatly contributes to crop production by its effective utilization of resources, as compared to the monoculture cropping system.

Currently, this system is attracting increasing interest in low- input crop production systems and is being extensively investigated. Inter-specific root interactions affect nutrient mobilization in the rhizosphere and contribute efficiently to nutrient acquisition, which in turn greatly increase crop yield. The integration of the legumes in the cropping system with application of MPR is a novel approach to increasing soil fertility for enhanced sorghum production in smallholder farming systems.

CHAPTER TWO

LITERATURE REVIEW

2.0 Growth and Distribution of Lupin, Chickpea and Sorghum.

2.1 Lupin

Lupin is a common name that represents four domestic species, *Lupinus albus* (white lupin), *Lupinus angustifolius* (narrow-leaf lupin), *Lupinus luteus* (yellow lupin) and *Lupinus mutabilis* (pearl lupin) (Sirtori *et al*., 2010). Lupin seeds (*Lupinus* spp.) have great potential for human and animal nutrition because of their high content of protein, minerals, vitamins, dietary fiber and oil (Porres *et al*., 2005). Lupin can survive in poor soils where the growth of other crop plants is limited (Li *et al*., 2011). Lupin species are well adapted to acid sandy soils because they are able to produce very deep roots, often more than 2.5 m deep.

White lupin has proven an illuminating model system for understanding plant adaptations to low P and N habitats. It can effectively acquire P even though it does not form a mycorrhizal symbiosis. Its adaptation to P stress is a highly coordinated modification of root development and biochemistry resulting in cluster roots that exude copious amounts of organic acids and acid phosphatase. Prolific release of the acids, citrate and malate, solubilize bound inorganic P, whereas exudation of acid phosphatase is important in solubilizing organically bound P (Vance, 2001).

2.2 Chick Pea

Chick pea (*Cicer arietinum* L.) is a valuable ancient leguminous plant which grows well in different soils and climates. It is the third most important cool-season food legume after common bean (*Phaseolus vulgaris* L.) and pea (*Pisum sativum* L.) (Mohammed *et al*., 2012). It is the third most important pulse crop with a total annual global production of 9.7 M tonnes from 11.5 million hectares.

Chick pea is grown in fifty two countries around the world, mainly in South and West Asia, North and East Africa, South Europe and Australia. Based on world production estimates (Ganjeali *et al.,* 2011), India is the largest producer of chickpea in the world and accounts for approximately 69% of the total world chickpea production (Islam *et al*., 2012). In 2008, India produced 5.97 million tons of chick pea which was about 75% of the world's production (Singh *et al*., 2010). Half of the world production of chickpea is exported from Syria and Turkey (Mohammed *et al*., 2012).

Chickpea serves as a source of inexpensive high-quality protein in the diets of many, and also contributes to the sustainability of cropping systems in cereal - legume rotations (Akem, 1999). Chickpea is also a major source of nutrients in human diet and animal feed contributing about 19.21% protein and 60% carbohydrates, comparable only to beef or fish (Shahid *et al*., 2008). The crop is predominantly grown in the semi-arid tropics under stored soil moisture, or in Mediterranean in-season rainfall systems, either as an autumn- or spring-sown crop, and therefore terminal drought is almost a ubiquitous stress. Low chilling tolerance in chickpea is an example of this, because it can delay the onset of podding and contributes to impaired fertilization resulting from reduced pollen function and/or ovule viability (Bergera *et al*., 2012). Chickpea is traditionally planted towards the end of the rainy season (March or April) and generally grown on progressively declining soil moisture residual and increasing temperature (Ganjeali *et al.,* 2011).

A large number of chickpea cultivars are grown and based on seed colour and geographic distribution, chickpea is grouped into two types, Desi (Indian origin) and Kabuli (Mediterranean and Middle Eastern origin (Singh *et al*., 2010). Chickpea mainly consists of a seed coat (the outer most part) and cotyledons (the inner part) (Ganjeali *et al.,* 2011). Kabuli is a large, cream-coloured seed with a thin seed coat and Desi is a small, wrinkled, dark-coloured seed with a thick seed coat. Chickpea is a protein (23–24%) and starch (36–41%) rich legume, with readily available energy (Sanjeewa *et al*., 2010). Phosphorus is an important major nutrient which determines the productivity of chickpea in addition to N and K. Chickpea is known to respond positively to P application with increased yield (Patil *et al*., 2011).

2.3 Sorghum

Sorghum (*Sorghum bicolor* L. Moench) is a crop native to sub-Saharan Africa and has been cultivated for centuries in Africa and Asia. It is an important grain crop and food source in many developing countries (Mutava *et al*., 2011). It is the fourth most important world cereal after wheat (*Triticum* spp.), rice (*Oryza sativa*), and maize (*Zea mays* L.). In Kenya, sorghum occupies 15,000 hectares, with an annual production of 100,000 tons and mean yield of 0.7 t ha^{-1} (Gateri *et al*., 2004). It is perennial in nature and is an erect plant, with a solid stem which can grow from 0.8- 5 meters. It is classified under the family of poaceae, tribe andopogoneae, sub tribe sorghinae, genus sorghum. The leaf has a prominent midrib, typical leaf blades, on average 8- 12 cm wide and 50- 90 cm long. The leaf sheath and stem is covered with a waxy boom and has an extensive fibrous root system that can grow as deep as 3 meters (Prasad *et al*., 2004).

It can grow with as little rainfall as 250 mm, but does best where 800- 1,200 mm is received annually. It grows well on light sandy soils which offer good drainage, but it can also withstand some waterlogging. Early maturing varieties take 3 to 4 months to be harvested while the late maturing varieties take 8 to 9 months to mature. The crop can also be cut for forage at 2 months or for silage at four months. Ratooning for forage or grain production is also possible (Gateri *et al*., 2004). It has many fine roots with higher absorption capacity which helps increase its drought-tolerance. It has effective deep rooting system of up to 3 meters. Water and mineral extraction patterns allow it to be often grown in intercropping or rotational systems (Moroke *et al*., 2011).

Root length, root absorbing area and root activity are used as important physiological parameters for evaluation of ion and water uptake in sorghum (Qia *et al*., 2012). From the agronomic point of view, sweet sorghum is more environmentally friendly because of its relatively low nitrogen needs and water requirements (Vasilakoglou *et al*., 2011). As a 4-Carbon (C4) species, it has also a high N use efficiency which may limit the fertilizer applied and reduce the environmental releases without compromising biomass yield (Qia *et al*., 2012).

2.4 Functions and Sources of phosphorus to Plants

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

Absolutely necessary for all forms of life, P is found in all living beings as part of proteins, nucleic acids, membranes and energy molecules such as ATP, GTP and NADPH. Usually, it is the second element limiting plant growth preceded by nitrogen, but depending on some environmental and biological factors it can be the main growth-limiting nutrient (Azziz *et al*., 2012). As the life-limiting element in natural ecosystems, regular inputs of phosphate fertilizer to replenish the P removed by crops are one property of modern agriculture (Li *et al*., 2011). Both soluble and insoluble P compounds are used as a fertilizer source (Park *et al*., 2011).

Worldwide soils are supplemented with inorganic P as chemical fertilizers to support crop production but repeated use of fertilizers deteriorates soil quality. Production of these fertilizers, which involves the use of sulfuric acid are considered as extremely polluting (Jain *et al*., 2010)**.** The use of such imported phosphate fertilizers by the resource poor farmers has not been possible due to high prices (Ndakidemi *et al*., 2007).

Natural phosphate rocks have been regarded as a valuable alternative for P fertilizer for a sustainable agriculture system and are increasingly recognized as potential fertilizers (Yu *et al*., 2012). Direct application of local phosphate rock (PR) can reduce dependency on expensive, imported and processed fertilizers (Antunes *et al*., 2007)**.**

2.5 Phosphate rock Types and Solubility

Phosphate rocks (PRs) are unprocessed P fertilizer of relatively low solubility. Types of PRs in Africa include *Tundulu* from Togo, Burundi and Malawi; *Minjingu* from Tanzania; *Busumbu* and *Sukulu* from Uganda; *Nkombwa* and *Kalume* from Zambia and *Dorowa* PR from Zimbabwe. PRs originate mainly from igneous or sedimentary rock sources with sedimentary being the most widely used in world phosphate production. In Tanzania there is a 6 million-ton reserve of *Minjingu* which can currently be mined at 100,000 tons per year.

A number of studies have also highlighted the suitability of Minjingu PR as P source for crops in P deficient soils. Shisanya *et al*. (2003) reported that this deposit may prove crucial to the amelioration of the 900,000 hectares of low-phosphorus soils in the highlands of Western Kenya for several years where farmers are currently cultivating several food legumes. A relative agronomic effectiveness (RAE) of 75% for Minjingu PR was reported in the five seasons following application to maize in Western Kenya. On-farm trials in P deficient soils in western Kenya demonstrate MPR to be as effective as triple superphosphate (TSP, 20% P) at equal P rates (Jama and Straaten, 2006).

The major problem with using PR is their low solubility under non-acid soil conditions. PRs is not plant available where the pH of the soil is greater than 5.5 and even when conditions are optimal; plant yields are lower than those obtained with soluble phosphate (Singh and Reddy, 2011). In fact, of all PR sources in Sub Saharan Africa, only the PRs from Mali, Senegal and Tanzania which are *Tilemsi*, *Matam* and *Minjingu* respectively have a solubility in 2% citric acid exceeding 10% (Vanlauwe and Giller, 2006)**.**

In soils, insoluble P compounds can be solubilized by organic acids, phosphatase enzymes and complexing agents produced by plants and microorganism (Park *et al*., 2011). Dissolution of phosphate rock and availability of phosphorus can also be achieved by use of nitrogen-fixing bacteria (NFB) which are considered as prospective biofertilizers. Numerous studies have been conducted to evaluate different soil amendments in order to increase the availability of phosphorus from phosphate rocks. Organic matter and sulfur applications and bacterial inoculation are considered as important amendments in phosphate rock application (Aria *et al*., 2010). In some parts of Tanzania crop yields were signifiantly increased where organic shrubs such as Tithonia (*Tithonia diversifolia*) were combined with MPR or TSP.

2.6 Phosphate rock Solubilization by Legumes

Evidences indicate that plants can solubilize P from PR (Badawi *et al*., 2011). Legumes can enhance PR dissolution through acidification of the rhizosphere and exudation of organic acids. Several studies have shown the significance of acid phosphatase exuded from legume roots for mineralizing organic P to allow its acquisition by plants. In this way, legumes revalue the PR into a more available P source (Pypers *et al.*, 2007).

Some plant species are known to utilize non-labile P effectively in either inorganic or organic forms. For instance, white lupin is highly efficient with respect to P uptake and the utilization of sparingly available sources of soil phosphorus. It develops proteoid (cluster) roots in response to phosphorus deficiency. Proteoid roots are composed of tight clusters of rootlets. Proteoid roots exude large quantities of malate and citrate during P deficiency, increasing the availability of mineral-bound P by solubilizing Ca, Fe and Al phosphates (Neumann *et al*., 2000). This is mainly by mechanisms of ligand exchange, and dissolution of P sorption sites in the soil matrix (Neumann *et al*., 2000).

On the other hand, phosphorus deficiency strongly induces the net release of protons from the roots of chickpea and these acidify the soil. Such release of protons determines its ability to utilize acid-soluble calcium phosphates in calcareous soils or PR. The acid phosphatases from chickpea roots has been shown to hydrolyze organic P compounds and release orthophosphate in the rhizosphere and this is an adaptive mechanism of chick pea, that contributes to the replenishment of soil solution P (Li *et al*., 2004).

2.7 Legume- Cereal Cropping Systems

Low crop yields due to continuous mono cropping and deteriorating soil health in smallholder farmers' fields of sub-Saharan Africa have led to a quest for sustainable production practices with greater resource use efficiency. Soil fertility in farmers' fields can be improved by several cereal and legume associations in rotation or intercropping systems (Groote *et al*., 2010; Bayala *et al.*, 2012). Intercropping, through effective use of water, nutrients and solar energy, can significantly enhance crop yields compared with monoculture cropping.

Most studies on intercropping have focused on the legume-cereal intercropping, a productive and sustainable system, its resource utilization (water, light, nutrients), and its effect on N input from symbiotic nitrogen fixation into the cropping system (Zhang and Li, 2003). Legumes, when integrated into cereal cropping systems either as rotational fallows or relay intercrops, have been shown to provide considerable amounts of organic matter and nitrogen to the soil. The organic matter thus added increases structural stability of the soil, resistance to rainfall impact, infiltration rates, and faunal and microbial activities (Sileshi *et al*., 2010). Intercropping systems have higher yield stability reduced disease severity and benefits weed control especially when combined with nutrient addition (Pypers *et al*., 2007). Smallholder farmers in East-Africa commonly intercrop maize (*Zea mays* L.) with grain legumes to maximize utilization of land and labor and attain larger crop yields (Muna *et al*., 2010).

Crop sequences and intercrops involving N_2 -fixing legumes have been shown to provide N to cereals through mineralization of the legume biomass (Nezomba *et al*., 2010). It has been well documented that an important N-transfer takes place in intercropping systems of legumes with cereals. These effects on P utilization are related to the release or activation of enzymes like acid phosphates and root exudation of carboxylates, phosphatases and phytase under P deficiency which improve solubility and uptake of P in rhizosphere. Plant roots release enzymes like phosphatases, phytase and carboxylates under P deficiency, allowing mobilization and utilization of P in soil under P deficiency stress (Botha *et al*., 2011).

A cereal crop following the legume can then benefit directly from the enhanced P availability in the soil and acquire P released from the decomposing legume residues (Pypers *et al*., 2007). Hence rotation is a key strategy for improving production and maintaining fertility of the soil. Growing cereals continuously in low input dry land conditions is likely to be an unsustainable system in the long run due to depletion in soil fertility and development of unfavorable soil physical and biological conditions. There is a strong need to introduce crop rotation practices, to increase N supply for cereals (Patil *et al*., 2011). There is published information on the ability of inexpensive MRP from Tanzania to react with and ameliorate phosphorus deficient soils of Western Kenya with combined importance of intercropped legumes within the predominant maize-based cropping system (Woomer *et al*., 2003).

2.8 Nutrient Balances

A nutrient balance is a land quality indicator that describes the rate at which soil fertility changes under actual management (Segala *et al*., 2010). Soil nutrient balances can be used as an indicator to determine nutrient use efficiency of farming systems. The nutrient balances can serve as indicators for the magnitude of losses of nutrients and help to identify the causes for such losses (Phong *et al.*, 2010). Soil nutrient balance studies in Africa show evidence of widespread nutrient mining leading to severe nutrient deficiencies across ecological zones. Nutrient mining has been estimated to average 660 kg of nitrogen (N), 75 kg of phosphorus (P) and 450 kg of potassium (K) per hectare per year during the last 30 years (Esilaba *et al*., 2005). Soil nutrient mining and the resultant soil fertility decline occurs in most areas in Kenya, as observed by the negative balances for N, P, and K at the farm level.

Nutrients are annually taken away in crops or lost in processes such as leaching and erosion which far exceed the nutrient inputs through fertilizers, deposition and biological fixation (Groote *et al*., 2010). The nutrient balance is calculated, through the independent assessment of the major inputs and outputs of nutrients for the relevant land use systems. The nutrient balance can be calculated for different scales such as: a plot, a farm, a region or a country by simply subtracting the nutrient inputs from the nutrient outputs (Segala *et al*., 2010). Whilst these studies have been highly influential in raising attention to the problem of soil fertility in Africa, nutrient balances are often been misinterpreted and misused (Vanlauwe and Giller, 2006).

Farm balances do not give information of internal processes, for example, soil biological processes and can lead to a failure in understanding the changes certain management practices would introduce, such as the use of legumes (Hossaina *et al*., 2012).With the addition of organic amendments, N balances tended to be positive while being generally negative with mineral fertilizer use in the Nitisol of Kenya Agricultural Research Institute (KARI), Kakamega. In contrast, P balances were highly positive with mineral fertilizers and neutral to slightly positive with organic amendments. Combining zero tillage with the use of a cover crop had the largest positive effect on the partial balances of N and P. The largest P use efficiency occurred with the application of farmyard manure (62–80%), irrespective of the soil type (Ngome *et al*., 2011). Negative nutrient balances indicate that a system is loosing nutrients and in severe or continuous disequilibria is not sustainable in the long term; on the contrary, nutrients are apparently accumulating (Cobo *et al*., 2010).

NUTMON (Nutrient Monitoring) is an integrated, multidisciplinary methodology that targets different actors in the process of managing natural resources in general and soil nutrients in particular (Roy *et al.*, 2003)**.** The calculations of nutrient flows and balances and financial indicators were integrated into one calculation tool (Muna *et al*., 2010). The NUTMON toolbox (manual plus accompanying software) has been developed to integrate the assessment of nutrient stocks and flows with economic farm analyses. It has been tested and applied in diverse AEZs in close cooperation with partners from Kenya, Ethiopia, Uganda, Burkina Faso and China (Roy *et al.*, 2003).

This study uses NUTMON which has proven to be a powerful tool for assessing soil nutrient balances. The concept of NUTMON is based on analysis of nutrient inputs and outputs. Nutrient flows like fertilizers, feeds, and farm products are monitored and measured. Other flows like nitrogen fixation, leaching, and erosion are more difficult to measure and are estimated by means of regression models (Phong *et al.,* 2010).

3.0 CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was conducted at the Agricultural Field Experimental site, Egerton University, Kenya (Fig. 1) during the short (SRS) and the long rain seasons (LRS) of 2012 and LRS of 2013. The farm lies at a latitude of 0° 23’ South, longitudes 35°35’ East in the Lower Highland III Agro Ecological Zone (LH3) (Jaetzold *et al*., 1983) with an altitude of approximately 2,238 meters above sea level. The average maximum and minimum temperature of the area, ranges from 19 to 22° C and 5 to 8°C, respectively with a total annual rainfall ranging from 1200 to 1400 mm (EMS, 2013). The rainfall distribution is bimodal. The long rains are experienced in April to August while short rains from September to November. The soils are predominantly vitric mollic Andosols (Jaetzold *et al*., 2006).

Fig 1: Map of Kenya showing study site

Initial physical and chemical properties of soil were determined before the experiments were set up (Table 1). The initial soil pH for the three depths ranged from 6.34- 6.5 which was almost neutral. The soil had a sandy loam texture with a low amount of soil available P since the P range in most agricultural soils is 30- 80 mg kg^{-1}. Soil bulk density reduced at lower soil depth. Cation exchange capacity was greater in the top soil, since this soil experiences direct contact with organic materials and even fertilizers, and decreased with depth increase. The top soil was richer in the nutrient levels.

Table 1: Initial physical and chemical properties of soil

	soil depth (cm)				soil depth (cm)		
Soil Property	0-15	15-30	30-60	Soil Property	0-15	15-30	30-60
Ph	6.34	6.43	6.5	Exchangeable bases			
CEC (C mol kg^{-1})	62.9	42.5	20.4	K (cmol$_c$kg^{-1})	6.0	6.55	5.44
Total N (%)	1.67	0.63	0.63	Mg (cmol$_c$kg^{-1})	0.25	0.25	0.24
Org. C (%)	1.57	1.59	1.5	Ca (cmol$_c$kg^{-1})	0.23	0.4	0.24
Available P (mg kg^{-1})	27.3	27	24.1	Exchangeable Al(%)	0.2	0.3	0.4
Mineral N (%)	0.79	0.73	0.59	% clay	20	20	20
Bulk density (g cm^{-3})	1.31	1.31	1.24	% sand	50	40	36
Textural class	sandy loam	Loam	Loam	% silt	30	40	44

3.2 Treatments and Experimental Design

Two field experiments comprising either lupin or chickpea legumes were laid side by side. Sorghum variety *Know Kanty* was the test crop in both of the experiments. The experiments are hereafter referred to as lupin sorghum (LS) and chickpea sorghum (CS), respectively. The experimental set up in both experiments was a split plot in a randomized complete block design and had three replicates (Fig. 3.2). The main plots were three cropping systems; sorghum monocrop, legume - sorghum rotation and a legume- sorghum intercrop. The subplots, of size 4.8 m × 3.75 m, comprised two P sources; TSP and MPR, both applied at the rate of 60 Kg P ha^{-1}. There was a 0.5 m wide path between the split plots and a 1 m wide foot path between the main plots and blocks (Fig. 3.2).

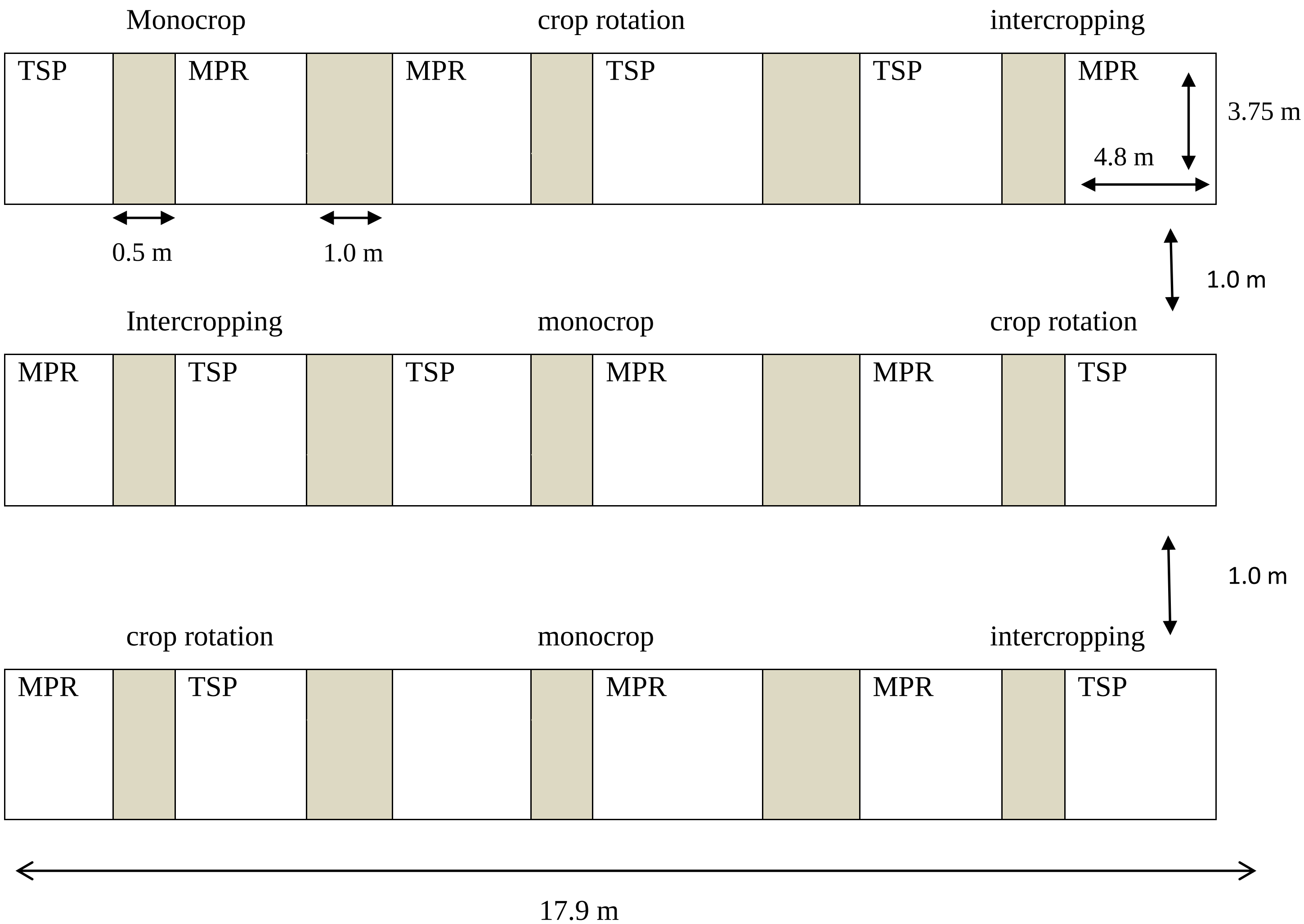

Figure 3.2: Field Layout

3.3 Agronomic Practices

Land preparation was done prior to the start of the rains, using a mould board plough. Harrowing was then performed twice using tractor to a depth of 30 cm so as to obtain a fine, firm and weed-free surface for planting. In the monocrop and rotation system, sorghum seeds were drilled at a depth of 1 cm in rows spaced at 75 cm by 20 cm. Chick pea seeds were planted at a spacing of 30 by 10 cm while lupin seeds were spaced at 50 by 30 cm. In the intercropping system, sorghum was spaced at 75 cm by 20 cm and lupin or chick pea seeds planted in the interow spaces of sorghum. Two lupin or chick pea seeds were planted per hole with a spacing of 30 cm between the lupin seeds in the lupin sorghum experiment and 10 cm between chick pea seeds in chick pea sorghum experiment. Fertilizer, both MPR and TSP, was applied by banding method and mixed well with soil before placement of the seeds. Calcium Ammonium Nitrate (CAN) was top dressed at the rate of 60 kg N ha^{-1} in all plots one month after planting.

Gapping was carried out in cases of poor germination within 7 days after sowing. After establishment the field was hand-weeded once every month so as to suppress weeds until a good canopy cover was established. The planting materials used in the study were certified sorghum, chick pea and lupin seeds obtained from the Kenya Seed Company.

3.4 Soil and Plant Sampling and Analysis

3.4.1 Soil Sampling and Analysis

Composite soil samples were collected from six profile pits at three soil depths (0-15, 15-30 and 30-60 cm) before set up of the experiment and was used to determine the initial physical and chemical properties of the soil (Table 3.1). Soil samples for the determination of soil available N, P, organic C and pH were thereafter collected from the top soil (0-15 cm) at seedling, flowering and maturity crop growth stages from at least four locations in each plot at random and bulked to get one composite sample. A sub sample was then taken and prepared for analysis.

Air- dried soil, sieved through 2 mm mesh (Otinga *et al*., 2013) was analyzed for pH (Soil: H_20: 1:2.5), texture (hydrometer method), total N (Kjedahl method), CEC (Chapman, 1965), organic Carbon (Walkley– Black, 1934), mineral N and available P according to Okalebo *et al*. (2002). Exchangeable bases (K, Ca and Mg) were extracted with 1.0 M-ammonium acetate at pH 7. K was measured by Flame Emission Spectrophotometry, whereas Ca and Mg were measured by Atomic Absorption Spectrophotometry. For bulk density determination, soil samples were taken at 0-15 cm, 15-30 cm and 30-60 cm depth from the profile pits by use of core rings. The soils were oven dried and bulk density determined according to standard method (Okalebo, *et al*., 2002).

3.4.2 Plant Sampling and Analysis

Six sorghum plants were sampled per plot at seedling, flowering and harvest stages. The above ground plants were cut close to the soil surface and chopped into small pieces. Sub-samples were taken and oven dried at 70°C, ground and wet digested for N and P analyses.

Nitrogen concentration was determined by semi micro-Kjeldahl digestion and distillation and P concentration determined by the vanadomolybdate yellow method (Okalebo et al., 2002).

3.4.3 Residue management

After removal of grains, crop residues were chopped into 5-20 cm small pieces spread across the plots and incorporated into soil, to a depth of 15 cm.

3.4.4 Grain and dry matter yield determination

At maturity, grain and dry matter yield was determined from three plants from the middle rows. A mixed sorghum plant sample of the whole plants, that is, stems, leaves, panicle axis and rachis branches after removing the grains was used in determination of dry matter yield. The plant materials were chopped into small pieces and fresh field weight taken. Sub-samples were then oven dried at 70°C to constant weight. The weight of the oven dry samples was recorded and used to calculate the total above ground dry matter yields of sorghum (Han *et al*., 2011). The grains were threshed manually, dried and weighed. Grain yield was be recorded and converted to t ha^{-1}.

3.4.5 Nutrient Balance by NUTMON

The NUTMON-toolbox (manual plus accompanying software) has been developed to integrate the assessment of nutrient stocks and flows with economic farm analyses. The NUTMON tool is used to calculate the flow and balances of N, K and P and the economic performance of the farm by independently assessing the major inputs and outputs (Phong *et al*., 2010). The concept is based on five inputs and five outputs (Van den Bosch *et al*., 1998).

The NUTMON-toolbox plays a central role in this phase as it quantifies the nutrient flows between soils, crops and livestock. Flows are expressed in kilograms of N, P and K (nutrient flows), but also in monetary values (financial flows). The quantified nutrient flows explain which activities within a farm are nutrient consuming and which are accumulating nutrients, and how and when nutrients flow from one activity to another. The quantified financial flows give insight into the profitability of activities (crops, livestock, fishponds and compost pits) and labour demands (FAO Fertilizer and Plant Nutrition Bulletin 14).

The N, P and K balances are calculated from a combination of input and output processes. The major inputs include; mineral fertilizer (IN1), organic matter (IN2), comprising manure and household refuse (IN2a), and leaf litter (IN2b), atmospheric deposition (IN3), BNF (IN4) and sedimentation (IN5). The major output flows include; removal in harvested products (OUT1), removal in crop residue OUT2), leaching (OUT3), de-nitrification (OUT4) water erosion (OUT5). The nutrient balance can be calculated for different scales such as: a plot, a farm, a region or a country by simply subtracting the nutrient inputs from the nutrient outputs to obtain a balance (Van den Bosch *et al*., 1998).

A negative nutrient balance tells us that more nutrients are exported from the system than imported into the system. This situation will diminish the nutrient stock; if the stock is low then it will have a negative effect on production. So the nutrient balance should always be related to the nutrient stock to determine the sustainability of a system.

The net partial and full nutrient balances are calculated as described below;

Net partial balance = (input 1 +input 2) - (Output 1 + Output 2)

Net Full balance = (Nutrients inputs) - (Nutrients Outputs)

= (1N1 + 1N2 + 1N3 + 1N4 + 1N5)- (1N1 + 1N2 + 1N3 + 1N4 + 1N5).

3.5 Data Analysis

All data collected were subjected to analysis of variance (ANOVA) to detect statistical variation in treatment effects on measured parameters. Means that were significantly different according to the F-test were separated by LSD test at $P \leq 0.05$. The SPSS Statistical package was used in the analysis (SPSS, 1999).

CHAPTER 4
RESULTS

4.1 Soil pH as affected by fertilizer type, cropping systems at different stages of sorghum growth

Fertilizer type, stage of sorghum growth and cropping systems interacted significantly to affect soil pH in chickpea sorghum experiment (Appendice 11). In lupin sorghum experiment, the interaction between cropping system and stage of growth significantly affected soil pH (Appendice 1).

The initial soil pH (H_2O) before the start of the experiment was slightly neutral (6.3) (Table 1). It declined after application of the treatments, to mean values of between 5- 5.9 in TSP plots and 4.9- 5.9 in MPR plots in the lupin sorghum experiment (Table 2) and 4.83- 5.9 in TSP plots and 4.4- 5.9 in MPR plots in chick pea sorghum experiment (Table 3).

4.2: Soil available N as affected by fertilizer type, cropping systems at different stages of sorghum growth

The main effects fertilizer type, cropping systems, stage of sorghum growth interacted significantly to affect the soil available N in lupin sorghum experiment and also in the chick pea sorghum experiment (Appendice 1&11).

There was a higher SAN after application of P treatments compared to initial value before the start of the experiment (Table 1). Soil available N mean ranged from 0.03- 0.99% in TSP plots and 0.04- 1.2% in MPR plots for LS experiments (Table 4) and 0.06- 3% in TSP plots and 0.12-1.44% in MPR plots for CS experiment (Table 5).

Table 2: Two- way interaction table for soil pH as affected by fertilizer type, cropping systems at different stages of growth of sorghum in lupin sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocroping	TSP	5.03 ± 0.5	5.9 ± 0.2	5.3 ± 0.1	5.3 ± 0.01	5.9 ±1.1	5.0 ± 0. 1	5.0 ± 0.01	5.7 ± 0.01	5.5 ± 0.2
	MPR	5.02 ± 0.1	5.9 ± 1.1	5.3 ± 0.1	5.4 ± 0.1	5.9 ± 0.02	5.4 ± 0.01	5.2 ± 0.01	5.80 ± 0.01	5.6 ± 0.2
Sorghum intercropping	TSP	5.3 ± 0.3	5.6 ± 0.9	5.5 ± 0.1	5.4 ± 0. 4	5.3 ± 0.2	5.3 ± 0.08	5.3 ± 0.01	5.8 ± 0.01	5.6 ± 0.13
	MPR	5.2 ± 0.7	5.7 ± 0.4	5.5 ± 0.1	5.5 ± 0.5	5.9 ± 0.02	4.9 ± 0.1	5.3 ± 0.01	5.8 ± 0.1	5.6 ± 0.12
Sorghum rotation	TSP	5.3 ± 0.7	5.7 ± 0.6	5.5 ± 0.1	5.5 ± 0.01	5.7 ± 0.03	5.1 ± 0.01	5.3 ± 0.01	5.1 ± 0.01	5.6 ± 0.07
	MPR	5.2 ± 0.7	5.6 ± 0.5	5.5 ± 0.1	5.3 ± 0.01	5.80 ± 0.1	5.3 ± 0.03	5.3 ± 0.1	5.3 ± 0.01	5.5 ± 0.17

Table 3: Three- way interaction table for soil pH results as affected by fertilizer type, cropping systems at different stages of growth of sorghum in chick pea sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocroping	TSP	5.2 ± 0.17	5.9 ± 1.08	5.3 ± 0.1	4.86 ± 0.01	5.71 ± 0.01	4.83 ± 0.01	5.37 ± 0.01	5.7 ± 0.1	5.66 ± 0.01
	MPR	5.4 ± 0.39	5.7 ± 0.24	5.1 ± 0.02	5.08 ± 0.01	5.77 ± 0.01	5.07 ± 0.01	5.34 ± 0.01	5.72 ± 0.63	5.86 ± 0.01
Sorghum intercropping	TSP	5.04 ± 0.03	5.8 ± 0.3	5.3 ± 0.1	4.84 ± 0.01	5.3 ± 0.01	4.9 ± 0.01	5.54 ± 0.01	5.7 ± 0.63	5.68 ± 0.01
	MPR	5.0 ± 1.2	5.7 ± 0.26	5. 3 ± 0.1	5.15 ± 0.01	5.5 ± 0.01	4.68 ± 0.01	5.52 ± 0.1	5.5 ± 0.01	5.78 ± 0.01
Sorghum rotation	TSP	5.29 ± 0.1	5.7 ± 0.62	5.3 ± 0.1	5.03 ± 0.01	5.8± 0.01	4.97 ± 0.01	5.57 ± 0.01	5.09 ± 0.2	5.74 ± 0.01
	MPR	5.05 ± 0.2	5.7 ± 0.1	4.4 ± 0.2	4.86 ± 0.01	5.67 ± 0.01	5.06 ± 0.01	5.45 ± 0.01	5.2 ± 0.17	5.84 ± 0.01

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting; Fl= 50% flowering; mat= maturity

Table 4: Three- way interaction table for Soil available N (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in lupin sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocroping	TSP	0.24	0.54	0.28	0.35	0.55	0.48	0.97	0.68	1.3
		± 0.02	± 0.05	± 0.03	± 0.45	± 0.01	± 0.01	± 0.01	± 0.01	± 0.08
	MPR	0.18	0.55	0.26	0.04	0.53	0.59	0.6	2.27	1.06
		± 0.06	± 0.05	± 0.01	± 0.26	± 0.01	± 0.01	± 0.1	± 2.6	± 0.05
Sorghum intercropping	TSP	0.18	0.61	0.33	0.72	0.82	0.88	0.63	0.69	0.66
		± 0.02	± 0.17	± 0.17	± 0.03	± 0.01	± 0.72	± 0.02	± 0.01	± 0.09
	MPR	0.2	0.51	0.31	1.08	0.91	1.15	0.53	3.6	0.66
		± 0.08	± 0.17	± 0.17	± 0.1	± 0.01	± 0.12	± 0.01	± 2.6	± 0.01
Sorghum rotation	TSP	0.17	0.55	0.47	0.03	0.7	0.91	0.83	0.71	0.99
		± 0.02	± 0.05	± 0.04	± 0.01	± 0.01	± 0.01	± 0.01	± 0.04	± 0.01
	MPR	0.2	0.4	0.24	0.53	0.74	0.77	0.77	0.73	0.68
		± 0.07	± 0.01	± 0.01	± 0.03	± 0.01	± 0.01	± 0.01	± 0.75	± 0.01

Table 5: Three way interaction table for Soil available N(%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in chick pea sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocroping	TSP	0.17	0.83	0.26	0.6	0.6	0.38	0.65	2.2	1.27
		± 0.01	± 0.06	± 0.01	± 0.1	± 0.1	± 0.01	± 0.03	± 0.01	± 0.12
	MPR	0.15	0.33	1.2	0.6	0.75	0.6	0.7	2.55	1.06
		± 0.01	± 0.08	± 0.09	± 0.1	± 0.01	± 0.1	± 0.1	± 0.01	± 0.49
Sorghum intercropping	TSP	0.15	0.51	0.37	0.84	0.97	0.74	0.54	0.24	0.99
		± 0.1	± 0.04	± 0.03	± 0.01	± 0.01	± 0.01	± 0.01	± 0.1	± 0.01
	MPR	0.22	0.54	0.31	1.08	0.99	0.67	0.77	2.25	1.07
		± 0.08	± 0.02	± 0.08	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01
Sorghum rotation	TSP	0.19	0.43	0.29	0.72	0.77	0.06	3.0	0.63	0.64
		± 0.03	± 0.02	± 0.03	± 0.01	± 0.02	± 0.1	± 0.06	± 0.01	± 0.01
	MPR	0.13	0.48	0.29	0.72	0.81	0.77	3.15	0.58	1.44
		± 0.08	± 0.01	±0.03	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

4.3: Soil available P as affected by fertilizer type and cropping systems at different stages of sorghum growth

The main effects fertilizer type, cropping systems, stage of sorghum growth interacted significantly to affect the soil available P in lupin sorghum experiment and also in the chick pea sorghum experiment (Appendice 1 & 11).

Soil available phosphorus (SAP) increased with application of either MPR or TSP, compared to the initial values at the start of the experiment (Table 1). SAP was lower for TSP than MPR plots in the first season but in the subsequent seasons, SAP was higher in MPR plots than TSP plots in both experiments (Table 6 & 7).The mean range of SAP was 14.2- 88 mg kg^{-1} for TSP plots and 18- 89.7 mg kg^{-1} for MPR plots in LS experiment (Table 6) and 6.18- 70.8 mg kg^{-1} for TSP plots and 10.7- 71.8 mg kg $^{-1}$ for MPR plots in the CS experiment (Table 7).

4.4: Soil C as affected by fertilizer type and cropping systems at different stages of sorghum growth

The main effects fertilizer type, cropping systems and stage of sorghum growth interacted significantly (Appendice 1&11) to affect the soil available C in lupin sorghum experiment (Table 8) and in the chick pea sorghum experiment (Table 9). The main effects in themselves; fertilizer type, stage of growth were not significantly different in lupin sorghum experiment but fertilizer type showed significant results in chick pea sorghum experiment (Table 2&3).

Fertilizer type had a significant effect on soil organic carbon (SOC) for the CS experiment only (Appendice 11). Soil organic carbon was observed to increase when compared with the initial (Table 1) with the application of the treatments. MPR plots had higher Soil organic carbon levels than TSP plots (Table 8 & 9). The mean range of SOC was 0.61- 2.99% for TSP plots and 0.63- 2.97% for MPR plots in the LS experiment (Table 8) and 0.4- 2.85% for TSP plots and 0.47- 3%for MPR plots in CS experiment (Table 9).

Table 6: Three- way interaction table for Soil available P (mg kg^{-1}) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in lupin sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	TSP	31.67 ±2.9	23.5 ± 4.4	25.0 ± 33.5	75.0 ±1.3	61.0 ± 1.6	126.0 ± 11.59	83.1 ± 0.1	2.50 ± 0.5	6.10 ± 0.1
	MPR	16.67 ± 5.8	31.5 ± 5.1	33.0 ± 19.1	70.0 ± 1.4	72.0 ±1.7	122.0 ± 31.2	26.5 ± 0.1	17.8 ± 0.98	19.3 ± 0.1
Sorghum intercropping	TSP	20.3 ± 0.3	19.8 ± 5.4	2.50 ± 0.01	63.0 ± 1.5	48.5 ± 1.6	106.0 ± 16.5	73.0 ± 1.3	50.0 ± 1.9	100.7 ± 0.6
	MPR	11.3 ± 1.2	17.0 ± 4.2	27.0 ± 0.1	73.0 ± 1.6	60.0 ±1.7	105.0 ± 0.12	100.7 ± 1.15	54.0 ± 1.5	114.3 ±10.7
Sorghum rotation	TSP	42.67 ± 0.6	20.2 ± 2.1	6.10 ± 0.1	73.0 ± 1.3	50.0 ±1.6	100.0 ± 0.6	26.0 ± 1.6	31.0 ± 1.5	6.50 ± 0.2
	MPR	33.3 ± 2.9	43.5 ± 6.1	19.3 ± 0.1	100.0 ±1.2	54.0 ±1.4	114.0 ± 10.1	17.2 ± 0.1	31.0 ± 1.73	33.5 ± 19.1

Table 7: Three- way interaction table for Soil available P (mg kg^{-1}) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in chick pea sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	T	21.5	30.5	24.15	0.8	95.0	87.0	27.9	5.80	5.5
		± 1.32	± 1.3	±0.01	±1.6	± 1.7	± 1.50	± 0.1	± 0.1	± 0.1
	M	16.0	29.8	43.67	0.4	36.0	130.0	11.5	5.70	5.4
		± 1.6	± 5.4	±1.3	±1.2	± 1.8	± 1.4.0	± 0.01	± 0.1	± 0.01
Sorghum intercrop	T	28.0	20.5	1.25	0.67	39.8	36.5	11.5 ±0.1	5.57	51.9
		± 2.6	± 2.6	± 0.9	± 1.3	± 0.1	± 0.1		± 0.6	± 0.01
	M	28.0	28.5	56.9	0.47	56.0	100.0	10.8	5.60	22.5
		± 2.6	± 2.6	± 0.88	± 1.9	±1.4	± 1.0	± 0.1	± 0.36	± 0.09
Sorghum rotation	T	25.0	33.5	42.5	96.0	41.5	75.0	9.6	3.60	5.35
		± 0.6	± 2.6	± 0.7	± 1.1	± 1.6	± 1.5	± 0.1	± 0.55	± 0.01
	M	4.0	25.0	35.5	73.0	50.5	92.0	10.5	16.2	5.35
		± 0.92	±2.7	± 1.8	± 1.4	± 1.3	± 1.6	± 0.01	± 0.15	± 0.01

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

Table 8: Three- way interaction table for Soil Carbon (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in lupin sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		S1	S2	S3	S1	S2	S3	S1	S2	S3
Sorghum monocrop	TSP	0.99 ±0.38	0.76 ±0.04	1.61 0±.04	2.23 ±0.04	2.02 ±0.02	2.0 ±0.10	1.75 0±.01	2.1 ±0.1	2.19 ±0.06
	MPR	0.99 ±0.24	0.64 0±.01	1.48 ±0.02	2.1 ±0.17	2.37 ±0.21	2.02 ±0.02	2.37 ±0.01	2.3 ±0.1	1.56 ±0.01
Sorghum lupin intercrop	TSP	0.61 ±0.29	0.64 0±.02	1.57 ±0.03	1.85 ±0.06	2.16 ±0.03	2.16 ±0.01	2.04 ±0.01	2.1 ±0.1	2.25 ±0.01
	MPR	0.68 ±0.79	0.66 ±0.04	1.25 ±0.01	2.97 ±0.08	2.02 0±.02	1.85 ±0.01	2.4 ± 0.1	2.1 ±0.85	2.4 ±0.07
Sorghum lupin rotation	TSP	0.9 ±0.01	0.71 ±0.11	1.42 ±0.34	2.16 ±0.19	2.99 ±0.04	2.41 ±0.01	2.34 ±0.01	1.95 ±0.01	0.72 ±0.01
	MPR	0.75 ±0.28	0.63 ±0.02	1.6 ±0.02	2.58 ±0.07	2.24 ±0.06	2.86 ±0.01	2.04 ±0.01	2.4 ±0.35	2.25 0±.05

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

Table 9: Three- way interaction table for Soil Carbon (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in chick pea sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	TSP	0.94 ±0.01	0.66 ±0.4	1.27 ±0.01	1.84 ±0.01	2.0 ±0.04	1.96 ±0.01	2.67 ±0.01	2.1 ±0.1	2.25 ±0.01
	MPR	0.83 ±0.03	0.47 ±0.04	1.48 ±0.01	2.72 ±0.01	2.37 ±0.01	1.54 ±0.15	2.25 0±.01	2.31 ±0.01	2.1 ±0.03
Sorghum chick pea intercrop	TSP	0.59 ±0.03	0.4 ±0.34	1.14 ±0.01	2.56 ±0.01	2.07 ±0.01	0.56 ±0.01	2.85 0.01	1.95 ±0.01	2.1 ±0.1
	MPR	0.84 ±0.01	0.66 ±0.04	1.4 ±0.01	2.8 ±0.01	2.02 ±0.01	1.66 ±0.57	3.0 ±0.08	3.0 ±0.01	2.55 ±0.01
Sorghum chick pea rotation	TSP	0.4 ±0.34	0.71 ± 0.03	1.4 ±0.01	2.58 ±0.01	2.0 ±0.04	2.21 0±.01	0.75 ±0.01	2.2 ±0.01	2.4 ±0.1
	MPR	0.91 ±0.02	0.61 ±0.02	1.42 ±0.01	2.58 ±0.01	1.84 ±0.01	2.24 ±0.01	0.72 ±0.01	2.55 ±0.01	1.92 ±0.01

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

4.5: Plant N as affected by fertilizer type and cropping systems at different stages of sorghum growth

The main effects fertilizer type, cropping systems and stage of sorghum growth interacted significantly (Appendice 1&11) to affect plant N in lupin sorghum experiment (Table 10) and in the chick pea sorghum experiment (Table 11). The main effects in themselves; fertilizer type, stage of growth were not significantly different in lupin and chick pea sorghum experiments (Appendice 1&11)

4.6: Plant P as affected by fertilizer type and cropping systems at different stages of sorghum growth

The main effects fertilizer type, cropping systems and stage of sorghum growth interacted significantly (Appendice 1&11) to affect plant P in lupin sorghum experiment (Table 12) and in the chick pea sorghum experiment (Table 13). The main effects in themselves; fertilizer type, stage of growth were not significantly different in lupin and chick pea sorghum experiments (Appendice 1&11) but for stage of growth in lupin sorghum experiment (Table 12).

Table 10: Three- way interaction table for plant N (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in lupin sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	TSP	4.3 ± 0.01	1.2± 0.01	0.93 ± 0.07	2.58 ± 0.33	1.98 ± 0.23	2.58 ± 0.52	1.73 ± 0.26	5.06 ± 0.3	7.94 ± 0.52
	MPR	4.2 ± 0.06	1.4± 0.2	0.98 ± 0.97	2.58 ± 0.09	2.18 ± 0.33	2.58 ±0.52	2.6 ±0.1	4.62 ± 0.69	4.69 ±0.42
Sorghum lupin intercrop	TSP	4.6 ± 0.52	0.94 ± 0.46	0.97 ± 0.08	2.38 ± 0.43	1.79 ± 0.85	1.77± ± 0.21	1.62 ±0.4	6.83 ± 0.41	8.41 ±0.54
	MPR	4.28 ± 0.06	1.01 ± 0.1	1.1 ± 0.1	2.58 ± 0.51	2.58 ± 0.52	2.00 ± 0.01	2.52 ± 0.01	6.28 ± 0.01	4.74 0.04
Sorghum lupin rotation	TSP	4.74 ± 0.25	0.85± 0.08	0.89 ± 0.02	2.38 ± 0.43	1.79 ± 0.85	2.78 ± 0.23	2.69 ±0.01	2.07 ± 0.13	7.47 ± 0.83
	MPR	4.68 ± 0.22	0.85 ± 0.02	1.12 ± 0.34	1.19 ± 0.28	1.79 ±0.85	1.19 ± 0.13	3.45 ± 0 .01	5.68 ± 0.49	12.2 ±2.98

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

Table 11: Three- way interaction table for plant N (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in chick pea sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	TSP	4.6 ± 0.65	0.98 ±0.98	0.89 ± 0.23	1.1 ± 0.9	1.59 ± 0.12	1.45 ± 0.49	1.1 ± 0.9	4.69 ± 0.42	5.87 ± 1.1
	MPR	4.8 ± 0.3	1.06 ±0.11	0.96 ± 0.06	1.31 ± 0.01	1.98 ± 0.47	1.0 ± 0.6	1.31 ± 0.01	3.16 ± 0.24	5.21 ± 0.21
Sorghum intercrop	TSP	3.18 ± 0.01	0.79 ± 0.96	0.95 ± 0.57	2.73 ± 0.15	0.6 ± 0.36	0.91 ± 0.01	2.73 ± 0.15	4.09 ± 0.24	6.38 ± 0.15
	MPR	3.58 ± 0.3	0.76 ± 0.05	1.13 ± 0.5	2.52 ± 0.8	2.18 ± 0.33	1.47 ± 0.01	2.52 ± 0.02	4.17 ± 0.29	6.28 ± 0.01
Sorghum rotation	TSP	4.52 ± 0.58	0.83 ± 0.01	0.92 ± 0.07	3.55 ± 0.28	2.18 ± 0.33	1.9 ± 0.53	3.55 ± 0.28	1.57 ± 0.01	7.0 ± 2.65
	MPR	4.52 ± 0.1	1.24 ± 0.03	1.31 ± 0.03	2.13 ± 0.23	1.98 ± 0.23	2.06 ± 0.11	2.13 ± 0.22	3.53 ± 0.55	10.0 ± 2.7

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting; Fl= 50% flowering; mat= maturity

Table 12: Three- way interaction table for plant P (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in lupin sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	TSP	56 ± 1.05	67± 0.1	23.3 ± 0.4	24.9 ± 0.4	29.5 ± 0.05	18.3 ± 0.05	49.5 ± 0.4	32.4 ±1.3	26.4 ± 0.15
	MPR	54.3 ±0.15	51.7 ± 0.32	20.65 ± 0.05	13.5 ± 0.65	18.5 ± 0.35	18.5 ± 0.1	33.55 ± 0.35	41.3 ± 0.1	24.25 ± 0.15
Sorghum lupin intercrop	TSP	43.35 ± 0.4	39.85 ±0.15	34 ±0.2	7.5 ± 0.4	12 ±0.45	15 ±0.05	29.47 ±0.4	15.65 ±0.1	6.5 ±0.1
	MPR	56 ±1	42± 0.45	27 ± 0.2	13.5 ± 0.2	7.5 ± 0.1	73 ± 0.01	7.5± 0.2	21.5 ± 0.35	12 ± 0.03
Sorghum rotation	TSP	49.5 ±0.3	25± 0.45	22.65± 0.1	26.45 ± 0.3	14.1 ± 0.1	59.2 ± 0.35	13.4 ± 0.2	36.9 ± 0.4	33.75 ±0.1
	MPR	86.69± 0.15	31.35 ± 0.3	36 ± 0.05	34.6 ± 0.2	22.5 ±0.1	34.3 ± 0.2	4.69 ± 0.42	75.7 ± 1.14	5.06 ± 0.46

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

Table 13: Three- way interaction table for plant P (%) as affected by fertilizer type, cropping systems at different stages of growth of sorghum in chick pea sorghum experiment. Values are mean ± SD

		2012 LRS			2012 SRS			2013 LRS		
		Sd	Fl	Mat	Sd	Fl	Mat	Sd	Fl	Mat
Sorghum monocrop	TSP	43 ± 1.25	39.5 ± 2.1	34 ± 2.2	25 ± 0.5	34.7 ± 0.4	21.5 ± 0	25.75 ± 0.66	14.44 ± 0.8	37.85 ± 0.7
	MPR	48.65 ± 0.3	34.65 ± 1.1	32 ± 1.1	19.15 ± 3.8	35 ± 0.1	31.4 ± 1.3	32.5 ± 0.6	28 ± 0.4	50.53 ± 0.1
Sorghum chick pea intercrop	TSP	52.6 ± 0.5	43.35 ± 2.5	34 ± 4.4	26.1 ± 1.5	32.4 ± 0.2	16.5 ± 1.1	35 ± 0.8	28.63 ± 0.6	35.15 ± 0.8
	MPR	42.65 ± 0.6	46.65 ± 0.6	38.65 ± 0.5	31.8 ± 4.7	33.25 ± 0.5	21.4 ± 0.5	62.8 ± 0.3	34.9 ± 0.9	50.77 ± 0.3
Sorghum chick pea rotation	TSP	58.6 ± 5.29	25.75 ± 7	35.55 ± 18.4	20 ± 0.1	63.5 ± 0.3	35.7 ± 0.3	51.5 ± 1.6	24.8 ± 0.2	30 ± 1.2
	MPR	23.3 ± 0.75	38.3 ± 0.17	34.85 ± 0.64	11 ± 0.5	14 ± 0.1	17.85 ± 0.1	32.85 ± 0.7	35.23 ± 0.51	25 ± 0.9

Key; SRS= short rain season; LRS = Long rain season; Sd= seedling, 50 days after planting ; Fl= 50% flowering; mat= maturity

4.7 Sorghum DM yield as affected by fertilizer type and cropping systems

Cropping system significantly affected dry matter content in both experiments (Appendice 111&1V). In the LS experiment, a higher sorghum dry matter yield was obtained in the intercropping system (Table 14) whereas in the CS experiment, sorghum monocroping system had the highest dry matter yield (Table 15).

4.8 Sorghum grain yield as affected by fertilizer type and cropping systems

Cropping system and fertilizer type interacted significantly to affect the grain yield content (Appendice 111&1V) in lupin sorghum experiment (Table 16). On the other hand, fertilizer type significantly affected the grain yield content (Appendice 111&1V) in chick pea sorghum experiment (Table 17).

A greater sorghum grain yield was obtained in MPR than TSP plots (Table 16 & 17). The mean range for sorghum grain yield was 10.53- 18 t ha^{-1} for TSP plots and 14.7- 18.3 t ha^{-1} for MPR plots in LS experiment (Table 16) and 14.3- 21.7 t ha^{-1} for TSP plots and 17.7- 24 t ha^{-1} for MPR plots in CS experiment (Table 17).

Table 14: Sorghum Dry matter yields (t ha^{-1}) as affected by fertilizer type and cropping system in lupin sorghum experiment. Values are mean ± SD

	2012 LRS				2012 SRS				2013 LRS			
	Mono	Inter	Rot	Aver.	Mono	Inter	Rot	Aver.	Mono	inter	Rot	Aver.
TSP	25.3	23.0	25.3	24.5	27.7	34.7	24.3	28.9	28.3	35	24.7	29.33
	± 11.6	± 14.8	± 1.53	±9.31	± 11	± 6.5	± 2.1	±6.5	± 10.7	± 7.3	± 2.5	±6.7
MRP	26.3	46.3	21.6	31.4	28	53.7	20	33.9	28.6	51	21	33.5
	± 14.6	± 27.9	± 0.6	±14.4	± 14	± 18.6	± 0.6	±17.5	± 13.7	±15.8	±1.3	±9.9

Table 15: Sorghum Dry matter yields (t ha^{-1}) as affected by fertilizer type and cropping system in chick pea sorghum experiment. Values are mean ± SD

	2012 LRS			2012 SRS			2013 LRS		
	Mono	Inter	Rot	Mono	Inter	Rot	Mono	Inter	Rot
TSP	52.3	36.3	23.3	52.7	37.3	23.7	52	37.3	24
	± 6	± 6	± 6	± 6.1	± 9	± 5	± 7.5	± 9.5	± 4.6
MRP	41.7	40.7	23.3	42.3	40.7	24	42.7	38.6	24
	± 12.6	± 4.6	± 3.2	± 12.2	± 5.5	± 2.6	± 13.2	± 3.5	± 3.5

Key; Mono= Sorghum monocroping; Inter = sorghum intercropping; Rot = sorghum rotation

Table16: Sorghum grain yield (t ha^{-1}) as affected by fertilizer type and cropping system in lupin sorghum experiment. Values are mean ± SD

	2012 LRS			2012 SRS			2013 LRS		
	Mono	Inter	Rot	Mono	Inter	Rot	Mono	Inter	Rot
TSP	11.27 ±5.1	16.3 ± 4.04	12 ± 2.6	10.53 ± 4.7	17.7± 4.2	12.7 ± 2.9	13 ± 6.08	18 ± 3.5	15 ± 2.6
MRP	18.3 ± 3.74	14.7 ± 9.3	17.3 ± 3.78	18.3 ± 4.7	16.7± 7.6	17.7 ± 3.2	18.3 ± 4.7	17 ± 7	16 ± 4.9

Key; Mono= Sorghum monocroping; Inter = sorghum intercropping; Rot = sorghum rotation

Table 17: Sorghum grain yield (t ha^{-1}) as affected by fertilizer type and cropping system in chick pea sorghum experiment. Values are mean ± SD

	2012 LRS			2012 SRS			2013 LRS		
	Mono	Inter	Rot	Mono	Inter	Rot	Mono	Inter	Rot
TSP	21.3 ± 1.5	15.7 ± 5.7	16.3 ± 5.1	21.7 ± 0.6	16.7 ± 6	14.3 ± 2.1	21 ± 1.73	17.3 ± 5	14.7 ± 3.05
MRP	24 ± 3.5	21.7 ± 2.5	20.6 ± 2.3	23 ± 1.7	21.7 ± 1.5	17.7 ± 3.2	22 ± 2	21.6 ± 1.5	19.3 ± 3.05

Key; Mono= Sorghum monocroping; Inter = sorghum intercropping; Rot = sorghum rotation

4.9 Nutrient Balance as affected by fertilizer type and cropping systems

Fertilizer type and cropping system significantly affected nutrient balances in the soil in both experiments (Appendice 111&1V). The nutrient balances generated from this research showed that the full balances were negative for all nutrients (N, P and K) (Table 17 & 18). Highest nutrient balances were observed with N, followed by P and least by K with the use of TSP fertilizer in both experiments. Based on the cropping systems, monocroping system showed the highest nutrient balances followed by intercropping and least by crop rotation as observed in (Table 17 & 18).

Table 18: N, P and K Nutrient Balances (Kg $ha^{-1}yr^{-1}$) as affected by fertilizer type and cropping system in lupin sorghum experiment. Values are mean ± SD

Cropping System	Area (ha)		N	P	K
				Kgha^{-1}	
MONO	0.0018	TSP	-411	-133	-130
		MPR	-400	-144	-137
INTER	0.0018	TSP	-207	-204	-106
		MPR	-137	-233	-112
ROT	0.0018	TSP	-213	-113	-99
		MPR	-144	-117	-93

Key; Mono= Sorghum monocroping; Inter = sorghum intercropping; Rot = sorghum rotation

Table 19: N, P and K Nutrient Balances (Kg $ha^{-1}yr^{-1}$) as affected by fertilizer type and cropping system in chickpea sorghum experiment. Values are mean ± SD

C.S	Area (ha)	P SOURCE	N	P	K
				Kgha^{-1}	
MONO	0.0018	TSP	-360	-144	-112
		MPR	-381	-133	-100
INTER	0.0018	TSP	-316	-106	-96
		MPR	-300	-100	-99
ROT	0.0018	TSP	-286	-100	-100
		MPR	-245	-117	-99

Key; Mono= Sorghum monocroping; Inter = sorghum intercropping; Rot = sorghum rotation

CHAPTER 5

DISCUSSION

5.1: Soil pH as affected by P source, sorghum growth stage and cropping system

The higher soil pH obtained with application of MPR than TSP in the LS experiment was due to its liming effect. MPR contains sizeable quantities of lime, equivalent to 38.3% CaO (Nekesa *et al*., 2005). The dissolution of apatite in PR consumes H^+ ions and thus, it can increase soil pH, depending on PR reactivity (Nekesa *et al*., 2005). In a five-year field trial conducted in an Oxisol fertilized with various PR sources, soil pH increased from 4.1 with the control to 4.7-5.0 with the PR treatments.

The lower soil pH resulting from use of TSP in the 2012 SRS could have been due to slow release of the acid it contains after application to soil. Production of TSP fertilizers requires the use of sulfuric acid that gets slowly released into the soil resulting into low soil pH (Jain *et al*., 2010; Shrivastava *et al*., 2011). In a laboratory investigation in Jimma research Center, Ethiopia, chemical fertilizers applied long term to the soil were reported to cause depletion of some plant nutrients and excess deposition of others in soil, and consequently caused increased acidity of soil (Kebede, *et al*., 2005).

Soil pH increase at flowering stage may have been due to release $CaCO_3$ from MPR which may have peaked at this growth stage. Legumes acidify the surrounding rhizosphere by acid secretion (Weisskopf *et al*., (2006). MPR contains calcium carbonate which has a liming effect on soil (Szilas *et al*., 2007).

A decrease in soil pH at the maturity could be due to inefficiency of the roots due to aging. As plant roots age they release accumulated acids in the nodules leading to a low soil pH. Weisskopf *et al*., (2006) observed fastest citrate excretion at mature stage of lupin cluster roots.

Lower soil pH in the intercropping system in both CS and LS experiments was due exudation of carboxylates from legume roots. Chickpea like lupin, exudes carboxylates from its roots (Veneklaas *et al*., 2003). White lupin is well known to exude large amounts of citric and malic acids, which are especially, released from cluster or proteoid roots. These acids were capable of lowering the soil pH. Soil pH was also low in the crop rotation system due to the carboxylate exudation as legumes followed sorghum crop in succession (Mimmoa e*t al*., 2011). A study conducted by Dakora *et al*. (2002) showed that, legumes release a net excess of protons. These protons can markedly lower rhizosphere pH.

5.2: Soil available N as affected by Fertilizer type, Cropping systems and Stage of growth

The expected N range in the soil is 0.02- 0.5% and results obtained in this study (Table 4.2) show that the soil was sufficient in SAN after application of treatments. The higher SAN observed in the MPR compared to TSP plots was due to increased availability of P to legumes which caused proper root development, nodule formation and consequently a higher N fixed (Christiansen and Graham, 2002). This can also justified from (Appendix XV111) where the root length and number of cluster roots was observed to be greater in MPR experiments compared to TSP experiments. Legumes can release locked P from MPR (Badawi *et al*., 2011). Besides, MPR has a liming effect to the soil as it contains calcium carbonate (Szilas *et al*., 2007) and thus raised the soil pH creating suitable environment for the survival of rhizobium bacteria responsible for N fixation (Dakora *et al*., 2002).

The higher SAN observed in the intercropping system and rotation systems than monocropping could have resulted from N fixed by the legume component (Zhang and Li, 2003) combined with CAN top dress. This is in addition to mineralization of incorporated legumes residues after harvest of grains. Most studies on intercropping have focused on the legume-cereal intercropping, and its effect on N input from symbiotic nitrogen fixation. Rotational fallows or relay intercrops have been shown to increases N input and structural stability of the soil (Sileshi *et al*., 2010).

The higher SAN observed at the flowering stage in both experiments could have resulted from the CAN top dress and also the N fixation process by legume component in the rotation and intercropping systems (Zhang and Li, 2003). At crop seedling stage, there was no N fertilizer applied and at harvest stage, much of the N had been used in seed formation. N is a key component of enzymes and other proteins essential to all growth functions (Christiansen and Graham, 2002). This may explain the lower amounts of SAN at these two growth stages.

5.3: Soil available P as affected by Fertilizer type, Cropping systems and Stage of growth

The higher SAP after fertilizer application compared to that at the start of the experiment (Table 3.1) signifies the importance of P fertilization in enhancing soil P fertility. The mean range of SAP of 14.2- 88 mg kg^{-1} for TSP plots and 18- 89.7 mg $kg^{-1}$for MPR plots in LS experiment and 6.18- 70.8 mg kg^{-1} for TSP plots and 10.7- 71.8 mg kg^{-1} for MPR plots in CS experiment shows the soil was sufficient in soil available P. In most agricultural soils, organic P comprises 30–80 mg kg^{-1} of the total P range for sufficiency (Li *et al*., 2004).

Lower SAP values for TSP than MPR plots in the first season was because TSP is water soluble thus availed its P easily in soil, which was subsequently taken up by the crop. Low amounts were thus left in the soil. Higher soil available P in MPR than TSP plots in the subsequent seasons was possible since MPR has high phosphate content (28-32% P_20_5), last long in the soil and can release locked and bound minerals and build the capital P which can be released over a long period of time.

Low SAP at seedling stage in both experiments was because much of the P was taken in by the plant for root growth and development (Kimiti and Jacinta, 2011). Low amounts at the flowering stage were because much of the phosphorus was taken up for legumes nodule formation and N fixation as N fixation is a P requiring process (Christiansen and Graham, 2002). This left insignificant amounts in the soil at this stage. The higher P in the soil at harvest stage could be due to less P uptake by the plant after grain filling, thus higher amounts of P were accumulated in the soil at the harvest stage. The MPR also had residual effects (Nekesa *et al*., 2005).

In both of experiments, SAP was lowest in the intercropping and crop rotation system in all the seasons, because much of the P was taken in by the plants for root development and growth and also nodule formation (Li *et al*., 2011) leaving insignificant amounts in the soil. The legumes in these two systems also required P for N fixation as N fixation is a P requiring process (Christiansen and Graham, 2002). Legumes acidify the rhizosphere changing the pH from 7.5 to 4.8 and cereal crops sown mixed with lupin could increase the absorption efficiency of P from PR (Ligaba *et al.,* 2004).

SAP was slightly higher in the monocroping system in both legume experiments. This was because sorghum crop was the sole crop at a stand unlike in the other two systems where P was required by the legume component for nodulation. In addition, there was low competition for P unlike in the other two systems, resulting in greater levels of SAP.

Higher SAP in MPR plots in the LRS 2013, with the intercropping system could have been due to the release of locked P MPR by legumes. Legumes are known for their potential in P solubilization (Badawi *et al*., 2011). Legumes can enhance PR dissolution through acidification of the rhizosphere and exudation of organic acids (Pypers *et al.*, 2007). Chickpea like lupin, exudes carboxylates from its roots and can thus mobilize calcium-bound phosphate (Veneklaas *et al*., 2003). Beside, white lupin was able to develop proteoid roots that exude large quantities of malate and citrate during P deficiency, increasing the availability of mineral-bound P by solubilizing Ca, Fe and Al phosphates (Neumann *et al*., 2000) which made P available (Li *et al*., 2004).

5.4: Soil organic C as affected by Fertilizer type, Cropping systems and Stage of growth

Results obtained indicate that soil was sufficient in SOC. In most agricultural soils, SOC ranges between 0.5- 10% for sufficiency (Chan *et al*., 2008). SOC is important for all three aspects of soil fertility, chemical, physical and biological fertility. SOC obtained upon plant dry matter decomposition releases N, P and a range of other nutrients for plant growth. SOC on other hand promotes soil structure thus leading to proper root growth and ease of cultivation and these in turn result in to proper plant overall growth, higher dry matter accumulation and a higher SOC upon decomposition (Chan *et al*., 2008).

The higher SOC content with MPR than TSP application could be due to higher phosphate content in MPR (28-32% P_2O_5). This led to proper root growth and development, which in turn led to proper overall plant growth and development and a resultant high dry matter accumulation (Table 4.7). The plants residues incorporated in the soil after harvesting increased in soil organic matter content and thus boosted the SOC level in the soil (Abbasi *et al*., 2012). Residue decomposition provides soil organic matter which plays an important role in nutrient cycling and availability, assisting in root growth and plant nutrient uptake (Chan *et al*., 2008).

Intercropping system with application of MPR led to a higher SOC in both legume experiments. This could be due to the effect of legumes in MPR solubilization and thus availing P to the soil for proper plant growth and development, higher dry matter accumulation and thus higher SOC content in the soil as aforementioned. Besides in intercropping, two plants are involved thus the bulk of the dry matter content was greater when compared with the other systems.

5.5: Plant N as affected by Fertilizer type, Cropping systems and Stage of growth

Both experiments show that the plants had adequate levels of plant N. The average range of plant N in sorghum is usually 2.4- 4% (Southern Cooperative Series Bulletin #394). This could have been due to adequate supply of N in the soil through N fixation and CAN application thus plants were able to take up higher levels of N.

Lack of significant differences in fertilizer types used in plant N content in both experiments showed that MPR was equally competitive as TSP in supplying of P for proper root development and nodule formation and N fixation (Jama and Straaten, 2006). This resulted in higher N levels in the soil was in turn taken up by the plant.)

A higher plant N in the intercropping system and rotation could have resulted from the presence of accumulated N levels after fixation by legume component as well as mineralization of incorporated residues (Saleem *et al*., 2011). This was taken up by sorghum. This may also explain higher plant N in the rotation system. Residue management by incorporating plant residues in soil led to decomposition and release of N back into the soil which was taken up by the succeeding plant. Absence of legumes for N fixation partly led to the lower plant N in the monocroping system. Growing cereals continuously in low input dry land conditions is likely to be an unsustainable system in the long run due to depletion in soil fertility and development of unfavorable soil physical and biological conditions. There is thus a strong need to introduce crop rotation practices as well as intercropping so as to increase N supply for cereals (Patil *et al*., 2011).

Increase in soil N in the subsequent seasons after LRS of 2012 could have been caused by an increase in soil N levels due to residue incorporation, decomposition and release of N which was in turn taken up by the plants. Legumes, when integrated into cereal cropping systems either as rotational fallows or relay intercrops, have been shown to provide considerable amounts of organic matter and nitrogen to the soil (Sileshi *et al*., 2010).

5.6: Plant P as affected by Fertilizer type, Cropping systems and Stage of growth

The observed lack of significant differences in plant P with use of either TSP or MPR shows that both were equally competitive. MPR can become a viable alternative nutrient source for P (Sahrawat *et al*., 2001). The effectiveness of MPR was enhanced by the use of legumes (Pypers *et al.*, 2007). Legumes crops exude acids from their roots providing an acidic environment that allows for MPR solubilization. MPR works best in low pH soils of less than 5.5 (Singh and Reddy, 2011). Besides, upon harvesting of the crop, the residues were incorporated in to the soil and due to decomposition; they were able to release acids that lowered soil pH. This caused MPR solubilization and increased P availability (Waigwa *et al*., 2003).

A higher plant P realized at the seedling stage and also at flowering stage was due to P requirement for root growth and nodule formation and N fixation respectively (Christiansen and Graham, 2002). A lower plant P was observed at the harvest stage since there was a low plant P requirement by the plant after grain filling and thus a lower uptake.

A higher plant P in the monocroping system was due to lack of competition for P since there was only one standing crop. The lower plant P in the intercropping system in both legumes and seasons could have been due to a competition for P by the two different crops standing on the field at the same time. The higher plant P in the rotation system was due to enhanced P availability from decomposing legume residues grown previously (Pypers *et al*., 2007).

5.7: Sorghum dry matter as affected by Fertilizer type, Cropping systems and Stage of growth

The results obtained indicate a higher sorghum dry matter content. The expected dry matter (DM) range for sorghum under optimal growth conditions ranges from 20- 75 t ha^{-1}. The lack of significant differences in sorghum DM with fertilizer type and interaction between cropping systems and fertilizer types in both experiments implies that both MPR and TSP were equally competitive in their effect on dry matter accumulation. Thus MPR, a cheaper source (Vanlauwe and Giller, 2006) can become a viable alternative to TSP as a source of P as described by (Jain *et al*., 2010).

Highest DM in monocroping system with application of MPR was possible because sorghum was the only standing crop and therefore received no competition for the various nutrients in the soil. This led to higher uptake of the N and P for proper plant growth and development and accumulation of dry matter. On the other hand, competition of resources by the component crops in the intercropping system led to a lower DM yields.

5.8: Sorghum grain yield as affected by Fertilizer type, Cropping systems and Stage of growth

Fertilizer type had no influence on grain yield in LS experiment, implying that both fertilizer sources were effective in their supply of P to sorghum for increased sorghum grain yield. MPR could thus serve as a viable alternative to TSP as it is also cheaper and environmentally friendly. Some grain yield losses may have also occurred due to bird infestation. Although cropping systems did not significantly affect sorghum grain yield in both experiments the intercropping system may be best system on focus compared to the other two systems. Intercropping system is well known for its opportunity to exploit nature's principle of diversity farms as well as contributing to crop production by its effective utilization of resources (Zhang and Li 2003).

5.9 Nutrient balances by NUTMON

There was a significant effect on type of fertilizer used on nutrient balances in both experiments. The higher negative values for nutrient balances with the use of TSP as opposed to MPR could be attributed due to the negative effect of mineral fertilizers on soil pH. At a low soil pH P undergoes fixation making it though present in the soil but un available to plants. BNF on the other hand is impaired. This is because most bacteria responsible for N fixation cannot thrive at a low soil pH (Dakora *et al*., 2002).

Besides, in Jimma research Center, Ethiopia, chemical fertilizers applied long term to the soil caused depletion of some plant nutrients and excess deposition of others in soil, and consequently caused increased acidity of soil. This could be the sure reason as to the effect of greater negative values of nutrient balances in the soil with the use of TSP. This situation if continued will diminish the nutrient stock; and this farm will have a negative effect on crop production (De Jager *et al*., 1998; Vlaming *et al*., 2001). Thus with the use of TSP, more nutrient elements are exported from the system than imported into the system resulting in a net imbalance. This was justified by Kebede, *et al*. (2005).

The greater negative nutrient balance in the soil with element N, at this farm, reflects a high outflow of N as opposed to inflow. The outflow could be through removal of harvested produce (OUT1), removal of crop residues (OUT2), leaching (OUT3), de-nitrification and volatilization (OUT5) and erosion (OUT 5). The inputs included inorganic fertilizer; CAN (IN1), incoporation of crop residues (IN2) and BNF (IN4). The outflows out balanced the inflows resulting in a net imbalance.

Outflow of inputs exceeded inflow in P nutrient element causing a negative balance. The outflow could be through removal of harvested produce (OUT1), removal of crop residues (OUT2) and soil erosion (OUT 5). The inputs included inorganic fertilizer; TSP or MPR (IN1), incoperation of crop residues (IN2) and sedimentation (IN5). In K, a negative balance was also observed. The outflow could be through removal of harvested produce (OUT1), removal of crop residues (OUT2) and soil erosion (OUT 5). The inputs included; incoperation of crop residues (IN2) and sedimentation (IN5).

There was a significant effect on nutrient balances with the cropping systems used. In both experiments, monocroping system showed the highest negative nutrient balances in N, P and K, followed by intercropping and least by crop rotation as observed in (Table 4.9). The greater negative values in the monocroping system could be due to absence of legumes for BNF to boost on the inputs. Besides, there was a low quantity of dry matter (crop residues) incoperated into the soil (IN2) as sorghum was the only standing crop at a time. Thus monocroping system was not thus a sustainable system.

To counter these negative nutrient balances, this farm could be compensated for lower mineral fertilizer inputs by intensive soil enriching and nutrient conserving practices, including: rational use of manure; systematic management and recycling of crop residues; collection and inco-operation of leaf litter; and improved soil conservation.

Besides, a judicious manipulation of nutrient stocks and flows in a way that leads to satisfactory and sustained production through integrated nutrient management (INM) could also be the way forward. This could be achieved through comprehensive solutions in the field of integration of organic and inorganic fertilizers (IN1 & 2), integration of livestock (IN2d), soil water conservation (OUT 3& 5), and integration of leguminous plants that have ability for BNF (IN4), agricultural policies and marketing (Van den Bosch *et al*., 1998).

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

The following conclusions and recommendations were drawn from this research

1) Legume crops due to their release and accumulation of carboxylic acids lowered the soil pH to below 5.5 and this enhanced solubilization of MPR and thus availability of P. Residue incorporation into the soil and decomposition also led to release of acids during the decomposition process. This led to a low soil pH. MPR has a potential for liming due to the presence of calcium carbonate and this positively affected soil pH creating a suitable environment for survival of bacteria responsible for N fixation. The use of TSP lowered the soil pH to below 4 and this impaired N fixation. Thus MPR was a preferred fertilizer to TSP as it influenced soil pH positively. A higher soil available P, N and Carbon was observed with the use of TSP fertilizer as compared to MPR in the first season. Subsequent seasons showed that soil available P, N and Carbon in MPR plots approached that of TSP plots and even exceeded in the long run. Since MPR is cheaper than TSP, combining legume crops; white lupin and chickpea with the use of MPR was thus preferable in availing P, N and Carbon to the soil.

2) Significant differences in plant N and P were observed in the various cropping systems. Intercropping system had the highest plant P and N followed by crop rotation and finally monocroping. The legumes in these cropping systems enhanced MPR mobilization thus availing P in soil which was in turn taken up by the plant. Higher levels of SAP led to improved root growth, proper nodulation and increased N fixation and accumulation of N. This was subsequently taken up by the plant resulting to higher levels of plant N.

3) Fertilizer type and interaction between cropping systems and fertilizer types in both experiments did not significantly affect sorghum dry matter. This implies that both MPR and TSP were equally competitive in their effect on dry matter accumulation. Thus MPR, a cheaper source became a viable alternative to TSP as a source of P. Monocroping followed by intercropping system with application of MPR showed the highest sorghum dry matter content. In monocroping system, there was less competition of resources as sorghum was the only standing crop. Thus it took up all the available nutrients especially N and P from the soil. This led to proper root growth and

development and subsequently high dry matter accumulation. Intercropping system also had a higher dry matter content due to the presence of the two crops at a time, thus the bulk of the dry matter was greater. This was however, slightly lower than in the monocroping system due to the competition of resources by the two crops. Sorghum grain yield increased with season with the highest observation in LRS 2013. The various cropping systems and fertilizer types had no significant effect on sorghum grain yield in both experiments. This implied that all the cropping systems and fertilizer types were equally important in their effect on grain yield accumulation and hence either could be adopted. Some yield losses may however have occurred through bird infestation.

4) Negative nutrient balances were observed with N, P and K. This shows that more nutrients were exported from this farm than imported. This situation if continued would diminish the nutrient stock, and this will have a negative effect on production. Therefore an increase in inputs is expected for this farm for increased crop production. This could be attributed through increased incorporation of legume crops for increased BNF, use of manure, leaf litter, household refuse and the use of both organic and in organic fertilizers and also through INM.

5) Thus, the type of fertilizer had a great influence on SAP, SAN, SC, soil pH, plant P and N, dry matter content and grain yield, NB and the overall plant growth. MPR in the presence of legumes and the employment of intercropping system led to a better performance in the long run as compared to TSP. There is a need for more research to improve the poor performance of MPR in the first season and to identify other mechanisms of P mobilization from MPR. Thus MPR could be a viable alternative to TSP in supplying P to both soil and plants.

REFERENCES

Abbasi, M. K., Khizar, A. (2012). Microbial biomass carbon and nitrogen transformations in a loam soil amended with organic–inorganic N sources and their effect on growth and N-uptake in maize. *Ecological Engineering* **39:**123-132.

Akem, C. (1999). Asocochyta blight of chickpea. Present status and future priorities. *International Journalof Pest Management* **45:** 131-137.

Antunesa, P. M., Sochneiderb, K., Hillisoc, D. and Klironomosa, J. N. (2007). Can the arbusocular mycorrhizal fungus *Glomus intraradices* actively mobilize P from phosphate rocks? *Pedobiologia* **51:**281-286.

Aria, M. M., Lakzian, A., Haghnia, G. H., Berenji, A. R. Besharati, H. and Fotova, A. (2010).Effect of Thiobacillus, sulfur, and vermicompost on the water-soluble phosphorus of hard phosphate rock. *Bioresource Technology* **101:** 551- 554.

Azziz, G., Bajsa, N., Haghjou, T., Taulé, C., Valverde, A., Igual, J. M. and Arias, A. (2012). Abundance, diversity and prospecting of culturable phosphate solubilizing bacteria on soils under crop–pasture rotations in a no-tillage regime in Uruguay. *Applied Soil Ecology* **61:**320-326.

Badawi, F. S. F., Biomy, A. M. M. and Desoky, A. H. (2011). Peanut plant growth and yield as influenced by co-inoculation with Bradyrhizobium and some rhizo-microorganisms under sandy loam soil conditions. *Annals of Agricultural Socience* **56:** 17-25.

Bandyopadhyay, K. K., Misra, A. K., Ghosh, P. K. and Hati, K. M. (2010). Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil & Tillage Research* **110:** 115- 125.

Bayala, J., Sileshi, G. W., Coe, R., Kalinganire, A., Tchoundjeu, Z., Sinclair, F. and Garrity, D. (2012). Cereal yield response to conservation agriculture practices in drylands of West Africa: A quantitative synthesis. *Journal of Arid Environments* **78:**13- 25.

Bergera, J. D., Kumarc, S., Nayyarc, H., Streetd, K. A., Sandhue, J. S., Henzellb, J. M. Kaure, J. and Clarke, H. C. (2012). Temperature-stratified SOCreening of chickpea (*Cicer* *arietinum* L.) genetic resource collections reveals very limited reproductive chilling tolerance compared to its annual wild relatives. *Field Crops Research* **126:** 119- 129.

Botha, A. (2011). The importance and ecology of yeasts in soil. *Soil Biology and Biochemistry* **43:** 1-8.

Buchanan, C.D., Lim, S., Salzman, R.A., Kagiampakis, I., Morishige, D.T., Weers, B.D., Klein, R.R., Pratt, L.H., Cordonnier-Pratt, M.M., Klein, P.E., Mullet, J.E., (2005) *Sorghum bicolor's* transcriptome response to dehydration, high salinity and ABA. *Plant Molecular Biology* **58:** 699 – 720.

Chan, Y. (2008). Increasing soil organic carbon of agricultural land. *Principal Research Scientist (Soils), Rich* PRIMEFACT 735.

Chapman, R. D. (1965). Cation exchange capacity by ammonium saturation, in: Methods of Soil Analysis. Agronomy. Part II, No.9, edited by Black, C. A; *American Socience of Agronomy.Madison, Wisoconsin,* USA. 891-901.

Christiansen, I. and Graham, P. H. (2002). Variation in di nitrogen fixation among Andean bean genotypes grown at low and high levels of phosphorus supply. *Field Crops Research* **73:** 133- 142.

Cobo, J. G., Dercon, G. and Cadisoch, G. (2010). Nutrient balances in African land use systems across different spatial Socales: A review of approaches, challenges and progress. *Agriculture, Ecosystems and Environment* **136:** 1-15.

Dakora, F. D. and Phillips, D. A. (2002). Root exudates as mediators of mineral acquisition in low-nutrient environments. *Plant and Soil* **245:** 35–47.

De Jager, A., Nandwa, S. M. and Okoth, P. F. (1998). Monitoring nutrient flows and economic performance in African farming systems (NUTMON). Concepts and methodologies. *Agriculture Ecosystems and Environment* **71:** 37-48.

Esilaba, A. O., Nyende, P., Nalukenge, G., Byalebeka, J.B., Delve, R. J. and Ssali, C. H. (2005). Resource flows and nutrient balances for crop and animal production in smallholder farming systems in Eastern Uganda Agriculture, *Ecosystems and Environment* **109:** 192- 201.

Ganjeali, A., Porsa, H. and Bagheri, A. (2011). Assessment of Iranian chickpea (*Cicer arietinum* L.) germplasms for drought tolerance. *Agricultural Water Management* **98:** 1477-1484.

Gateri, M. W., Muriuki, A. W. and Kanyanjua, S. M. (2004). Sorghum responses to inorganic fertilizer and farmyard manure in Kenya. *Journal of Experimental Botany* **55:** 2251-2259.

Gerke, J., Beibner, L. and Romer, W. (2000). The quantitative effect of chemical phosphate mobilization by carboxylate anions on P uptake by a single root. II. The importance of soil and plant parameters for uptake of mobilized P. *Journal of Plant Nutrition and Soil Socience* **163:** 213- 219.

Groote, H. D., Rutto, E., Odhiambo, G., Kanampiu, F., Khan, Z., Coed, R. and Vanlauwe, B. (2010). Participatory evaluation of integrated pest and soil fertility management options using ordered categorical data analysis. *Agricultural Systems* **103:** 233-244.

Han, L. P., Steinbergerc, Y., Zhaoa, Y. L., and Xie, G. H. (2011). Accumulation and partitioning of nitrogen, phosphorus and potassium in different varieties of sweet sorghum. *Field Crops Research* **120:** 230- 240.

Hossaina, M. F., Elahi, S. F., White, S. K., Alam, Q. K., Rother, J. A. and Gaunt, J. L. (2012). Nitrogen budgets for Boro rice (Oryza sativa L.) fields in Bangladesh. *Field Crops Research* **131:** 97- 109.

Islam, M. N., Nizam, S. Verma, P. K. (2012). A highly efficient Agrobacterium mediated transformation system for chickpea wilt pathogen *Fusarium oxysporum*. sp. ciceri using DsRed- Express to follow root colonization. *Microbiological Research* **131:** 97-109.

Jaetzold, R. and Sochmidt, H. (1983). Farm Management Handbook of Kenya.Natural Conditions and Farm Management Information.Part B. Central Kenya (Rift Valley and Central Province).*Ministry of Agriculture* **2:** 389- 413.

Jaetzold, R., Sochmidt, H., Hornetz, B and Shisanya, C. (2006). Farm management handbook of Kenya- natural conditions and farm management information (2ndEdition). Volume II/A western Kenya Ministry of Agriculture, Nairobi.

Jain, R., Saxena J. and Sharma V. (2010). The evaluation of free and encapsulated *Aspergillus awamori* for phosphate solubilization in fermentation and soil–plant system.*Applied Soil Ecology* **46:** 90- 94.

Jama, B. and Straaten P. V. (2006). Potential of East African phosphate rock deposits in integratednutrient management strategies. *Anais da Academia Brasileira de Ciências* **78(4):** 781- 790.

Jayasinghearachchi, H. S., Seneviratne, G. (2006). Fungal solubilization of phosphate rock is enhanced by forming fungal–rhizobial biofilms. *Soil Biology & Biochemistry* **38:** 405-408.

Kebede, T. and Mikru, Z. (2005). The nutrient status of long term fertilized soils of coffee plantation in Southwestern Ethiopia. *Jimma agricultural research center, P.o.Box 192, Jimma Ethiopia.*

Kifuko, M. N., Othieno, C. O., Okalebo, J. R., Kimenye, I. N., Ndung'u, K. W. and Kipkoech A. K. (2007). Effect of combining organic residues with *Minjingu* phosphate rock on sorption and availability of phosphorus and maize production in acid soils of Western Kenya*. Explanatory Agriculture* **43:** 51-66.

Kimiti, Jacinta M. (2011). Influence of integrated soil nutrient management on cowpea root growth in the semi-arid Eastern Kenya. *African Journal of Agricultural Research* **6(13):** 3084-3091.

Li, S. M., Li, L., Zhangi, F. S. and Tang, C. (2004). Acid Phosphatase Role in Chickpea/ Maize Intercropping. *Annals of Botany* **94:** 297-303.

Li, S. X., Wang, Z. H. and Stewart, B. A. (2011). Differences of Some Leguminous and Non leguminous Crops in Utilization of Soil Phosphorus and Responses to Phosphate Fertilizers. *Advances in Agronomy* **110:** 130- 202.

Ligaba, A., Yamaguchi, M., Shen, H., Sasaki, T., Yamamoto, Y. and Matsumoto, H. (2004). Phosphorus deficiency enhances plasma membrane H+- ATPase activity and citrate exudation in greater purple lupin (*Lupinus pilosus*). *Functional Plant Biology* **31:** 1075-1083.

Mimmoa, T., Hann, S., Jaitz, L., Cesoco, S., Emanuele, G. C. and Pusochenreiter, M. (2011). Time and substrate dependent exudation of carboxylates by Lupinus albus L.and Brassica napus L. *Plant Physiology and Biochemistry* **49:** 1272-1278.

Mohammed, I., Abdelrahman, R. Ahmed, A. R. and Senge, B. (2012). Dough rheology and bread quality of wheat–chickpea flour blends. *Industrial Crops and Products* **36:** 196-202.

Moroke, T. S., Sochwartz, R. C., Brown, K. W. and Juo, A. S. R. (2011). Water use efficiency of dryland cowpea, sorghum and sunflower under reduced tillage. *Soil and Tillage Research* **112:** 76- 84.

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

Mutava, R. N., Prasad, P. V. V., Tuinstra, M. R., Kofoid, K. D. and Yu, J. (2011). Characterization of sorghum genotypes for traits related to drought tolerance. *Field Crops Research* **123:** 10- 18.

Mutisya, J., Sitieney, J.K., Gichuki, S.T., (2010) Phenotypic and physiological aspects related to drought tolerance in sorghum. *Journal of African Crop Science* **18:** 175 – 182.

Ndakidemi, P. A. (2007). Agronomic and Economic Potential of Tughutu and *Minjingu* Phosphate Rock as Alternative Phosphorus Sources for Bean Growers. *Pedosphere* **17(6):** 732- 738.

Nekesa, A. O., Okalebo, J. R., Othieno, C. O., Thuita, M. N., Kipsat1, M., Bationo, A., Sanginga, N.,Kimettu J.A and Vanlauwe, B. (2005). The potential of Minjingu phosphate rock from Tanzania as a liming material: Effect on maize and bean intercrop on acid soils of western Kenya. *African Crop Socience Conference Proceedings* **7:** 1121-1128.

Neumann, G., Massonneau, A. S., Langlade, N., Dinkelaker, B., Hengeler, C., Mheld, V. R. and Martinoia, E. (2000). Physiological aspects of cluster root function and development in phosphorus-deficient white lupin (*Lupinus albus* L.). *Annals of Botany* **85:** 909-919.

Nezomba, H., Tauro, T. P. and Mtambanengwe, F. M. (2010). Indigenous legume fallows (indifallows) as an alternative soil fertility resource in smallholder maize cropping systems. *Field Crops Research* **115:** 149- 157.

Ngome, A. F., Becker, M., Mtei, K. M. and Mussgnug, F. (2011). Fertility management for maize cultivation in some soils of Western Kenya. *Soil and Tillage Research* **117:** 69- 75.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. J. (2002). f*Laboratory Methods of Soil and Plant Analysis: A Working Manual. 2nd Edition*. Nairobi, Kenya: Marvel EPZ K Ltd.

Otingaa, A. N., Pypers, P., Okalebo, J. R., Njorogeb, R., Emongole, M., Six, L., Vanlauwe, B. and Merckxa, R. (2013). Partial substitution of phosphorus fertilizer by farmyard manure and its localized application increases agronomic efficiency and profitability of maize production. *Field Crops Research* **140:** 32- 43.

Park, J. H., Bolana, N., Megharaja, M. and Naidua, R. (2011). Isolation of phosphate solubilizing bacteria and their potential for lead immobilization in soil. *Journal of Hazardous Materials* **185:** 829- 836.

Patil, S. V., Halikatti, S. I., Hiremath, S. M., Babalad, H. B., Sreenivasa, M. N., Hebsur, N. S. and Somanagouda, G. (2011). Effect of organic manures and phosphate rock on growth and yield of chickpea (*Cicer arietinum* L.) in vertisols. *Karnataka Journal of Agricultural Socience* **24 (5):** 636- 638.

Phong, L. T., Stoorvogel, J. J., Mensvoort, M. E. F. and Udo, H. M. J. (2010). Modeling the soil nutrient balance of integrated agriculture aquaculture systems in the Mekong Delta, Vietnam.*Nutrient Cycling Agroecosystems* **17(6):** 732- 738.

Porres, J. M., Aranda, P., Jurado, M. L. P. and Urbano, G. (2005). Nutritional Potential of Raw and Free r-Galactosides Lupin (*Lupinus albus Var. multolupa*) Seed Flours. Effect of Phytase.Treatment on Nitrogen and Mineral Dialyzability. *Journal of Agricultural Food Chemistry* **53:** 3088- 3094.

Prasad, P. V. V. and Staggenborg, S. A. (2004). Growth and production of sorghum and millets.*Soils, Plant Growth and Crop Production* **3:** 1-9.

Pypers, P., Huybrighs, M., Diels, J., Abaidoo, R., Smolders, E. and Merck, R. (2007). Does the enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability? *Soil Biology and Biochemistry* **39:** 2555- 2566.

Qia, W. Z., Liua, H. H., Liua, P., Donga, S. T., Zhaob, B. Q., Soc, H. B., Li, G., Liud, H. D., Zhanga, J. W. and Zhao, B. (2012). Morphological and physiological characteristics of corn (Zea mays L.) roots from cultivars with different yield potentials. *European Journal ofAgronomy* **38:** 54– 63.

Rai, K.N., Murty, D.S., Andrews, D.J., Bramel-Cox, P.J. (1999). Genetic enhancement of perl millet and sorghum for the semi-arid tropics of Asia and Africa. *Genom* **42:** 617 – 628.

Roy, R.N., Misra, R. V., Lesochen, J. P. and Smaling, E.M. (2003). Assessment of soil nutrient balance. Food and agriculture organization of the united nations Rome. Research Report 82. Colombo, Sri Lanka: International Water Management Institute.

Saleem, R., Ahmed, Z. I., Ashraf, M., Arif, M., Malik, M. A., Munir, M. and Khan, M. A. (2011). Response of maize-legume intercropping system to different fertility sources under rainfed conditions. *Sarhad Journal Agriculture* **27(4):** 503-511

Sanchez, P. A. and Leakey, R. R. B. (1997). Land-use transformation in Africa: three determinants for balancing food security with natural resource utilization. *European Journal of Agronomy* **7:** 15-23.

Sanjeewa, W. G. T., Wanasundara , J. P. D., Pietrasik, Z. and Shanda, P. J. (2010). Characterization of chickpea (*Cicer arietinum* L.) flours and application in low-fat pork bologna as a model system. *Food Research International* **43:** 617-626.

Segala, E., Shouseb, P., Poss, J. A., Crohna, D. M. and Bradfordb, S. A. (2010). Recommendations for nutrient management plans in a semi-arid environment.Agriculture, *Ecosystems and Environment* **137:** 317- 328.

Shahid, A. A., Husnain, T. and Riazuddin, S. (2008). ASOCochyta blight of chickpea: Production of phytotoxins and disease management. *Biotechnology Advances* **26:** 511-515.

Shane, M. W. and Lambers, H. (2006). Systemic suppression of cluster-root formation and net P-uptake rates in *Grevillea crithmifolia* at elevated P supply: a proteacean with resistance for developing symptoms of 'P toxicity'. *Journal of Experimental Botany* **57:** 413- 423.

Shisanya, C. A. (2003). A note on the response by smallholder farmers to soil nutrient depletion in the East African highlands. *Food, Agriculture and Environment* **1, 3 & 4:** 247- 250.

Shrivastava, M., Kale, S. P. and Souza, S. F. D. (2011). Phosphate rock enriched post-methanation bio-sludge from kitchen was the based biogas plant as P source for mung bean and its effect on rhizosphere phosphatase activity. *European Journal of Soil Biology* **47:** 205-212.

Sileshi, G., Akinnifesi, K. F., Debusho, L. K., Beedy, T., Ajayi, O. C. and Mong'omba, S. (2010). Variation in maize yield gaps with plant nutrient inputs, soil type and climate across sub-Saharan Africa. *Field Crops Research* **116:** 1- 13.

Singh, H. and Reddy, M. S. (2011). Effect of inoculation with phosphate solubilizing fungus on growth and nutrient uptake of wheat and maize plants fertilized with phosphate rock in alkaline soils. *European Journal of Soil Biology* **47:** 30- 34

Singh, N., Kaur, A. S., Isono, N. and Noda, T. (2010). Genotypic diversity in physico-chemical, pasting and gel textural properties of chickpea (*Cicer arietinum L.*).*Food Chemistry* **122:** 65-73.

Sirtori, A. E., Resta, D., Brambilla, F., Zacherl, C. and Arnoldi, A. (2010). Effects of various processing conditions on a protein isolate from Lupinus angustifolius. *Food Chemistry* **120:** 496-504.

Szilas, C., Semoka, J. M. R., Borggaard, O. K. (2007). Can local Minjingu phosphate rock replace superphosphate on acid soils in Tanzania? *Nutrient Cycling in Agroecosystems* **77(3):** 257-268.

Vanlauwe, B. and Giller, K. E. (2006). Popular myths around soil fertility management in sub-Saharan Africa. *Agriculture, Ecosystems and Environment* **116:** 34- 46.

Vasilakogloua, I., Dhimab, K., Karagiannidis, N. and Gatsisb, T. (2011). Sweet sorghum productivity for biofuels under increased soil salinity and reduced irrigation. *Field Crops Research* **120:** 38- 46.

Veneklaas, E. J., Stevens, J., Cawthray, G. R., Turner, S., Grigg, A. M. and Lambers, H. (2003). Chickpea and white lupin rhizosphere carboxylates vary with soil properties and enhance phosphorus uptake. *Plant and Soil* **248:** 187-197.

Vlaming, J., Van den Bosch, M. S., Van Wijk, A., De Jager, A. B. and H. Van Keulen. (2001). Monitoring nutrient flows and economic performance in tropical farming systems. (NUTMON). Publishers: Alterra, Green World Research and Agricultural Farming. Economics Research Institute, LEI, the Netherlands.

Waigwa, M. W., Othieno. C. O. &Okalebo, J. R. (2003). Phosphorus Availability as Affected by the Application of Phosphate Rock Combined with Organic Materials to Acid Soils in Western Kenya. Expl Agric **39:** 395-407.

Walkley, A. and Black, C. A. (1934). An estimation of the Degjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Socience* **37:** 29-38.

Weisskopf, L., Mansour, E .B.,Efromin, N., Tomasi1, N., Antelia, D., Edelkott, I., Neumann, G., Aragno, M.,Tabacchi, R. &Martinoia, E. (2006). White lupin has developed a complex strategy to limit microbial degradation of secreted citrate required for phosphate acquisition. Plant, Cell & Environment **29(5):** 917-927.

Woomer, P. L., Okalebo, J. R., Maritim, H. K., Obura, P. A., Mwaura, F. M., Nekesa, P. and Mukhwana, E. J. (2003). PREP-PAC: a nutrient replenishment product designed for smallholders in Western Kenya. *Agriculture, Ecosystems and Environment* **100:** 295-303.

Yu, X., Liu, X., Zhu, T. H., Liu, G. H. and Mao, C. (2012). Co-inoculation with phosphate-solubilizing and nitrogen-fixing bacteria on solubilization of phosphate rock and their effect on growth promotion and nutrient uptake by walnut. *European Journal of Soil Biology* **50:** 112-117.

Zhang, F. and Li, L. (2003).Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil* **248:** 305-312.

APPENDICE

Appendice 1: Summary of Anova Results for Parameters Analyzed in Lupin Sorghum Experiment

Source of Variation	DF	soil pH	Soil available N	Soil available P	Soil Carbon	Total Plant N	Total plant P
Fertilizer (F)	1	0.065 NS	0.821 *	676.92 *	0.462 NS	0.175 NS	1138.12 NS
Stage (S)	2	2.641 NS	2.597 *	2865.77 *	0.342 NS	10.12 NS	2768011.42 *
S × F	2	0.034 NS	1.243 *	1498.36 *	0.180 NS	2.065 NS	4331.14 NS
Cropping System (CS)	8	0.277 *	2.035 *	16417.87 *	6.756 *	39.098*	1554053.45*
CS × F	8	0.023 NS	0.524 *	308.76 *	0.177 *	6.921 *	42291.026 *

CR× S	16	*	0.533	1950.71	0.601	26.44	216715.51
			*	*	*	*	*
CR × S × F	16	0.065	0.677	505.61	0.446	2.551	5217.81
		NS	*	*	*	*	*

Key: * = significant at P ≤ 0.05 level (LSD test); NS= non-significant at P ≤ 0.05 level (LSD test)

Appendice 11: Summary of Anova Results for Parameters Analyzed in Chick Pea Sorghum Experiment

Source of Variation	DF	soil pH	Soil available N	Soil available P	Soil Carbon	Total plant N	Total plant P
Fertilizer (F)	1	1297.89 *	0.335 *	604.90 *	0.985 *	0.686 NS	651.611 NS
Stage (S)	2	6002.79 *	1.468 *	3998.60 *	0.178 NS	15.518 NS	1107915.3 NS
S × F	2	3714.69 *	0.163 *	3371.81 *	0.021 NS	1.571 NS	15922.51 NS
Cropping System (CR)	8	19727.64 *	4.128 *	12135.51 *	7.951 *	25.648 *	620912.61 *
CR × F	8	967.14 *	0.037 *	654.45 *	0.255 *	1.375 *	42059.244 *
CR × S	16	1292.99 *	2.409 *	925.13 *	1.658 *	21.27 *	439464.29 *

CR × S × F	16	642.15 *	0.148 *	580.26 *	0.263 *	1.287 *	9121.24 *

Key: * = significant at P ≤ 0.05 level (LSD test); NS= non-significant at P ≤ 0.05 level (LSD test)

Appendice 111: Summary of Anova Results for Parameters Analyzed in Lupin Sorghum Experiment

Source of Variation	DF	Dry Matter Yield	Grain yield	Nutrient Balances
Fertilizer (F)	1	394.741 Ns	135.692 Ns	*
Stage (S)	2	-	-	-
S × F	2	-	-	-
Cropping System (CR)	8	430.741 *	31.769 Ns	*
CR × F	8	179.241 Ns	4.269 *	-
CR× S	16	-	-	-
CR × S × F	16	-	-	-

Key: * = significant at P ≤ 0.05 level (LSD test); ns= non-significant at P ≤ 0.05 level (LSD test);

Appendice 1V: Summary of Anova Results for Parameters Analyzed in Chick Pea Sorghum Experiment

Source of Variation	DF	Dry Matter Yield	Grain yield	Nutrient balance
Fertilizer (F)	1	73.5 Ns	177.852 *	*
Stage (S)	2	-	-	-
S × F	2	-	-	-
Cropping System (CR)	8	638.375 *	31.769 Ns	*
CR × F	8	54.458 Ns	4.269 Ns	-
CR × S	16	-	-	-
CR × S × F	16	-	-	-

Key: * = significant at P ≤ 0.05 level (LSD test); ns= non-significant at P ≤ 0.05 level (LSD test);

Appendice V: Legume Data on Root Length and Number of Cluster Roots

Cropping system		INTER		ROT		INTER		ROT		INTER		ROT	
Crop	P source	N.O	RL	N.O	RL	N.O	RL	N.O	RL	N.O	RL	N.O	RL
Chickpea	TSP	12	15	10	12	7	10	18	16.8	8	12	16	14.3
	MRP	13	16.7	10	15.3	9	13.7	19	16.3	11	12.7	19	14
Lupin	TSP	13	14.4	15	15.7	12	24.7	9	19.7	11	20	12	24
	MRP	13	17.5	17	16.5	14	27.3	11	19.7	15	24	15	26
Chickpea	TSP	20	15	20	15	25	19.7			13	12.7		
	MPR	24	16	24	16	29	25			15	14		
Lupin	TSP	11	19.3	11	19.3	14	19			9	11		

MPR	13	21	13	21	14	23.7	9	10

Key; INTER= intercropping; ROT = Rotation; N.O = Number of cluster roots; RL= Root length; MPR= Minjingu phosphate rock; TSP= triple superphosphate.