UNIVERSITY OF NAIROBI

EFFECT OF LEGUME INTEGRATION AND APPLICATION OF ORGANIC FERTILIZERS ON SOIL NUTRIENT STATUS AND KALE YIELD IN KABETE, KENYA

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DECLARATION:

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

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DEDICATION

This thesis is dedicated to my parents and siblings for their endless love and support during my masters' program.

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GENERAL ABSTRACT

Kale production in Kenya is being hindered by declining soil fertility among other factors. A study was done on ways of improving soil fertility, quality and yield of kale (*Brassica oleracea* var. *acephala*) in Kabete - Kenya, through use of farmyard manure and Minjingu rock phosphate with integration of chickpea (*Cicer arietinum)* and white lupin (*Lupinus albus cv. Amiga)* either as an intercrop or in rotation. The study was carried out for two seasons during the long rains of 2014 and short rains of 2014. Experimental layout was a Randomized Complete Block Design with a split plot arrangement replicated thrice. The main plots were cropping systems; (Crop rotation, Monocropping and intercropping). The split plots were organic fertilizers (Farmyard Manure and Minjingu rock phosphate) whereas the test crop was kale. Soil organic carbon, N, P, and mineral N were tested at an interval of 1, 2 and 3 months of kale development. Kale N, P, K and yield were measured at an interval of 1, 2 and 3 months on kale leaves. The determination of nitrogen fixed by legumes under different organic fertilizers and cropping systems was done using the extended difference method where wheat was sown as a reference crop and sampling done at the late pod fill stage of the legumes. As part of the study, once the legumes were harvested, they were put in litterbags incorporated into soil for determination of their decomposition and mineralization rates. The study was done to address the asynchrony of nutrients between legume nutrient release and kale nutrient uptake. The decomposition and mineralization rate of the legumes was done by taking weights after every retrieval and chemical analysis done in the laboratory at an interval of 0,15,30,45,60,75,90,105 and 120 days. The decay formula was adopted ($y = y_{0*}e^{-kt}$) for determining the rate of decomposition and mineralization. The half life's for the legumes was determined (time when half of the nutrients are released) by calculating using t1/2=In (2)/k. The cropping system white lupine-kale rotation (FYM) (0.59%) significantly increased the amounts of soil available nitrogen in the 1st season. Soil available phosphorus was significantly higher in white lupine/kale intercrop (MRP) (21.83ppm) at the 3rd month of sampling. Mineral nitrogen was significantly highest where white lupine-kale rotation (FYM) at the 3rd month of sampling. During the short rain season, there was a significant ($P \leq 0.05$) increase in the level of organic carbon under white lupine-kale rotation (FYM) (3.16%). Soil available nitrogen was significantly increased where white lupine/kale intercrop (FYM) (0.614%) at the 3rd month of sampling. The concentration of potassium in the kale leaves during the first season were increased where monocrop (FYM, MRP and Control) (4.00%, 4.87%, 4.17%); chickpea/kale intercrop (FYM, MRP and Control) (3.80%, 4.15%, 3.75%); lupin/kale intercrop (FYM, MRP and Control) (3.90%, 3.70%, 4.00%) the increment was recorded at the 2nd month of sampling. A lower level of potassium concentration was recorded in the 1st and 3rd month of sampling. During the second season, the trend was similar to the first season. The kale % N concentration was significantly ($P \leq 0.05$) increased in lupin/kale intercrop (FYM, MRP and Control) (1.63%, 0.97% and 1.27%); chickpea/kale intercrop (FYM, MRP and Control) (1.53%, 1.20%, 1.00%); monocrop (FYM, MRP and Control) (1.26%, 1.53% and 1.40%) during the second month of sampling. Season two had an increase in nitrogen concentration, chickpea-kale rotation (FYM, MRP and Control) (3.47%, 3.17%, and 2.18%). Phosphorus concentrations during season one was increased in the order , monocrop (FYM, MRP and Control) (50ppm, 63ppm and 47ppm); chickpea/kale and lupin/kale intercrop (FYM, MRP and control), the same trend was recorded in season two where, chickpea-kale rotation(FYM, MRP and control); white lupine-kale rotation(FYM, MRP and Control) .There was a significant ($P \leq 0.05$) effect of cropping systems with organic fertilizers where, white lupine-kale rotation (FYM) (3.68t/ha). Number of nodules was significantly affected by application of organic fertilizers in the different cropping systems, white lupine-kale rotation (Control (32); white lupine/kale intercrop (Control) (31) and the chickpea/kale intercrop (MRP) (27). Lupin significantly ($P \leq 0.05$) higher amounts of N_2 (62-86.13 $kgha^{-1}$) as compared to chickpea (50.4 - 82.16 $kgha^{-1}$) in both seasons with significantly higher amounts fixed in white lupine/kale intercrop (FYM, MRP and CNTRL), chickpea/kale intercrop (FYM, MRP and CNTRL). White lupin-kale rotation (CNTRL, FYM) (3076.8$kgha^{-1}$, 2348.9$kgha^{-1}$) yield was higher as compared to white lupine/kale intercrop (MRP) (1798.44$kgha^{-1}$), chickpea had significant high yields chickpea-kale rotation (MRP, FYM) (1024$kgha^{-1}$, 845 $kgha^{-1}$) in season one whereas in the second season, white lupine/kale intercrop (CNTRL, FYM and MRP) (3324.5 $kgha^{-1}$, 2346.9 $kgha^{-1}$ and 1987.3 $kgha^{-1}$); Chickpea/kale intercrop (MRP, FYM) (1287 $kgha^{-1}$ and 768 $kgha^{-1}$) had significant higher yields more than those of season one. The fresh weights (tha^{-1}) across treatments and cropping systems increased, white lupine-kale rotation (CNTRL, FYM, MRP) (15.37 tha^{-1}, 13.53 tha^{-1} and 13.13 tha^{-1}), chickpea-kale rotation (MRP, FYM and CNTRL) (9.31tha^{-1}, 6.05 tha^{-1} and 6 tha^{-1}) while intercrops recorded lower biomass during both seasons. The lowest green matter content was recorded under white lupine/kale intercrop (FYM) (2.01 tha^{-1}). For the decomposition and mineralization of legume residues, weights dropped after every retrieval and chemical compositions of the residues also declined with time. After 120 days of incubation, the white lupin had.24% of N, 16 %P, 16% K of the initial weight, whereas for chickpea was 19% N 15% P and 9 % K. A 50 % in weight loss of the legumes was found after 9 days of incorporation in the soils for the two legumes. A 50 % loss in N, P and K release of the legume residues was found at day 18 (N) 23 (P) and 11 (K) for chickpea and day 14(N), 11 (K) and 25 (P) for white lupin. Use of organic methods for enhanced soil fertility and improved kale quality and yield, can always be achieved by the small scale farmers. Integration of legumes (lupine) in a kale production systems and use of organic fertilizers (farm yard manure) led to increased yields of kale an improvement in the nutrient status of the kales. Application of organic fertilizers is a better solution for improved soil nutrients. Use of MRP with a lupin as an intercrop, more nitrogen was fixed as compared to chickpea. Determination of the mineralization rates of chickpea and lupine residues shows the farmer's adequate time for application of the residues for maximum synchrony between nutrient release and nutrient uptake.

Key words: Biological nitrogen fixation, chickpea, cropping systems, decomposition, farm yard manure, white lupine, Minjingu rock phosphate, kales, Synchrony.

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LIST OF ABBREVIATIONS AND ACRONYMS

BNF	Biological Nitrogen fixation
CNTRL	Control
C: N	Carbon: Nitrogen
FAO	Food Agricultural Organization
FYM	Farm yard manure
IFOAM	International Federation of Organic Agriculture Movements
K	Potassium
KALRO	Kenya Agricultural and livestock Research Organization
MRP	Minjingu Rock Phosphate
$N0_3$-	Nitrate ions
NH_4+	Ammonia ions
OC	Organic carbon
OM	Organic matter
P	Phosphorus
SSA	Sub-Saharan Africa
% N	Percentage nitrogen

CHAPTER ONE

1.0 GENERAL INTRODUCTION

In Kenya, kale (*Brassica oleracea acephala group*) commonly known as *sukuma wiki* is a popular vegetable in many households (Mose *et al*., 2003). It is a highly rated leafy vegetable and a marvelous food item related to wild cabbage with green or purple leaves that do not form a head (Balkaya and Yanmaz, 2005) with origins in Eastern Mediterranean. The tender leaves are used for human consumption and older ones for forage. It is much easier to produce compared to other vegetables, and requires fewer chemical inputs and labor, produces large volumes of leaves when sufficiently nourished and can be harvested several times a week. Low production costs translate into lower selling prices in the market, thus making it affordable even to households with less income (Sarah Maina and Mwangi, 2008).

Fadigas *et al*., (2010) found out that Kales can withstand drought and temperature of -10^{0}C to 15^{0}C. It is a highly nutritious vegetable, rich in vitamins, particularly vitamin C and provitamin A and minerals. According to Ahnmad and Beigh, (2009) kale is known to have attracted more attention due to its multifarious use and great nutritional value. Kale has a high nitrogen (N) requirement, so good nitrogen availability which is sustainable is a pre-requisite for economic yield.

Kale's production however, is limited by several factors including poor soil fertility especially P and N, pests, diseases and weed interference (Anyango, 2005). Deficiency of Phosphorus, an important macronutrient for plant growth (Shen *et al*., 2011), is common in several areas of East Africa. The deficiency is aggravated by rising costs of inorganic P fertilizer (Rao *et al*., 2002, Onwonga *et al.*, 2013). Similarly, (N) is one of the most yield-limiting nutrients for crop production in the world and a nutrient element applied in the largest quantity for most annual crops (Huber and Thompson, 2007).

To increase kale productivity, it requires improvements in soil fertility and disease control through, perhaps, use of agrochemicals. However due to escalating levels of poverty small scale farmers cannot afford so are not able to apply any inputs for enhanced production. Agricultural systems have in addition become addicted to the soluble acidic-based NPK fertilizers and this addiction which has led to soil degradation, and this has kept producers on the production treadmill with “more on” farming (Pettit, 2006). This thus calls for alternative, innovative and sustainable methods of kale production such as organic based soil fertility management strategies is one such approach.

Organic based soil management strategies which includes; organic cropping systems as crop rotation, intercropping, integrated pest management and use of organic fertilizers lead to improved soil fertility and hence improved kale production. Organic inputs used include animal manure, green manure, off-farm organic wastes and mineral-bearing rocks to feed the soil and supply plant nutrients, in order to maintain sustainable yield production (Luttikhot, 2007).

To elevate the P deficiency and improve kale production in Kenya, use of MRP is an alternative cheaper to the expensive Triple super phosphate (TSP) (Onwonga *et al*., 2013). Minjingu rock phosphate could be a viable option to the expensive inorganic P fertilizers as it costs about 50% of processed P fertilizers, on elemental P basis (Okalebo and Nandwa, 1997; Lelei, 2004). However, its use for soil fertility improvement is limited by its insolubility.

Efficient legume growth and nitrogen fixation is highly dependent on an adequate supply of phosphorus. White lupines (*Lupinus albus L cv Amiga*) and chickpeas (*Cicer arietinum*) are thought to enhance soil fertility by mobilizing P from MRP and increasing soil available N through biological nitrogen fixation (Lelei *et al.,* 2014). The said legumes exudates acidic carboxylates from their roots that have the capacity to solubilize rock phosphate (Veneklaas *et al*., 2003 Gerke *et al*., 2001).

Majority of the farmers harvest the legumes grain and either burn the residues or apply them haphazardly on the farms. Many of the soil and crop benefits of legume residues are realized upon decomposition of the residues (Giller, 2001). New decomposition technologies work towards avoiding nutrient loss from the decomposing residue, but ensure that nutrients mineralized are available for crop uptake. This method ensures synchrony of nutrients that might have been lost through leaching or otherwise (People *et al*., 2004). Several methods have been used to determine decomposition and nutrient release of plant materials in the field, and the litterbag technique is probably the most widely used because of its simplicity, replicability and ability to selectively exclude classes of soil fauna (Vanlauwe *et al.*,1997).

Therefore the study was aimed at improving soil nutrient status, kale nutrient concentrations and yield through integration of legumes with application of organic fertilizers and decomposition of legume residues.

1.1 STATEMENT OF THE PROBLEM

Kale production in Kenya is limited by poor soil fertility (Halberg *et al*., 2006). Alternative sources of soil nutrients have been expensive for the small scale farmers to purchase and the poor timing of application for improved kale productivity (Onwonga *et al.,* 2013). MRP is a viable alternative but has problems of solubility unless in acidic soils, of which are not common in the study area. Some legumes through their acidic exudates can solubilize rock P but the interaction between use of legumes with application of organic fertilizers to improve soil N, P and organic carbon has not been widely explored (Watson *et al*., 2002).

Majority of the smallholder systems are characterized by continuous cropping with few or no external inputs applied. They rarely practice intercropping or rotational cropping systems of kales with legumes which lead to depletion of soil nutrients. The resulting depletion of soil nutrients and organic matter is threatening the sustainability of many agricultural systems (Place *et al.*, 2003).

Addition of legume residues has become a pivotal strategy for soil fertility improvement and sustainable of land use. Small holder farmers apply these residues haphazardly without considering the time of maximum asynchrony (Shi, 2013). In order to optimize the benefits of legume residue on soil fertility improvement, it is critical to synchronize the release of nutrients from residue decomposition with patterns of kale nutrient uptake, which may minimize the loss of available nutrients via leaching, runoff and erosion (Shi, 2013). Consequently, the amounts of Furthermore white lupine and chickpea are known to fix nitrogen, there is need to know how much is fixed when the legumes are integrated with kale and organic fertilizers (Watson *et al*., 2002).

1.2 JUSTIFICATION

There is need for more safe food production in Kenya. The use of the locally available resources poses to be a cheaper and environmentally friendly solution. Integration of legumes will lead to soil nitrogen being enhanced through biological nitrogen fixation and therefore improving kale production a cheap source of Nitrogen. Determination of nitrogen fixed by the legumes is important as there will be surety of the amount of N fixed in the soil for kale uptake. Farmers will be in a position to know how much N is in the soil for kale production and if there is need for enhancing the nutrient pool hence avoiding purchase of external inputs and use the resources which would have been used.

Inclusive of improved soil fertility, there is a temporal and spatial benefit of the organic based cropping systems. Intercropping ensures more than one harvest of food products from the same piece of land, while crop rotation ensures continuous harvesting of crops.

Litter decomposition plays an important role in carbon cycling. Decomposition of chickpea and lupin residues helps in synchronizing the residue nutrients for crop uptake, which could have been lost. There is surety that all nutrients used during the growth of the legumes are returned back to the soil for kale uptake.

1.3 OBJECTIVES

1.3.1 Overall objective

To contribute towards improved soil nutrient status, legume biological nitrogen fixation and kale yield through application of organic inputs with different cropping systems.

1.3.2 Specific objectives

- To determine the effects of integration of white lupine and chick peas in kale based cropping systems and application of organic fertilizers on soil available N, P and OC.
- To determine the effects of integration of white lupine and chick peas in kale based cropping systems and application of organic fertilizers on kale nutrient uptake and yield.
- To assess the decomposition and mineralization rates of chickpea and white lupine residues and synchronize nutrient release with kale uptake.

- To determine the effect of application of organic fertilizers on BNF by chickpea and white lupine in kale based cropping systems.

1.4 HYPOTHESES

- Application of MRP and FYM will improve soil available N and P.
- Kale tissues will have high nutrient concentration in their leaves and increased yield due to increased nutrients supplied by the organic fertilizers.
- White lupin and chickpea residues will decompose and release nutrients rapidly.
- Application of farmyard manure will lead to increased nitrogen fixation by white lupine.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Kale consumption

The species *brassica oleracea* contain a wide variety of vegetables including kales, broccoli, cauliflower, collard green and Brussels sprouts. With origins in the Eastern Mediterranean, kales (*Brassica oleracea acephala group*) are a vegetable related to wild cabbage with green or purple leaves that do not form a head (Balkaya and Yanmaz, 2005). The tender leaves are used for human consumption and older ones for forage. It is the most consumed green vegetable in both urban and rural areas of East Africa (Mariga, 2011).

Consumption of brassica vegetables such as kale improves human health and reduces the risk of certain cancers and cardiovascular diseases (Francisco *et al*., 2010; Traka and Mithen, 2009). Numerous studies have indicated that a high intake of plant products such as kale results in a reduced risk of a number of chronic diseases and cancer (Podsedek, 2007; Gosslau and Chen, 2004; Gundgaard *et al*., 2003; Hashimoto *et al*., 2002; Kris-Etherton *et al.*, 2002; Temple, 2000). The high nutritional value of kale derives from its intense chemical composition which comprises of crude protein, phosphorus, potassium and amino acids among others (Velasco *et al.*, 2007).

2.1.1 Kale production and constraints facing production

According to Mariga, (2011) kale is much easier to produce compared to other vegetables, and requires fewer chemical inputs and labor. Another advantage is that when kale is sufficiently nourished with compost manure and well watered, it produces huge volumes of leaves, which can be harvested repeatedly (several times a week from the same plant).

In Kenya, kale is grown by 90% of small holder farmers thus providing employment mostly for women and youth who are involved in their production. They also provide a positive spillover effect upon a range of other industries like transport and trade. Another reason for its popularity is that kale is rich in numerous health benefiting polyphenolic flavonoid compounds such as lutein, zeaxanthin, and beta-carotene, and vitamins than found in any other green leafy vegetables (USDA, 2005). Overall kales have the potential to transform African economies and contribute to poverty reduction and it is for this reason that its production should be increased.

Although kale is the most popular leafy vegetable in Kenya, its economic production is limited by several factors including poor soil fertility, pests and diseases and weed interference (Anyango, 2005). To combat these problems, several approaches have been recommended which include use of inorganic fertilizers which are readily available in the markets.

2.2 Organic based approaches in soil fertility management

Soil fertility is most commonly defined in terms of the ability of a soil to supply nutrients to crops. It is viewed as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production (IFOAM, 2005). Soil fertility is fundamental in determining the productivity of all farming systems (IFOAM, 2005). This view is appropriate to organic based farming, as it recognizes the complex relationships that exist between different system components and that the sustainability of the system is dependent upon the functioning of a whole integrated and inter-related system (IFOAM, 2005). Organic based farming systems, as an example of low external-input systems, avoid the use of synthetic fertilizers; instead they rely on crop rotations, legume cultivation, mineral-bearing rocks and animal green manure and off-farm organic wastes and to feed the soil and supply plant nutrients, in order to maintain sustainable yield production (IFOAM, 2005).

All this is in an effort to increase soil organic matter content, which can support microorganisms that help in improving soil fertility and structure and also can destroy potential weed seeds in the soils. Wang *et al*., (2009) reported on the use of rich cover crops to enhance tomato yield and quality. Prolonged application of inorganic fertilizers has resulted in negative environmental impacts. A good example is soil degradation (acidification) due to repeated application of diammonium phosphate (Reganold, 2001). Frequent utilization of nitrates leads to soil and water pollution lowering the crop performance.

The foundation of organic farming is a microbial active soil enriched with organic matter and a balanced mineral diet (Stamatiadis *et al*., 1999). Humus building practices and additions of rock minerals not only supply plant nutrients, but increase tolerance to insects and diseases, help control weeds, retain soil moisture, and finally, ensure produce quality (IFA, 2000). On soils managed biologically for several years, tomatoes and maize yielded well from legume intercrop and compost treatments (Stamatiadis *et al*., 1999). Nutrient stocks are maintained through use of natural (non-synthetic) substances and approved synthetic substances. Organic farms that achieve their goals maintain soils and protect the environment while using modest amounts of inputs. Soil tests and simple budgeting tools can help producers maintain balance to achieve success (IFA, 2000).

2.2.1 Supplying and Managing Soil Nutrients

Although crop nutritional requirements are the same for organic and conventional farms, organic producers apply natural materials and emphasize practices that retain and recycle nutrients within the soil (Watson *et al*., 2002). Sixteen elements are consistently found to be necessary for plants to complete their life cycles (IFA, 2000). Additional elements are essential for some species and for animals relying on plants for their nutrition. Carbon, hydrogen, and oxygen, which account for about 95% of plant biomass, are supplied from carbon dioxide and water (Stamatiadis *et al*., 1999).

The other macronutrients with concentrations greater than 500 micrograms/g of plant include nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. Micronutrients taken up in lower abundance are no less necessary but are not limiting to growth in most situations. Sandy soils with inherently low nutrient contents are an exception. Micronutrients include iron, zinc, manganese, copper, boron, chlorine, and molybdenum (IFA, 2000). Major factors that influence fertility decisions on an organic farm include: crop rotation; the presence or absence of livestock on the farm; nearby manure sources; availability of equipment (compost turners, manure spreaders, fertilizer drills); and the availability and cost of commercial organic fertilizers in the area (IFA, 2000).

Maintenance and management of soil fertility is the core of development of sustainable food production systems (Doran *et al.*, 1988). To be sustainable, organic farming needs to be self-sufficient in nitrogen (N) through the fixation of atmospheric nitrogen by legumes (Berry *et al.*, 2005); recycling of crop residue (green manures) (Chepkemoi., 2014) ; application of farm yard manure (FYM) and compost (Rokhzadi and Toashih, 2011). Proper use of N sources is therefore, required to optimize the economic yield (Mason and Brennan, 1998) and to minimize the potential environmental pollution (Aufhammer *et al.*, 1994).

The efficient use of nutrients within crop production system has been in focus for several decades. The application of manures to soil provide potential benefits including improving the fertility, structure, increasing soil organic matter, water holding capacity and reducing the amount of synthetic fertilizer needed for crop production (Phan *et al.*, 2002, Blay *et al.*, 2002). Manures are the main sources of nitrogen (N) supply in organic production.

2.2.2 Nutrient cycling and cover crops

Organic farming's goal is to maximize internal self-regulation of ecosystem processes, including nutrient and carbon cycling to ensure crop productivity and minimize environmental contamination (Scialabba, 2000). Organic fertilizers, crop rotations, and cover crops constitute multifunctional management practices that conserve soil organic matter, enhance soil quality, protect soil from erosion, and sequester carbon to help mitigate global climate change (Scialabba, 2000). Nitrogen (N) fertility is maintained through synchronization of N mineralization from soil organic N pools and plant uptake of inorganic N. Management of soil organic matter to enhance soil quality and supply nutrients in the long term on an organic farm requires balancing mineralization of carbon and nitrogen for short-term crop uptake and sequestering these nutrients for long-term maintenance of soil fertility and structure (Scialabba, 2000).

2.3 Organic fertilizers influence on soil nutrient status.

The use of organic soil amendments has been associated with desirable soil properties including improved plant available nutrients, higher water holding capacity, cation exchange capacity and low bulk density besides fostering beneficial microorganisms (Drinkwater *et al.*, 1995). The benefits of compost amendments to soil also include pH stabilization and faster water infiltration rate due to enhanced soil aggregation (Stamatiadis *et al.*, 1999). These soil attributes are enhanced in legume intercrop farming systems (IFA, 2000).

2.3.1 Minjingu Rock Phosphate

This is a non-detrital sedimentary rock which contains high amounts of phosphate bearing minerals. The phosphate content of phosphorite is at least 15 to 20% which is a large enrichment over the typical sedimentary rock content of less than 0.2% (Blatt *et al.*, 1996). Phosphorus (P) is very important for vigorous plant growth and fruit production.

It is however characterized by low solubility in water (Thuita *et al.,* 2005). In a study by Onwonga *et al*., (2013), solubilization of MPR was achieved by the acidic nature of the study soils (pH in water solution <5.0) and with the application of manure, conditions necessary for PR solubilization (Okalebo *et al*., 2007). In non acid soils, such as found in Kabete in Kenya, or in the absence of manure, other alternatives of solubilizing MPR must be explored particularly those involving leguminous plant species.

Crops such as white lupin (*Lupinus albus* L.) and chickpea (*Cicer arietinum L*) are important in solubilizing rock phosphate. These legumes form special root structures called cluster or proteoid roots in response to P deficiency (Shane and Lambers, 2005). The roots strongly acidify the surrounding rhizosphere and secrete large amounts of organic acids, mainly citrate (Weisskopf *et al*., 2006) and this enables them access sparingly available nutrients such as phosphate (Weisskopf *et al.*, 2011). Integration of legumes in a kale based cropping system with Rock phosphate application leads to increased kale production. According to Lelei *et al*., (2009), RP led to efficient legume growth thus more efficient nitrogen fixation which in turn increased kale yield under intercropping with legumes.

2.3.2 Farm yard manure

Low soil fertility is a major challenge facing kale production in Central Kenya, use of farm yard manure as fertilizer is a cheaper source of nutrients compared to the inorganic fertilizers, and its use also leads to improved soil nutrient status and improved kale yield.

This is the traditional manure and is mostly readily available to the farmers. Farm yard manure is a decomposed mixture of Cattle dung and urine with straw and litter used as bedding material and residues from the fodder fed to the cattle. Well rotten farm yard manure contains 0.4 to 1.5 per cent N, 0.3-0.9 % P_2O_5 and 0.3-1.9% K_2O.

Manure offers a natural means to cycle plant nutrients. As such, animal manure forms an important part of organic soil fertility programs. Manure, either on its own or blended with crop residues, makes up much of the raw material for the compost used on organic farms (Baker *et al.*, 1990).The most common kinds of farmyard manures are horse, cow and pig manure. Of these three kinds, horse manure has the best balance of nutrients. Cow manure has relatively little phosphate. Pig manure is usually rich in mineral salts but has relatively little potassium. Manure from goat and sheep is also good organic manure (Wageningen, 2005).

The quantity of nutrients in manures varies with type of animal, feed composition, quality and quantity of bedding material, length of storage and storage conditions (Dewes & Hunsche, 1998; Shepherd *et al.*, 1999). Composting of FYM is recommended as an organic based management tool for controlling weeds, pests and diseases. Previous studies have shown that application of farm yard manure increased crop yield (Chepkemoi, 2014).

Composted manure thus has a more long-term role in building soil fertility, and has been shown to be more effective in building soil microbial biomass and increasing activity than un composted manure (Fließbach & Mäder, 2000). Fresh manure may have an effect on the occurrence of diseases such as root knot nematodes. However, some studies report that adding fresh organic matter such as poultry manure, cattle manure and different kinds of green manure greatly reduced infestations of root knot nematodes (FAO, 2005).

2.4 Integration of legumes in cropping systems

2.4.1 Crop rotation

Farmers practice crop rotation in order to build and maintain soil health and to break the lifecycle of pests, thus reducing the need for synthetic fertilizer and pesticide applications (Rodale, 1971). Rotation design should avoid preceding kale with other Brassica species, thus reducing the potential for pest, disease and weed carryover. Rotation to non-Brassica crops for three years is usually recommended to avoid pest problems common to this group of vegetables (Robyn and Nelson, 2005). Rotation with legumes improves soil fertility due to nitrogen fixation which the subsequent crop will benefit from.

Plant residues of untilled crops form a nutrient reserve (Rosolem *et al.,* 2003). Therefore, the use of species different from the main crop such as legumes contributes to the nutrient balance, which may consequently increase soil fertility over time. Leguminous species are known for their capacity to fix atmospheric nitrogen and narrow the C/N ratio, resulting in faster residue decomposition (Aita and Giacomini, 2003) and consequent release of accumulated N and other nutrients such as P and K, to the soil (Borkert *et al.,* 2003).

Shifting crop types also helps vary water demand within the soil profile. The deep-rooted crops following shallow crops can access moisture reserves as well as capture any nutrients that have leached below the shallower root zones before they reach groundwater (Adam *et al.,* 2011).

According to (Witters *et al*., 2009) the aims of crop rotation include; improve or maintain soil fertility, reduce soil erosion, reduce the buildup of pests and weeds and mitigate risk of weather changes. Studies have shown that cereals derive both yield and N benefits from rotation with grain legumes compared to cereal monoculture (Kirkegaard *et al.,* 2008). The yield advantage may be entirely due to the N fixed by the legumes (Chalk, 1998).

Legume green manures have the added benefit of producing plant-available N through biological N_2 fixation (BNF) from the atmosphere, and greatly improve the residue biomass quality. Legumes are also efficient at mobilizing P from the soil (Knight and Shirtliffe, 2005), and the stimulation of rhizosphere activity increases P uptake by other crops in the rotation (Johnston *et al.,* 2008). The C: N: P ratios of legumes are narrow, which results in rapid release of N and P from the residues (Lupwayi *et al.,* 2006, 2007). According to Genga *et al*., (2014) chickpea-kale rotation led to improved kale yield.

In crop rotation, legumes are known to contribute significantly to the yields of subsequent crops like cereals and tubers (Nottidge *et al.,* 2008), this has been attributed to the amount of nitrogen and other nutrients returned into the soil by the legumes.

2.4.2 Intercropping

This is the practice of growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of the resources which could have been utilized by a single crop. Most intercrops involve use of a legume. It involves a combination of crops with different planting times and different length of growth periods, which spreads the labor requirement of planting and harvesting (Hudson, 1987). The use of legumes in this system contributes to improving the nitrogen status for the crops. Other advantages include maximization of soil fertility, minimization of erosion, weeds labor and reduction of the crop loss risk (FAO, 1993). The legumes improves soil fertility and yields of associated as well through biological (N) fixation, nutrient pumping, and incorporation of green manure (Chikowo *et al.,* 2004).

Intercropping of compatible plants also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single-crop environment. This in turn can help limit outbreaks of crop pests by increasing predator biodiversity. Additionally, reducing the homogeneity of the crop increases the barriers against biological dispersal of pest organisms through the crop.

Intercropping plays an important role in agriculture because of the effective utilization of resources, significantly enhancing crop productivity compared with that of monoculture crops. Two or more crops planted together were known as intercropping system in order to maximize beneficial interactions. Intercropping is a sustainable soil management means in many developed and developing countries. Introduction of a grain legume in cereal-based cropping system aims at increased productivity and profitability to achieve food and nutritional security and sustainability (Mehdi *et al.,* 2010).

Intercropping generate beneficial biological interaction between crops increasing grain yield and stability, more efficient use of available resources and reducing weed pressure (Kadziuliene, 2009). The main principle of better resource use in intercropping is that if crops differ in the way they utilize environmental resources when grown together, they can complement each other and make better combined use of resources than when they grown separately (Ghanbar-Bonjar, 2000).

Intercropping preferentially involves spreading types of crops legumes, pumpkins, or sweet potato contribute to a faster and denser ground cover and suppress weed growth at least during the growing season (Steiner and Twomlow, 2003). According to (Terhan *et al.,* 2009) combination of a legume and cereal are most common among small scale farmers in semi-arid tropics and it benefit them in resource limiting conditions compared with corresponding sole crops. Yield advantages have been recorded in cereal- legume intercropping. The reason for yield advantage are mainly that environmental resources such as water, light and nutrients can be utilized more efficiently in intercropping than in the respective sole cropping systems.

According to (Faroda *et al., 2007,* Sheorena *et al., 2009*) intercropping stabilizes crop production and provides insurance mechanism against aberrant weather situation characterized by rain fed agriculture intercropping could be a viable agronomic means of risk minimizing.

Intercropping increase light interception and shading reduce water evaporation, and improve conservation of soil moisture compared to sole crops (Ahmad *et al., 2009*).

Legume intercrop are the potential source of plant nutrients especially N that compliment or supplement inorganic fertilizers. Legume intercrops are included in cropping systems due to their ability to reduce soil erosion (Giller and Cadisch, 1995), suppress weed and fix N (Giller *et al.*, 1995). Intercropping is widely practiced as a means to increase efficiency of land use (Carberry *et al., 1993*), water and nutrient (Morris *et al.,* 1993*).*

Intercropping kales with legume will ensure the supply of nitrogen for enhanced kale production in the rural household. Furthermore intercropping legumes and kales would not only ensure better environmental resource utilization but would also provide better yield stability, reduce pests and diseases and diversify rural income (Egbe, 2010, Njogu *et al.,* 2007).

Legume green manures are efficient at mobilizing P from the soil (Chepkemoi, 2014). As green manures decompose, the P is released in a labile form that enhances the P nutrition of succeeding crops (Cavigelli and Thien, 2003). Organic acids released in the decomposition process aid in dissolving soil mineral P to improve crop uptake (Sharpley and Smith, 1989).

2.4.3 Chickpea.

Chickpea (*Cicer arietinum L.*) is a legume of the *fabaceae* subfamily and is also the third most important food legume crop worldwide with major production areas on the Indian sub-continents, West Asia, and North Africa (WANA). Chickpea meets 80% of its nitrogen (N) requirement from symbiotic nitrogen fixation and can fix up to 140 kg N ha-1 from air. It leaves substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter to maintain and improve soil health and fertility.

Chickpea physiological traits (exudation of protons and phosphatase enzymes) facilitate mobilization of MRP through the process of acidification (Dakora and Phillips, 2002). Root exudation of high concentrations of organic acid anions as a result of P deficiency (Hoffland *et al.*, 1989) does lower rhizosphere pH, making P (Haynes, 1990; Jones and Darrah, 1994) and micronutrients such as Manganese, Iron and Zinc to be more available in calcareous soils (Dinkelaker *et al.*, 1989).

Where carboxylates exudation is associated with proton extrusion, the lower pH may itself contribute to greater P availability, if the soil pH is relatively high. The effectiveness of carboxylates depends on the number of carboxyl groups and molecular structure. Tricarboxylates (citrate) are generally more effective than dicarboxylates (e.g., malate, malonate) due to stronger ligand binding.

Soil properties also have large effects on the effectively of carboxylates. For example, the stability of organic anion – metal complexes depends strongly on pH (Jones, 1998), and there is large variation in the mechanisms and strength with which phosphate is held in the soil. Root exudates patterns may need to be different on different soils for optimal effects on P availability. It is known that species differ in the carboxylates they exude, e.g., malonate in chickpea, (Ryan *et al.,* 2001; Roelofs *et al*., 2001).

2.4.4 White lupin.

White lupin (*Lupinus albus L cv Amiga*) is a legume of the family fabaceae. It is adapted to well drained, light to medium textured, moderately acidic or neutral soils with a pH range of 4.5-7.5 (Jensen, 2006). Their seeds are known for its relatively high protein value. Its seed protein contents range between 30-40% (Jensen, 2006). It is very efficient in accessing unavailable phosphorus (Pi). It develops short, densely clustered tertiary lateral roots (clusters / proteid roots) in responsible Pi limitation. It has the ability to fix nitrogen between 50-100kgha^{-1} (Shandu *et al*., 2008).

When exposed to phosphorous deficiency, white lupin (*Lupinus albus L.*) exudates large amounts of citric acids from specialized clusters of closely spaced lateral rootlets (Proteid roots), which have limited growth and are densely covered with root hairs (Gardner *et al*.,1983; Dinkelaker *et al.,* 1989; Gerke *et al* ;1994).

In white lupin high quantities of citrate and protons are excreted, at the mature stage of cluster roots leading to drastic rhizosphere acidification (Weisskopf *et al.*, 2006). White lupin has been found to effectively utilize Phosphorus from rock phosphate particularly when soils are deficient in Phosphorus or in response to Al toxicity (Arcand and Schneider, 2006).

White lupin *(Lupinus albus L. cv. Amiga)* responds phosphorus deficiency by producing special root structures called cluster roots. The cluster roots secretes large amount of carboxylates into the rhizosphere i.e. citrate and malate which act as phosphate solubilize and enable the plant to grow in soils with sparingly available phosphorus. White lupin has the capacity to dissolve the phosphorus which is not available in the rock Phosphate. Integrating white lupine with kale and application of MRP and FYM will lead to improved soil nutrient status especially P and kale yield.

2.4.5 Biological nitrogen fixation

Biological nitrogen fixation (BNF), discovered by Beijerinck in 1901, is carried out by a specialized group of prokaryotes. These organisms utilize the enzyme nitrogenase to catalyze the conversion of atmospheric nitrogen (N_2) to ammonia (NH_3). Plants can readily assimilate NH_3 to produce nitrogenous biomolecules (NH_4). These prokaryotes include aquatic organisms, such as cyano bacteria, free-living soil bacteria, such as Azotobacter, bacteria that form associative relationships with plants, such as Azospirillum, and most importantly, bacteria, such as Rhizobium and Bradyrhizobium, which form symbioses with legumes and other plants (Postgate, 1982).

Biological nitrogen fixation is reported to vary with legume species (Chemining’wa *et al.,*2004) and to be closely correlated with legume dry matter production (Kumar and Goh., 2000; Lelei *et al.,*2009).The amount of nitrogen added to a cropping system depends on the legume nitrogen yield and the proportion of N due to biological nitrogen fixation (Giller, 2001).

2.4.5.1 N_2 fixation in legumes and the associated benefits to the kale component

Biological nitrogen fixation by legume grain has received a lot of attention (Høgh-Jensen and Schjoerring, 2000) because it is significant N source in agricultural ecosystems (Dakora and Keya, 1997) the amount of nitrogen fixed by lupin and chickpea in a kale production system has not been well explored. Intercropping usually includes a legume which fixes N_2 that benefits the system and a vegetable component that depends heavily on nitrogen for maximum yield. Controlled studies have shown a significant direct transfer of fixed –N to the associated non legume species ((Høgh-Jensen and Schjoerring, 2000; Chu *et al*., 2004).

2.5 Soil Fertility

2.5.1 N_2 fixation in legumes and the associated benefits to the kale component

Biological nitrogen fixation by grain legume crops has received a lot of attention (Høgh-Jensen and Schjoerring, 2000) because it is a significant N source in agricultural ecosystems (Dakora and Keya, 1997). However, studies on N_2 fixation in complex cereal/legume mixtures are few (Høgh-Jensen and Schjoerring, 2000). Intercropping usually includes a legume which fixes N_2 that benefits the system, and a cereal component that depends heavily on nitrogen for maximum yield (Høgh-Jensen and Schjoerring, 2000). Controlled studies have shown a significant direct transfer of fixed-N to the associated non- legume species (Høgh-Jensen and Schjoerring, 2000; Chu *et al*., 2004).

There is evidence that the mineralization of decomposing legume roots in the soil can increase N availability to the associated crop (Chu *et al*., 2004). In mixed cultures, where row arrangements and the distance of the legume from the cereal are far, nitrogen transfer could decrease. Research has shown that competition between cereals and legumes for nitrogen may in turn stimulate N_2 fixation activity in the legumes (Chu *et al*., 2004). The cereal component effectively drains the soil of N, forcing the legume to fix more N_2. Therefore it is important to manipulate and establish how the management practice in legume/cereal mixtures may influence N_2 fixation and nutrition in the traditional African cropping systems (Chu *et al*., 2004).

2.6 Nutrient Synchrony

As best described by Swift, (1984) the concept of synchrony is the linking of nutrient demand with nutrient release from mineralization of organic matter. With the concept of synchrony defined as a close balance between nutrient supply and demand, there is the potential for two types of asynchrony. One occurs when nutrient availability exceed plant requirements, often because release occurs at a time when plant demand is restricted or non-existent, as in winter or early spring in temperature annual cropping systems. The second occurs when nutrient is insufficient to meet plant needs at certain times (Myers *et al*., 1994). These two will be referred to as "excess-asynchrony" and "insufficient –asynchrony" respectively.

Most of the environmental hazards known to be associated with N in cropping systems are the result of excess asynchrony. Despite the ability to purchase the expensive N fertilizers, unfortunately only a fraction of the fertilizer of legume N applied to crops is recovered by plants under current farming practices (Fillery, 2001; Balasubramanian *et al.,* 2004). Some of the ineffectiveness in uptake can be attributed to the volatile and mobile nature of N. It is easy transformed among various reduced and oxidized forms and is readily distributed by hydrological and atmospheric transport processes.

2.6.1 Crop residue decomposition and mineralization

The litter bag experiment studies the microbial decomposition of litter by measuring the mass losses and the changes in the chemical composition of the litter (Anderson and Ingram, 1987). A certain amount of litter is placed in a litter bag, sewed and buried in the ground and retrieved after a stipulated time and analyzed for weight loss and mineralization rates. The weight loss is determined by taking their weights after retrieving the residues

2.6.2 Decomposition and mineralization of chickpea and white lupine residues

The decomposition and mineralization rate of chickpea and white lupin was done after previous studies recommended the one for use. Whereas Giller, (2001) indicates that residues from legumes can contribute nitrogen to the soil if their residue is not removed, in the cold semi-arid regions, crop residues are burnt or removed from the fields and fed to livestock.

Decomposition is one of the most important processes that accounts for carbon and nutrient cycling. For legume green manures to be an effective nitrogen (N) source for organic farming systems, their N release must be in synchrony with crop N demand. Fallow legumes contribute significant quantities of N after their residues decay following incorporation into the soil (López-Bellido *et al*., 2004, Walley *et al.*, 2007).

However, to develop effective legume fallowing techniques, it is necessary to know their residue decomposition and nutrient-release dynamics. With such knowledge, it is easy to synchronize the period of maximum supply with the period of maximum demand (Delin and Engström, 2010) by the succeeding kale crop.

According to (Giller *et al*., 2002) he did a study and found that insufficient-nutrient asynchronies can be problematic in some legume-based systems of less developed countries, particularly in the tropics. He also describes how farmers with few resources can improve synchrony significantly by observing crop development during the growing season and broadcasting modest levels of N on fields at times of high nutrients demand.

The study involved use of litter bag technique, whereby this litter bag as described by (Berg and McClaugherty, 2007) as a very common method to define litter decomposition. And that it is used for incubations in the field or in a laboratory.

The amount and timing of mineralization determines N availability. Different from conventional farming systems, which dependent on chemical fertilizers, organic farming systems rely on the management of soil organic matter to optimize crop production (Watson, *et al.*, 2002). Hence, addition of plant residues has become a pivotal strategy for soil fertility improvement and sustainable of land use.

Cover crop composition and its breakdown rate affect soil physical, chemical, and biological properties. In order to optimize the benefits of plant residue on soil quality improvement, it is critical to synchronize the release of nutrients from residue decomposition with patterns of plant nutrient uptake, which may minimize the loss of available nutrients through leaching, runoff and erosion. Strategies in legume-based systems to potentially reduce the rate of N supply around periods of potential asynchrony include changing the timing and placement of legume residues (Palm *et al*., 2001).

2.6.3 Kale nutrient uptake

The amount of nutrient taken up by kale has a major impact on overall kale growth rate. Maximizing the nutrients recovery by kales is of paramount importance in organic systems. The amount of nutrients taken up by the crop of choice requires synchrony of the nutrients release from incorporated plant material with crop nutrients demand. The concept of synchrony as described above and coined by Swift, (1987), was proposed to describe the linking of nutrient demand with nutrient release from mineralization of organic matter.

One of the major nutrients taken up by kales is nitrogen and since N is not stable in soil and becomes less available for crop uptake over time, application timing is important (Chu *et al*., 2004). It is shown that much of the N uptake occurs in a relatively short time period. If nitrogen is in sufficient during this period, yield loss will occur. Application of nitrogen immediately before or during this period will result in higher uptake by the crop and less nitrate lost to leaching or transformation to unavailable forms and ultimately in greater yields.

Kale is known to have high concentrations of nutrients between days 25 to 60 of development.

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CHAPTER THREE

3.0 GENERAL MATERIALS AND METHODS

3.1 STUDY AREA

The on-station study was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi. The station is about 1940 m above sea level and is located on latitude 1° 15 S and longitude 36° 41' E, Agro-climatical zone III (Jaetzold and Schmidt, 2006)

The site has a bimodal rainfall distribution (mid March to May, long rains; October to – December, short rains). Average annual precipitation is 1000 mm Kabete has a minimum and maximum mean temperature of 13.7°c and 24.3°c respectively. The soils are predominantly deep red Nitisols containing 60 – 80% clay particles (FAO, 1990). The clay mineral is predominantly kaolin white and the parent material is the Kabete *trachyte.* In reference to soil analysis prior to sowing, the soil had a near neutral pH of 6.3(neutral), which is slightly acidic, organic carbon level of 2.75% (moderate) organic N level of 0.32% (high), available P of 10 ppm (low) according to KARI-Kabete working manual and Landon, 2014)..

3.1.1 Socioeconomic status

The main activities carried out in Kabete are agricultural activities which include; coffee, beans, carnations, peas, maize, tomatoes, kales and dairy production. Kabete is located near the central market for organic produce which is Nairobi. Its accessibility to the market greatly reduces farm losses which may occur due to storage and transportation. The region is also known for housing a large group of organic based farmers.

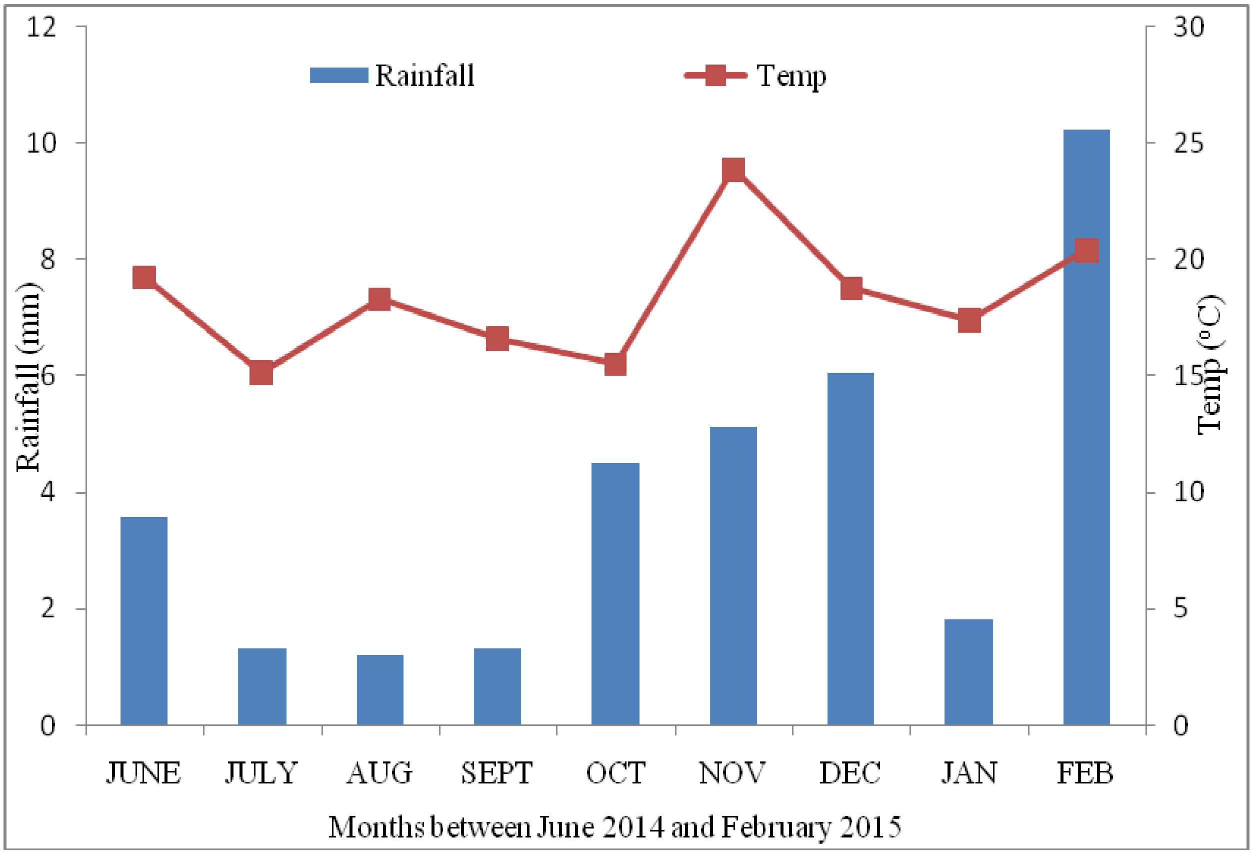

Figure 3.1: Mean monthly rainfall and temperature data during the study period

3.2 EXPERIMENTAL DESIGN AND TREATMENTS

The experimental design used was a Randomized Complete Block Design (RCBD) with a split plot arrangement replicated thrice. The main plots were the different cropping systems (i) monocrop (sole kales), (ii) intercrop (white lupin (*Lupinus albus L*)/kale; chickpea (*Cicer arietinum L)/* kale and (iii) crop rotation (white lupin-kale; chickpea-kale) while the split plots were the different organic fertilizers (Farm yard manure, Minjingu rock phosphate) plot sizes measured 3.75 by 4.8 m with a 0.5 m and 1 m wide footpath between the plots and blocks respectively (Table 3.1)

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Table 3.1 Treatments and crop sequence on field experiment for the LRS and SRS of 2014

Cropping Systems	Treatment	Description	Organic fertilizers	Crop/season	
				LRS	SRS
Monocrop	1	Kale	MRP	Kale	Kale
	2	Kale	FYM	Kale	Kale
	3	Kale	CNTRL	Kale	Kale
Rotation	4	Lupin-kale	MRP	Lupin	Kale
	5	Lupin-kale	FYM	Lupin	Kale
	6	Lupin-kale	CNTRL	Lupin	Kale
	7	Chickpea-kale	MRP	Chickpea	Kale
	8	Chickpea-kale	FYM	Chickpea	Kale
	9	Chickpea-kale	CNTRL	Chickpea	Kale
Intercropping	10	Lupin/kale	MRP	Lupin/kale	Lupin/kale
	11	Lupin/kale	FYM	Lupin/kale	Lupin/kale
	12	Lupin/kale	CNTRL	Lupin/kale	Lupin/kale
	13	Chickpea/kale	MRP	Chickpea/kale	Chickpea/kale
	14	Chickpea/kale	FYM	Chickpea/kale	Chickpea/kale
	15	Chickpea/kale	CNTRL	Chickpea/kale	Chickpea/kale

MRP-Minjingu Rock phosphate; FYM-farm yard manure; CNTRL- Control; SRS- Short rain season; LRS- Long rain season

3.3 Soil, plant sampling and analyses

3.3.1 Soil and plant sampling

Composite top soil (0-20 cm) samples, for determination of initial soil properties (Table 3.2) were collected in a zig zag manner, from the experimental area before set up of the experiment. For determination of N, P and organic carbon, composite samples were collected after 1, 2 and 3 months of kale sowing in all plots. The samples were kept in polythene sampling bags and transported to the laboratory for analysis. Nutrient concentrations and yields of the kales were determined after 1, 2, and 3 months where leaves were randomly sampled from ten kale plants, fresh weights were taken using a weighing balance. The samples were later kept in khaki bags and transported to the laboratory for analysis during every sampling period by determining the fresh weights. The above ground biomass of lupin and chickpea was determined at harvesting. Fresh weights were measured at the field using a weighing balance. Plant samples were analyzed for N, where shoots and roots were sampled at flowering and at pod fill stages of the legumes. For the decomposition studies, analysis was done for residue C, N, K and P.

Table 3.2: Initial soil physical and chemical properties and farm yard manure nutrient levels

Element and Units	Soil		FYM
pH -H_2O	6.03	Neutral[1]	8.53
pH- $CaCl_2$	5.16	Neutral[1]	7.97
N - %	0.32	High[1]	1.88
C - %	2.83	Moderate[1]	11.92
P- ppm	11	Low[1]	5
Bulk density- g/cm^3	1.25	Moderate[1]	-
Mineral N- kg/ha	25.20	Moderate[1]	-

3.3.2 Soil analyses

Air dried soil, sieved through 2mm mesh was analyzed for pH (in H_2O and KCl solution), nitrogen, available P, organic carbon. Soil texture was determined using hydrometer method (Black *et al*., 1965). Undisturbed core samples were used in bulk density determination (Blake and Hartge, 1986).

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[1] Landon, 2014

Organic Carbon: The method used to analyze organic matter was wet combustion which involved reduction of potassium dichromate (K2Cr2O7) by OC compounds and subsequent determination of the unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulphate (Walkey, 1947; FAO, 1974).

Total Nitrogen: The procedure involved digestion and distillation. The soils were digested in concentrated H2SO4 with a catalyst mixture that raised the boiling temperature and promoted the conversion from organic-N to ammonium-N. Ammonium-N from the digest was obtained by steam distillation, using excess NaOH to raise the pH. The distillate was collected in saturated H`3BO3; and then titrated with dilute H2SO4 to pH 5.0 (Bremner and Mulvaney, 1982).

Extractable Phosphorus**:** The sodium bicarbonate procedure of Olsen *et al.*, (1954) was used to measure P in the soil.

3.3.3 Plant analysis

The dried plant samples were finely ground and 5 grammes used for analysis C, N, K and P.

Phosphorus**:** Plant P was extracted by shaking for 30 minutes at 1:10 ratio with double acid. The Molybdenum Blue method was followed (Mehlich *et al*., 1962).

Organic carbon (%C)**:** The organic carbon was estimated by the Walkley-Black method. Recovery factor was used (Black, 1965).

Total nitrogen (%N)**:** The total nitrogen was estimated by the semi-micro Kjeldahl method (Black, 1965).

Potassium: Plant P was extracted and measured using Flame Emission Spectrophotometry (Jońca and Lewandoski, 2004)

3.4 STATISTICAL ANALYSIS

All measurable data were subjected to general analysis of variance using Genstat statistical software (version 15) (Payne *et al.*, 2006). Least significant difference (LSD) test was used to identify significant differences among treatment means ($P \leq 0.05$).

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CHAPTER FOUR

4.0 EFFECTS OF LEGUME INTEGRATION AND APPLICATION OF ORGANIC FERTILIZERS ON SOIL NUTRIENT STATUS

Abstract

Soil fertility depletion has hampered kale production in Kabete, Kenya. The main soil nutrients needed for plant growth, and are diminishing rapidly include P and N. To address this challenge, a study was conducted to evaluate the contribution of different cropping systems and organic fertilizers on soil nutrients in Kabete field station, Kenya. The study was carried out for two seasons between June and September (season one) between period of November and February 2015 (second season). The experimental design was a Randomized Complete Block Design with a split plot arrangement. The main plots were cropping systems (monocrop, intercrop and rotations) the sub plots were the different organic inputs (MRP, FYM). The test crop was kales *(Brassica oleracea acephala group)* intercropped and or in rotational with white lupin (*Lupinus albus L*) and chickpea (*Cicer arietinum)*. Soil was sampled at an interval of 1, 2 and 3 months of kale for soil % N, Organic Carbon, mineral nitrogen and phosphorus analysis. During season one, there was significant increase in N levels where white lupine-kale rotation (FYM) (0.59%). Soil available phosphorus was significantly higher in white lupine/kale intercrop (MRP) (21.83ppm) at the 3rd month of sampling. Mineral nitrogen was significantly highest where white lupine-kale rotation (FYM) at the 3rd month of sampling. During the second season, there was a significant ($P \leq 0.05$) increase in the level of organic carbon under white lupine-kale rotation (FYM) (3.16%). The cropping system chickpea/kale intercrop (MRP) at the 3rd month of sampling lead to a significant increase in soil available phosphorus. Soil available nitrogen was significantly increased where white lupine/kale intercrop (FYM) (0.614%) at the 3rd month of sampling. Integration of white lupin (intercrop/rotation) with application of FYM and MRP in a kale production system leads to a significant improvement on soil available total N, available P and organic carbon.

Key words: Cropping systems, kale nutrient concentrations, organic fertilizers, legumes, soil fertility

4.1 INTRODUCTION

In Kenya kale, commonly known as *sukuma wiki*, is a popular vegetable in many smallholder households because it is consumed together with maize, the staple food for majority of Kenyans (Mose *et al*., 2003). Kale is much easier to produce compared to other vegetables, and requires fewer chemical inputs and labor (Mariga, 2001) when nourished with compost manure and well watered, it produces large volumes of leaves, which can be used several times a week.

The economic production of kale its popularity notwithstanding, is limited by several factors including poor soil fertility, pest and diseases and weed interference (Anyango, 2005). Phosphorus is an important macronutrient for plant growth (Shen *et al*., 2011). Its deficiency is common in several areas of East Africa, and is aggravated by rising costs of inorganic P fertilizer (Rao *et al.*, 2002, Onwonga *et al*., 2013). Nitrogen also (N) is one of the most yield-limiting nutrients for crop production in the world. It is also a nutrient element applied in the largest quantity for most annual crops (Huber and Thompson, 2007). To increase productivity, it requires improvements in soil fertility through thus use of inorganic fertilizers (Shrivastava *et al*., 2011).

The smallholder farming systems are characterized by use of sub optimal rate of inorganic fertilizer doses due to their exorbitant prices vis-à-vis low financial return from crops (Henao and Banate, 2001) this has resulted in declined kale yield leading to unsustainable kale production. However due to escalating levels of poverty small scale farmers cannot afford to purchase the inorganic fertilizers and are also environmentally unfriendly (Ginkel, 2011). This thus calls organic based soil fertility management strategies for alternative, innovative and sustainable methods of kale production (Jayasinghearachchi and Seneviratne, 2006).

To elevate the P deficiency and improve kale production in Kenya, use of MRP is an alternative cheaper to the expensive Triple super phosphate (TSP) (Onwonga *et al*., 2013). Minjingu rock phosphate could be a viable option to the expensive inorganic P fertilizers. However, its use in soil fertility improvement is limited by its being insoluble. It is envisioned that white lupin (*Lupinus albus L*) and chickpea (*Cicer arietinum L.*) can enhance soil fertility by mobilizing P from MRP and increasing soil available N through biological nitrogen fixation. Chickpea and lupin exude carboxylates from their roots that have the capacity to solubilize rock phosphate (Veneklaas *et al*., 2003 Gerke *et al*., 2001).

4.2 MATERIALS AND METHODS

4.2.1 Study site

The on-station study was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi. More details are described in chapter three section 3.1.

4.2.2Treatments and Experimental design

The experimental design was a RCBD with a split plot arrangement. More details are described in chapter three section 3.2

4.2.3 Field Practices

Main plots were the cropping systems; Monocrop, intercrop and crop rotation whereas the split plots were the (MRP, FYM and control). The MRP was applied at the rate of 60 kg P ha^{-1} (~496 kg of MRP/ha). Plot sizes were 3.75 m by 4.8 m with a 0.5 m and 1 m wide footpath between the plots and blocks respectively. They were replicated three times.

All plots were ploughed and residues removed manually before the application of treatments. MRP was broadcasted at the rate of 60 kg P/ ha (496kg per ha) and then incorporated to a depth of 0 – 0.15 m before planting. Farm yard manure was applied at a rate of 10 tonnes per ha. Kale (*Brassica oleracea* var. *acephala* D.C.) chick pea (*Cicer arietinum*) and white lupin (*Lupinus albus L)* (intercrop) were planted and sown. Kales were planted at a spacing of 60 cm and 45 cm between and within the row in all treatments. Four weeks after sowing, the seedlings were thinned to one plant per hole. Weeding was carried out after the emergence of weeds and was done twice.

4.2.4 Soil sampling and analysis

Soil sampling and analysis were done using methods described in chapter three section 3.3.1 and 3.3.2.

4.2.5 Statistical analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne *et al.,* 2006). Least significant difference (LSD) test was used to identify significant differences among treatment means ($P \leq 0.05$).

4.3 RESULTS AND DISCUSSIONS

4.3.1 Effect of cropping systems and organic inputs on soil nutrients:

4.3.1.1 Total Nitrogen

There was a significant increase in the levels of nitrogen in a chickpea/kale intercrop (FYM,MRP and CNTRL) ; white lupine/kale rotation (MRP and FYM) (Table 4.1). At the 3rd month of sampling, lupin-kale rotation (FYM, MRP); white lupine-kale rotation (FYM, MRP and Cntrl) recorded significantly higher amounts of total nitrogen.

The 1st month of sampling in season one, recorded a higher level of nitrogen throughout the cropping systems and treatments. Chickpea intercrop and rotation recorded significant high amounts of nitrogen whereFYM was applied. In the 2nd month of sampling recorded a slighty lower level of nitrogen cutting across the cropping systems and organic fertilizers was recorded whereas. In the 3rd month white lupin-kale rotation (FYM); white lupin/kale rotation (FYM) recorded the highest amounts of nitrogen.

Lower amounts of nitrogen was recorded under kale monocrop (FYM, MRP and Cntrl). The 3rd month recorded the highest amounts of nitrogen in the season (Table 4.1). During the second season, 1st month, white lupin/kale interccrop (FYM, MRP); chickpea/kale intercrop (FYM, MRP) recorded significant higher amounts of nitrogen as compared to other cropping systems (Table 4.1). At the 3rd month of sampling, whitelupine-kale rotation (FYM) (0.614%) recorded the highest amounts of nitrogen, whereas kale monocrop (FYM, MRP and CNTRL) recorded lowest amounts of nitrogen (Table 4.1). There was a significant interaction effect between cropping systems and organic fertilizers.

Table 4.1: Effects of organic fertilizers and cropping systems on soil nitrogen (%)

			N LRS 2014				N SRS 2014			
Month of kale growth	CS	CROPS	FYM	MRP	CNTRL	Mean	FYM	MRP	CNTRL	Mean
1	Intercrop	Lup:kales	0.330^{hij}	0.328^{hij}	0.340^{hijk}	0.33^{b}	0.44^{c}	0.320^{ghi}	0.27^{bcde}	0.34^{b}
	Intercrop	Cp:kales	0.585^{n}	0.376^{kl}	0.405^{l}	0.45^{c}	0.35^{b}	0.25^{bcd}	0.334^{hij}	0.31^{b}
	Crop rotation	Lup	0.324^{ghi}	0.24^{abc}	0.23^{ab}	0.26^{a}	0.3127^{fghi}	0.348^{ijk}	0.305^{efgh}	0.32^{b}
	Crop rotation	Cp	0.487^{m}	0.368^{jkl}	0.376^{kl}	0.41^{c}	0.302^{efgh}	0.305^{efgh}	0.268^{bcde}	0.29^{a}
	Monocrop	Kales	0.26^{bcd}	0.26^{bcd}	0.25^{abcd}	0.25^{a}	0.21^{a}	0.22^{a}	0.287^{defg}	0.24^{a}
2	Intercrop	Cp:kales	0.33^{f}	0.33^{f}	0.34^{fg}	0.33^{b}	0.24^{b}	0.28^{cd}	0.27^{cd}	0.26^{a}
	Intercrop	Lup:kales	0.59^{h}	0.37^{hi}	0.41^{c}	0.45^{c}	0.33^{gh}	0.26^{bc}	0.24^{ab}	0.28^{a}
	Crop rotation	Cp	0.32^{ef}	0.24^{a}	0.23^{a}	0.26^{a}	0.31^{e}	0.35^{fgh}	0.30^{de}	0.32^{b}
	Crop rotation	Lup	0.49^{d}	0.234^{a}	0.234^{a}	0.31^{ab}	0.30^{de}	0.29^{d}	0.27^{cd}	0.29^{a}
	Monocrop	Kales	0.26^{abc}	0.25^{ab}	0.25^{ab}	0.25^{a}	$0. 21^{a}$	0.22^{a}	0.29^{d}	0.26^{a}
3	Intercrop	Cp:kales	0.29^{cd}	0.32^{ef}	0.348^{fgh}	0.31^{ab}	0.413^{j}	0.35^{bc}	0.41^{j}	0.39^{b}
	Intercrop	Lup:kales	0.582^{m}	0.379^{hi}	0.263^{bcd}	0.40^{b}	0.614^{n}	0.35^{4ghi}	0.411^{j}	0.46^{d}
	Crop rotation	Cp	0.35^{fgh}	0.415^{j}	0.384^{ij}	0.383^{b}	0.452^{k}	0.33^{fg}	0.353^{ghi}	0.38^{b}
	Crop rotation	Lup	0.59^{mn}	0.414^{j}	0.224^{a}	0.403^{b}	0.51^{ef}	0.490^{l}	0.453^{k}	0.48^{d}
	Monocrop	Kales	0.293^{de}	0.24^{ab}	0.28^{cd}	0.27^{a}	0.21^{a}	0.22^{a}	0.27^{cd}	0.23^{a}

LRS 2014– Long rain season, SRS 2014–Short rain season, MRP-Minjingu rock phosphate, FYM- Farm Yard Manure, CNTRL-control, C/P-chickpea, LUP-lupin CS-Cropping system. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

In season one; white lupine /kale intercrop (FYM, MRP and CNTRL) recorded higher amounts of nitrogen as compared to chickpea/kale intercrop (FYM, MRP and CNTRL). The higher levels of nitrogen recorded where lupin was intercropped could be attributed to the fact that lupin fixes much nitrogen than chickpea; white lupin is known to fix more nitrogen than chickpea Brady & Weil (2002).

The high soil available nitrogen observed in the intercropping system and rotation systems than monocropping across all seasons could have resulted from N fixed by the legume component (Zhang and Li, 2003). These findings are also similar to those conducted by Anyango (2005) who found that kale-legume intercrop had the highest soil nitrogen content in both seasons if the rotation of kales was not available. In a study conducted by Defra 2004, as well, legume intercrops and organic rotations were found to often provide a supplementary boost of N during the fertility depleting phase by the growing of a leguminous crop, such as field beans or peas. Similarly, rotational fallows or relay intercrops have been shown to increases N input and structural stability of the soil according to a study done by, (Sileshi *et al.,* 2010).

In season two, the white lupin-kale rotation (FYM) and chickpea-kale rotation (FYM) systems had highest N followed by chickpea-kale rotation (MRP) and white lupine-kale rotation (MRP) system with application of Rock P. This is because FYM contains N and its application into the soil resulted to an increase in soil N as compared to application of MRP. These findings are similar to those of K. Banger (2008), who found that continuous application of FYM to the soil lead to increase in total N in all the soil fractions. Brar *et al* (1989) also reported that an increase in the levels of applied N such as FYM causes an increase in the total nitrogen (TN) content of the soil. Increased levels of nitrogen where RP was applied could be attributed to improved soil conditions and hence nitrification. This is because of increased number of nitrifies where MRP is applied. Similar study was carried out by Onwonga *et al*., (2008) on soil Nitrogen upon application of MRP and liming of acid soil.

White –lupin rotations and intercrops recorded higher nitrogen levels across all treatments as compared to chickpea/kale intercrop and chickpea-kale rotation. This may be attributed the high above ground biomass by white lupine as compared to that of chickpea. Similar results were documented by (Engedaw 2012).

4.3.1.2 Organic Carbon

There was a significant ($P \leq 0.05$) increase in the level of organic carbon when FYM and MRP were applied. This was observed in all the plots and in different cropping systems but there was no significant difference in control and MRP applied alone. An increase percentage of organic carbon (3.16%) was recorded in the white lupin-kale rotation with application of FYM (Table 4.2).

In the 2nd and 3rd month, a significant difference was observed in the cropping systems, the different legumes and in the organic inputs. All the intercrops systems with the legume chickpea recorded high levels of OC as compared to that with lupin. In season two, rotation system with application of FYM had the highest C (3.16%) followed by rotation system with application of Rock P (3.12%) under white lupin and under chickpea intercrop during the third month, rock P (3.09%) followed by rotation with application of FYM (3.17%) (Table 4.2).

Table4.2: Effects of different cropping systems and organic inputs on soil organic carbon

			organic carbon Long Rain Season 2014				Organic carbon Short Rain Season 2014			
Month of kale growth	CS	CROPS	FYM	MRP	CNTRL	Mean	FYM	MRP	CNTRL	Mean
1	Intercrop	Lup:kales	2.88^{gh}	2.78^{ef}	2.69^{ab}	2.78^{b}	2.95^{efg}	3.01^{gh}	2.80^{b}	2.92^{d}
	Intercrop	Cp:kales	2.83^{fgh}	2.71^{abc}	2.74^{bcde}	2.76^{ab}	3.07^{i}	2.72^{a}	2.73^{a}	2.74^{a}
	Crop rotation	Lup-kales	2.79^{efg}	2.77^{ef}	2.71^{abcd}	2.76^{ab}	3.09^{i}	2.90^{de}	2.87^{e}	2.90^{cd}
	Crop rotation	Cp-kales	2.98^{h}	2.68^{a}	2.75^{cde}	2.80^{b}	3.06^{hi}	3.08^{k}	2.96^{efg}	3.04^{e}
	Monocrop	Kales	2.75^{bcde}	2.77^{cdef}	2.77^{def}	2.76^{ab}	2.97^{fg}	2.88^{bc}	2.83^{bc}	2.82^{bc}
2	Intercrop	Lup:kales	2.91^{ab}	2.80^{ab}	2.76^{a}	2.82^{a}	3.09^{c}	3.05^{cd}	2.98^{e}	3.14^{de}
	Intercrop	Cp:kales	3.09^{d}	3.08^{d}	2.86^{ab}	3.01^{c}	3.08^{c}	2.98^{c}	2.97^{c}	3.01^{abc}
	Crop rotation	Lup	3.05^{c}	3.04^{c}	2.79^{a}	2.98^{c}	3.16^{e}	3.14^{de}	3.02^{cd}	3.12^{d}
	Crop rotation	Cp	2.92^{ab}	2.84^{b}	2.75^{a}	2.84^{a}	3.09^{c}	3.12^{cde}	3.04^{cd}	3.15^{de}
	Monocrop	Kales	2.81^{ab}	2.78^{a}	2.76^{a}	2.78^{a}	2.78^{a}	2.82^{ab}	2.92^{abc}	2.84^{a}
3	Intercrop	Lup:kales	3.05^{bc}	2.90^{ab}	2.86^{b}	2.94^{ab}	3.09^{ab}	3.05^{cd}	3.09^{d}	3.24^{bcd}
	Intercrop	Cp:kales	3.10^{c}	3.09^{c}	3.03^{bc}	3.07^{d}	3.07^{e}	3.11^{e}	3.03^{d}	3.07^{cd}
	Crop rotation	Lup-kales	2.95^{abc}	2.84^{b}	2.81^{a}	2.87^{b}	3.09^{ab}	3.01^{c}	3.06^{cd}	3.09^{d}
	Crop rotation	Cp-kales	3.05^{bc}	2.86^{b}	2.84^{b}	2.92^{ab}	3.07^{cd}	3.15^{f}	2.85^{b}	3.07^{cd}
	Monocrop	Kales	2.89^{ab}	2.83^{b}	2.83^{b}	2.85^{b}	3.01^{c}	2.56^{a}	2.76^{ab}	2.84^{b}

MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea, LUP-lupin CS-CROPPING SYSTEM Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

The adequate levels of OC in the lupin/kale intercrop; chickpea-kale rotation in season two, was due to the legume forages from the first season that was incorporated into the soil hence raising the OC content. Where Farm yard manure was applied, even in a monocrop system, there was a significant increase in the organic carbon levels; the same was reported by Banger (2008), who found that continuous application of FYM to the soil lead to increase in soil organic carbon (SOC) in all the soil fractions.

The organic carbon levels in the second season especially under the chickpea-kale rotation (FYM, MRP and CNTRL); White lupine-kale rotation (FYM, MRP, CNTRL) were higher during the first month of plant growth and sampling. As the experiment progressed, the level of organic carbon kept reducing. Organic carbon is a result of decomposed materials which was greatly influenced by temperature and moisture content for the activities of the soil microbes to perform better.

Increased organic carbon level under application of FYM conform to the study by Bayu *et al*. (2006) who also concluded that FYM application increased soil organic carbon content by up to 67% over the control treatment. The crop rotations systems as evidenced by the higher levels of organic carbon showed in season two was a result of crop residues from the legumes would further act as manures thus increasing the soil organic carbon. This was in agreement with study by Knight and Shirtliffe, (2005) who found out that legume green manure have increased benefits such as the ability to fix atmospheric N_2 and mobilize P from the soil.

4.3.1.3 Available phosphorus:

There was a significant increase in P levels in white lupine /kale intercrop (MRP, FYM and CNTRL) (Table 4.3). The cropping system white lupine-kale rotation (MRP, FYM and CNTRL) recorded high levels of phosphorus, while kale monocrop (MRP, FYM and CNTRL) resulted in lower levels of Phosphorus even lower than the initial amount throughout the two seasons. There was however no significant difference between chickpea/kale intercrop and chickpea-kale rotation (MRP) (Table 4.3). During the 1st month of season one, chickpea/kale intercrop (MRP, FYM) recorded higher amounts of phosphorus with the lowest amounts in chickpea-kale rotation (Cntrl) (8.67) (Table 4.3).

Table 4.3: Effects of different organic inputs and cropping system on soil available phosphorous

			P ppm LRS2014				P ppm SRS 2014			
Months of kale growth	CS	CROPS	FYM	MRP	CNTRL	Mean	FYM	MRP	CNTRL	Mean
1	Intercrop	Lup:kales	11.91^{cde}	13.74^{f}	10.82^{bcd}	12.15^{g}	8.06^{g}	9.50 i	8.86^{g}	8.81^{d}
	Intercrop	Cp:kales	12.65^{ef}	12.99^{ef}	9.65^{ab}	11.76^{fg}	12.66^{j}	10.94^{i}	18.25^{l}	13.95^{h}
	Crop rotation	Lup	11.55^{cde}	12.33^{def}	10.24^{abc}	11.37^{f}	6.90^{d}	7.40^{f}	5.50^{b}	6.60^{b}
	Crop rotation	Cp	10.33^{abc}	11.53^{cde}	8.67^{a}	10.17^{e}	7.40^{f}	9.53^{h}	6.53^{cd}	7.82^{ab}
	Monocrop	Kales	10.52^{bc}	9.64^{ab}	11.37^{bcde}	10.51^{e}	8.30^{f}	6.20^{c}	3.567^{a}	8.12^{c}
2	Intercrop	Lup:kales	14.11^{d}	19.96^{e}	12.20^{bcd}	15.42^{c}	14.80^{g}	13.08^{f}	10.99^{def}	12.96^{b}
	Intercrop	Cp:kales	19.02^{e}	21.40^{e}	11.43^{abc}	17.28^{e}	10.87^{bcd}	17.93^{h}	12.41^{ef}	13.74^{b}
	Crop rotation	Lup	12.80^{cd}	10.94^{abc}	$11 .84^{bcd}$	11.86^{ab}	10.41^{abc}	11.21^{cd}	10.10^{ab}	10.57^{a}
	Crop rotation	Cp	19.05^{e}	19.54^{e}	11.04^{abc}	16.54^{d}	9.90^{a}	11.24^{cd}	10.90^{bcd}	10.68^{a}
	Monocrop	Kales	9.62^{ab}	9.03^{a}	8.96^{a}	9.20^{a}	11.64^{de}	18.48^{h}	10.98^{bcd}	13.7^{cd}
3	Intercrop	Lup:kales	20.21^{de}	21.83^{de}	13.66^{bc}	18.57^{g}	14.29^{f}	13.43^{e}	15.05^{g}	14.26^{d}
	Intercrop	Cp:kales	15.65^{c}	18.46^{d}	11.60^{b}	15.24^{de}	15.75^{h}	20.71^{k}	19.84^{j}	18.77^{g}
	Crop rotation	Lup	18.62^{d}	24.26^{f}	11.48^{b}	18.12^{eg}	18.17^{j}	16.74^{i}	11.55^{d}	15.48^{e}
	Crop rotation	Cp	13.33^{b}	13.89^{bc}	12.36^{b}	13.19^{c}	7.87^{a}	8.60^{b}	7.70^{a}	8.05^{a}
	Monocrop	Kales	12.56^{b}	8.07^{a}	11.93^{b}	10.85^{b}	7.72^{a}	8.05^{ab}	9.43^{c}	8.40^{ab}

LRS 2014-long rain season, SRS 2014–Short rain season, MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea and LUP-lupin. Means followed by the same letters in the same season in a column are not significantly different at P ≤ 0.05.

In season two, 1st month there were higher amounts of P under chickpea/kale intercrop (FYM, MRP and Cntrl), with kale monocrop (FYM, MRP and Cntrl) having the lowest amounts of phosphorus. During the 2nd month higher amounts were recorded in chickpea/kale intercrop (MRP) whereas the third month, chickpea/kale intercrop (MRP) also recorded highest amount (Table 4.3). The low levels of P at the 1st month could be attributed to kale uptake, while at the 3rd month significantly higher amount of P were recorded.

Initial soil available P at the study area was low (11 ppm) according to Landon, (2014) classification, indicating that P was deficient in this soil and it is a limiting factor for crop production. All lupin/kale intercrops (FYM, MRP and Control); Chickpea/kale intercrop (MRP, FYM and control) showed high levels of Phosphorus. There were significant differences in the amount of available P across cropping system and organic treatments.

The improved levels of phosphorus could be attributed to soil amendments which improved the soil conditions. RP supplied P and its solubility was enhanced by Chickpea and lupin exudates. According to Vanlauwe, (2003) the high proton excretion of legume roots typically for symbiotically living leguminous species (Mengel, 1994), contributed to the dissolution of rock phosphate.

Organic molecules, provided by the FYM, enhance P availability by binding exchangeable and hydroxyl-Al, the key fixers of P in acid soils and they are also key in dissolving phosphate rock (Haynes and Mokolobate, 2001). The controls with lupin in either intercrop or rotation system showed higher levels of P, this is due to the exudates released by lupine which was able to release any P which might have been fixed in the soil.(Weisskopf, 2006).

During the first month of sampling the soils generally recorded lower amounts of Phosphorus, this could be attributed to kales growth and hence taking up more phosphorus. Phosphorus is important in early crop development. Similar results have been recorded by White, (2010) who found out that most crops take up majority of the nutrients during the periods of vegetative growth which in the case ok kales they are more vegetative during the early stages of growth.

During the second season most of the intercrops and legume pure stands had high levels of phosphorus. During the first month of sampling on the second season, the monocrop had higher amounts of P even as compared as the other systems; the reason for these is because of lack of competition by the crops for the nutrients and previous land management practices.

4.3.1.4 Soil NH_4-N and NO_3-N

The soil NH_4-N was significantly ($P \leq 0.05$) influenced by the application of the different organic inputs and legume integration. Amounts of NH_4^+-N, in chickpea-kales rotation (FYM, MRP and Control), white lupine-kale rotation (FYM, MRP and control), intercrop white lupin/kale (FYM, MRP and control) had higher levels of NH_4^+-N. Lower levels of NH_4-N were recorded under kale monocrop (FYM, MRP and control). During season two, lupin-kale rotation (Control, MRP and FYM), chickpea-kale rotation (control, FYM, MRP), lupin/kale intercrop (FYM, MRP and control) had higher levels of NH_4^+-N as compared to all monocrop (FYM, MRP and control). During the 1st month 23kg/ha^{-1} under FYM, while the 3rd month of sampling the monocrop 27kgha^{-1}.

The interactions of organic fertilizers and cropping systems significantly increased NO_3-N. Chickpea/kale intercrop (FYM, MRP and Control), lupin/kale intercrop (FYM, MRP and Control) recorded significantly high levels of NO_3-N, these results were recorded during the first two months, while during the third month of sampling, lupin/kale intercrop (FYM) recorded higher levels as compared to chickpea/kale intercrop (FYM, MRP and control), chickpea-kale rotation (FYM, MRP and control) and lupin/kale rotation (FYM, MRP and control).

The trend in the levels of both NO_3-N and NH_4^+-N in season one was similar to season two (Fig4.1, 4.2, 4.3 and 4.4.). During the second season, the levels of NO_3-N and NH_4^+-N were slightly lower as compared to the first season of the kale growth. The mineral nitrogen progressively increased throughout the season, at the first month. The plots treated with rock phosphate showed high levels of the NO_3-N and NH_4^+-N. As the experiment progressed, the farm yard manure recorded higher levels of NO_3-N and NH_4^+-N.

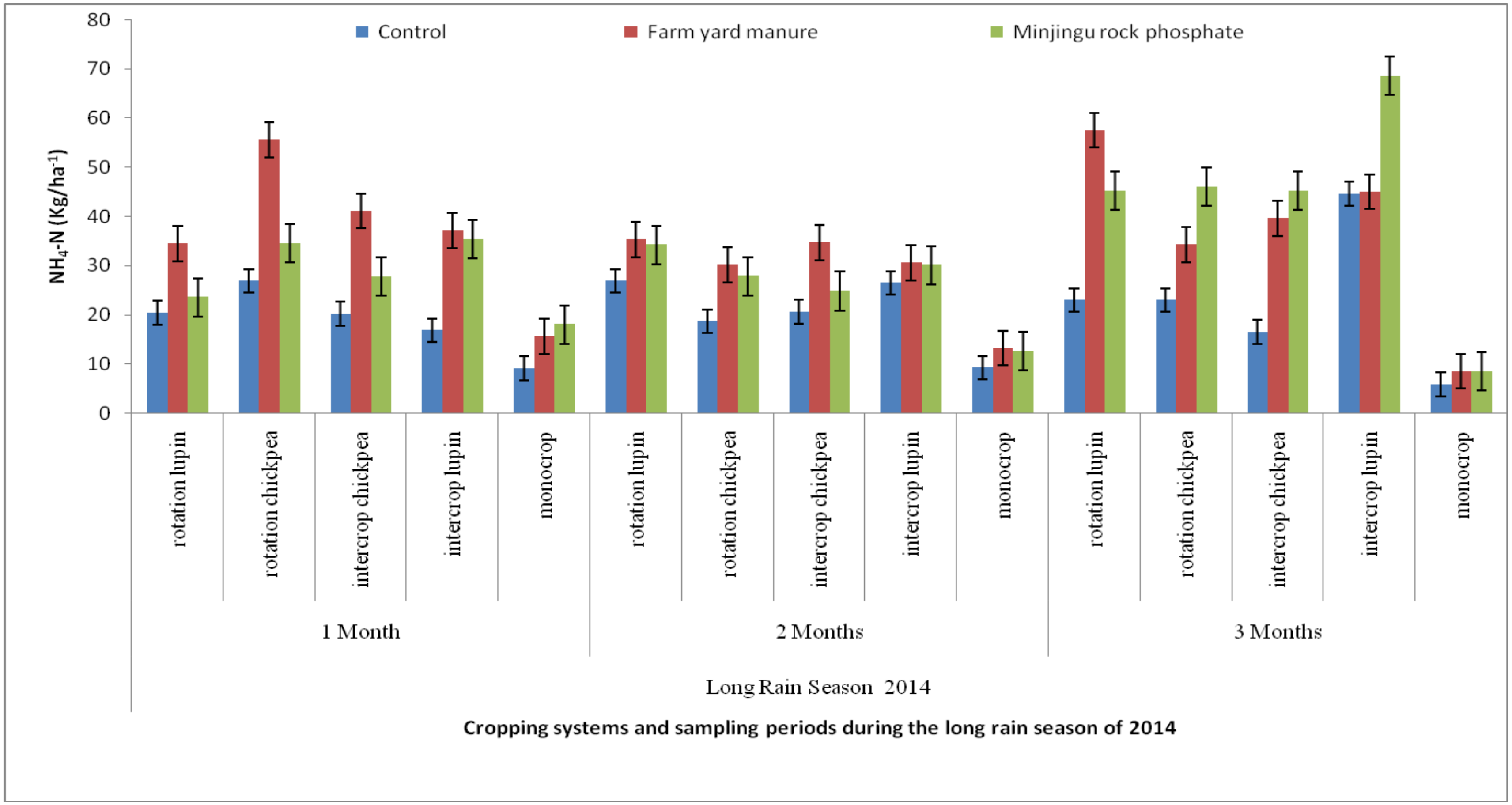

Figure 4.1: Effects of legume integration and application of organic fertilizers on soil ammonia (NH_4^+-N) during the long rains of 2014.

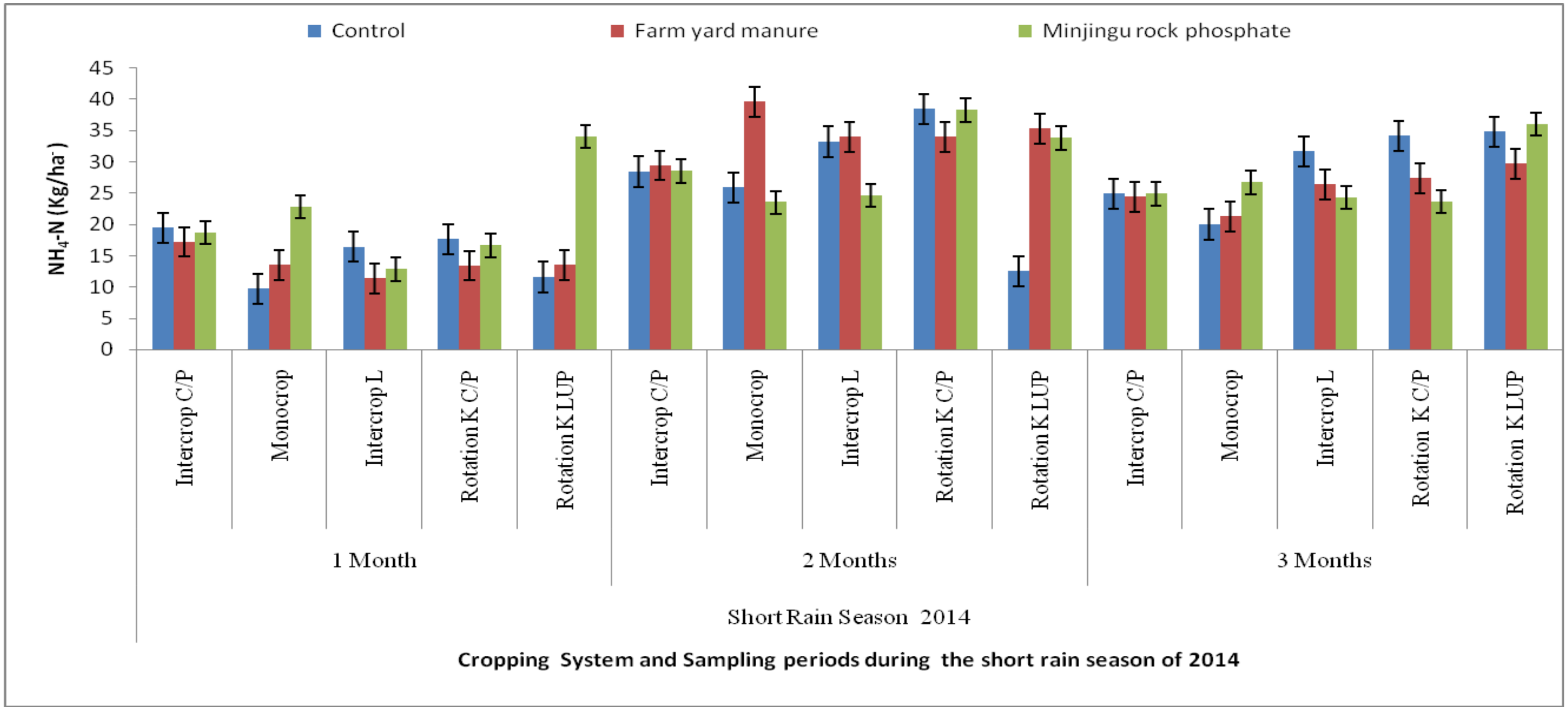

Figure4.2: Effects of legume integration and application of organic fertilizers on soil ammonia ($NH_4{}^+$-N) during the short rains of 2014

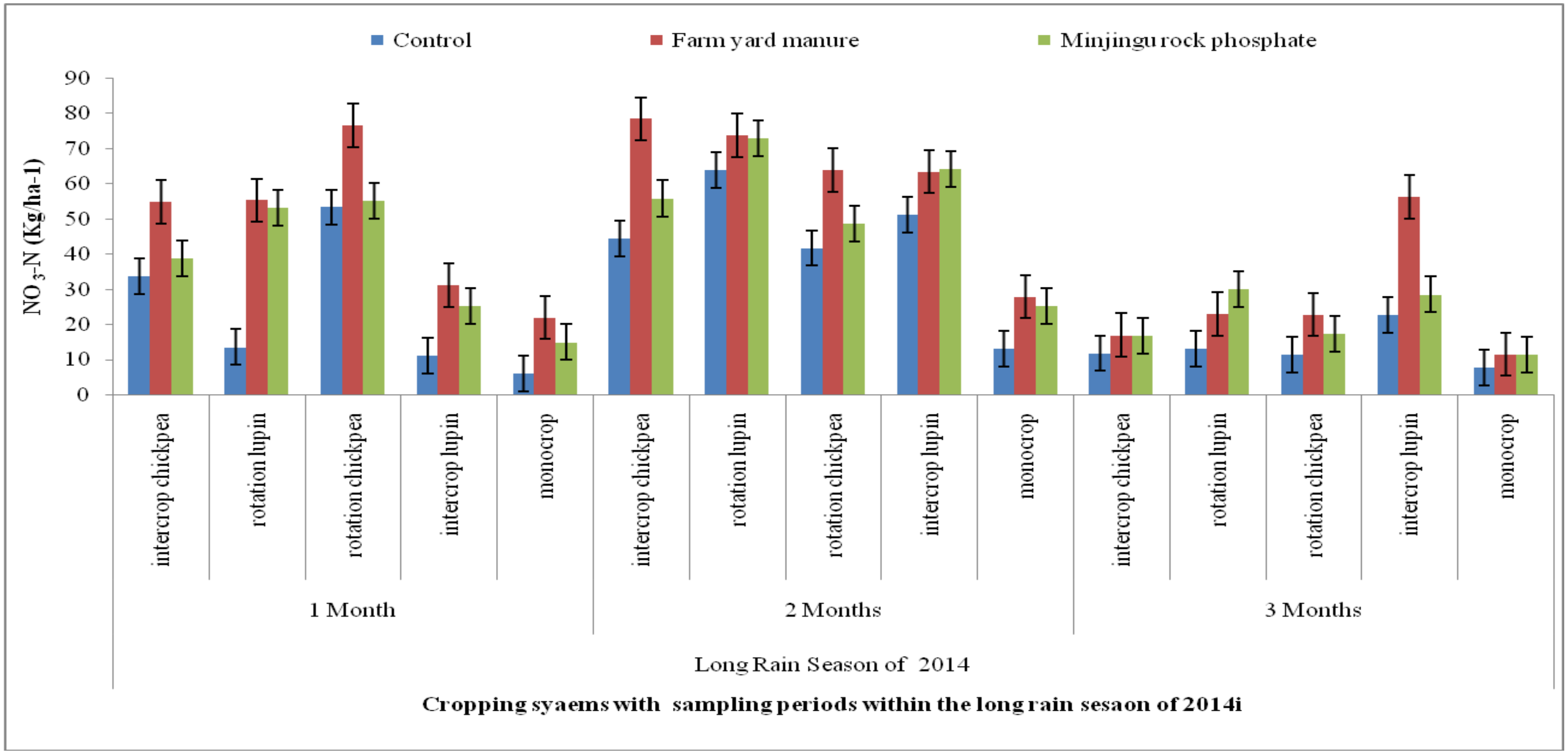

Figure4.3: Effects of legume integration and application of organic fertilizers on soil nitrate (NO_3-N) during the long rains of 2014.

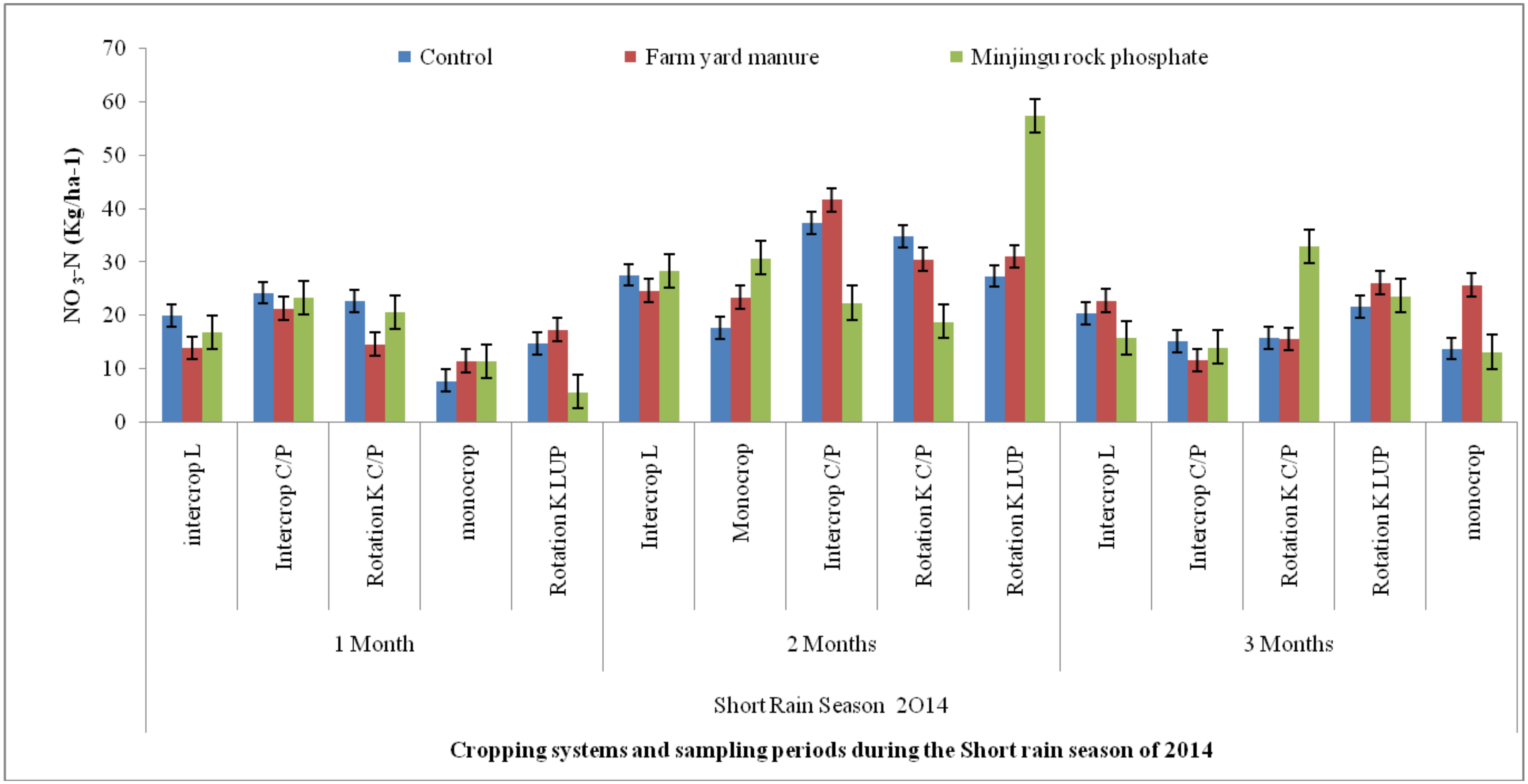

Figure4.4: Effects of legume integration and application of organic fertilizers on soil nitrate (NO_3-N) during the short rains of 2014.

Kale/chickpea intercrop or a pure stand with application of farm yard recorded higher levels of NO_3-N and NH_4^+-N throughout the season as compared to other cropping system and across organic fertilizers. Generally the soils under FYM treatment recorded higher amounts of NO_3-N and NH_4^+-N.

During the second season, the amounts of NO_3-N and NH_4^+-N declined as compared to the first season, these could be the explained with the effects of weather changes and especially the insufficient rainfall and the increased temperatures experienced during the sampling time as is shown in fig 3.1. During the second month of kale growth, NO_3-N and NH_4^+-N were lower as compared to the other months of sampling, it was so because of the kale uptake and the demand for nitrogen at 40 days to 70 days of kale development, the kales had high levels of nitrogen.

Soil mineral nitrogen increased with legumes integration with lupin out performing chickpea. Intercrops and pure stands of white lupin showed increasing amounts of NO_3-N and NH_4^+-N as compared to chickpea and it is evidenced in both the seasons. Similar results on NO_3-N and NH_4^+-N increasing when legumes are included in rotations have been reported by others workers (Bationo and Ntare, 2000).

The high NO_3-N and NH_4^+-N under the rotation cropping system as evidenced in season two of the project can be explained by the fact that after the removal of the previous legumes, the below ground biomass contribute to improve soil organic matter and thereby soil mineral N. Similar results have been reported by (Chalk, 1998) on effects on legume rotations on NO_3-N and NH_4^+-N.

MRP treated plots generally showed increased levels of NO_3-N and NH_4^+-N as compared to the other treatments. In the farm yard treated plots, ammonia release was generally high throughout the two seasons as compared with the release of nitrate. Similar studies done by Mahmoud *et al.*, (2009) support the same that in FYM treated plots, nitrate release was comparatively low.

Moreover in the control treatment it is likely that the first rains of the season stimulated the microbial activity leading to a high mineralization of soil organic matter resulting in an increase in mineral N. Nitrate content in the plots treated with FYM decreased thus was attributed to the supply of readily available nitrate to the kales. A similar result of lower nitrate levels where FYM is applied has been recorded by Esawy Mahmoud *et al*., (2009).

4.4 CONCLUSION

The soil organic fertilizers MPR and FYM are viable alternatives to the expensive inorganic fertilizers for improving the soil nutrient status in Kabete sub County. Intercropping of kale with white lupin and application MRP significantly increased soil phosphorus whereas, rotating kale with white lupin with application of FYM lead to an increase in soil % carbon and total nitrogen. Moreover, the MRP, FYM are locally available, thus making it an ideal source of nutrients for smallholders economically and the famers get to enjoy a diversity of crops to harvest from same piece of land.

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CHAPTER FIVE

5.0 EFFECTS OF LEGUME INTEGRATION AND APPLICATION OF ORGANIC FERTILIZERS ON KALE NUTRIENT CONCENTRATION AND YIELD

Abstract

Kale production in Kenya is hindered by several factors; pests and diseases, overdependence on rain fed agriculture and low soil fertility. A study was conducted to evaluate the effects of legume integration and application of organic fertilizers on kale nutrient concentration and yield at Kabete field station of the University of Nairobi, Kenya during the long and short rains of 2014. The experimental design was a RCBD with a split plot arrangement. The main plots were cropping systems (monocrop, intercrop and rotations) while the sub plots were the different organic inputs (Minjingu Rock Phosphate and Farm Yard Manure). The test crop was kale (*Brassica oleracea var. acephala*) integrated with white lupin (*Lupinus albus cv Amiga)* and chickpea (*Cicer arietinum L*). Kale leaves were sampled at an interval of 1, 2 and 3 months for N, P and K analysis and yield determination. There was a significant ($P \leq 0.05$) increase in nitrogen concentrations during the first season where monocrop (FYM, MRP and Control) (4.00%, 4.87%, 4.17%); chickpea/kale intercrop (FYM, MRP and Control) (3.80%, 4.15%, 3.75%); lupin/kale intercrop (FYM, MRP and control) (3.90%, 3.70%, 4.00%). During the second season, the trend was similar to the first season, monocrop (FYM, MRP and control); lupin-kale rotation (FYM, MRP and Control); chickpea-kale rotation (FYM, MRP and Control). Kale potassium concentration was significantly ($P \leq 0.05$) increased in lupin/kale intercrop (FYM, MRP and Control) (1.63%, 0.97% and 1.27%); chickpea/kale intercrop (FYM, MRP and Control) (1.53%, 1.20%, 1.00%); monocrop (FYM, MRP and Control) (1.26%, 1.53% and 1.40%) during the second month of sampling. The second season had an increase in potassium concentration, chickpea-kale rotation (FYM, MRP and Control) (3.47%, 3.17%, and 2.18%). Phosphorus concentrations during the first season was increased by, monocrop (FYM, MRP and Control) (50ppm, 63ppm and 47ppm); chickpea/kale and lupin/kale intercrop (FYM, MRP and control), the same trend was recorded in season two where, chickpea-kale rotation (FYM, MRP and control); lupin-kale rotation (FYM, MRP and Control). There was high yield ok kale in kale monocrop (FYM) (4.01tha), Lupin-kale rotation (FYM) (3.68t/ha) as compared to kale monocrop (Cntrl) (2.77 t/ha). The results indicate that integration of lupin in rotation with application MRP improved nutrient concentrations and yield of kales. Similarly application of FYM significantly improves kale nutrient concentration with integration of lupin and hence viable practices.

Key words: cropping systems, organic fertilizers, kales, kale nutrient concentration legumes,

5. 1 INTRODUCTION:

Kale (*Brassica oleracea var. acephala*) is the most important vegetable in Kenya (Mariga *et al.*, 2001). It is known as a source of many nutrients, vitamins, antioxidants, minerals and important proteins (Akula *et al*., 2007). Among fresh leafy greens, kale is the most important source of nutrients in the diet followed by spinach in total carotenoids and folate (USDA 2002) and second in total antioxidant capacity behind only garlic (Cao *et al*., 1996). Furthermore, nitrogen compounds, in which amino acids predominate forms about one third of the dry matter in kale and is particularly rich in vitamins, minerals, dietary fiber and antioxidant compounds (Lisiewska *et al.*, 2008).

Its production has been in a decline hence not matching the demand forces. For increased production by the smallholder farmers, it has lead to use of the rather expensive inorganic fertilizers which have negative impacts on degrading the soils and the environment. New production technologies need to be identified for enhanced production and improved nutrient concentrations. The use of organic soil amendments such as farm yard manure and rock phosphate has been associated with desirable soil properties including increased plant available nutrients, water holding capacity and cation exchange capacity and low bulk density besides fostering beneficial microorganisms (Drinkwater *et al*., 1995).

Use of rock phosphate, compost and weed teas improve plant growth and optimize fertilizer use efficiency (Bouagnimbeck, 2009). These soil attributes are enhanced in kale/ legume intercrop farming systems (Reganold, 2001). Kale production in Kenya is a highly relevant activity due to its importance as it is a dominant vegetable crop (Duflo *et al.*, 2008). To meet their nutritional needs, application of organic amendments such as rock phosphate, farm yard manure and practicing chickpea/lupin integration are called for (Oikeh and Asiegbu, 1993).

The aim of this study was to determine and compare nitrogen, phosphorus and potassium concentrations in kale, where legumes were introduced and application of organic fertilizers at different harvesting stages so as to suggest the most appropriate stage of maturity in mineral content for consumers that prefer fresh vegetables.

5.2 MATERIALS AND METHODS

5.2.1 Study Site

The on-station study was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi. More details are described in chapter three section 3.1.

5.2.2 Treatments and Experimental design

Experimental design was a RCBD with spilt plot arrangements. More is described in chapter three section 3.2.

5.2.3 Field Practices

Main plots were the cropping systems; Monocrop, intercrop and crop rotation whereas the split plots will be the (MRP, FYM and control). The MRP was applied at the rate of 60 kg P ha^{-1} (~496 kg of MRP/ha). Plot sizes were 3.75 m by 4.8 m with a 0.5 m and 1 m wide footpath between the plots and blocks respectively. They were replicated three times.

All plots were ploughed and residues removed manually before the application of treatments. MRP was broadcasted at the rate of 60 kg P/ ha (496kg per ha) and then incorporated to a depth of 0 – 0.15 m before planting. Farm yard manure was applied at a rate of 10 tonnes per ha. Kale (*Brassica oleracea* var. *acephala* D.C.) chick pea (*Cicer arietinum*) and white lupin (*Lupinus albus L)* (intercrop) were planted and sown. Kales were planted at a spacing of 60 cm and 45 cm between and within the row in all treatments. Four weeks after sowing, the seedlings were thinned to one plant per hole. Weeding was carried out after the emergence of weeds and was done twice.

5.2.4 Plant sampling and analysis

Plant sampling for the leaves was done at every sampling stage of 1, 2 and 3 months within the middle rows and two rows left on the sides. Fresh weight was determined by weighing and the samples taken to the laboratory for analysis.

5.2.5 Statistical analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne *et al.*, 2006). Least significant difference (LSD) test was used to identify significant differences among treatment means (P≤0.05).

5.3 RESULTS AND DISCUSSIONS

5.3.1 Effect of legume integration and application of organic fertilizers on kale nutrient concentrations

5.3.1.1 Nitrogen:

During the 1st month of season one, there was a higher levels of nitrogen in the Monocrop (FYM, MRP and control), chickpea/kale intercrop (FYM, MRP and control) as compared to month 2 and 3 (Table 5.1). During the 2nd month, the levels of nitrogen were slightly lower as compared to month 1 but higher levels were recorded in monocrop (FYM, MRP and control), chickpea/kale intercrop (FYM, MRP and control) whereas in the 3rd month, lower levels of nitrogen in lupin/kale intercrop (FYM, MRP and control) were recorded (Table 5.1).

Season two, the trend of nitrogen concentrations was similar to that of season one. The highest nitrogen concentration was recorded in kale monocrop (FYM, MRP and control), lupin-kale rotation (FYM, MRP and control), and lupin/kale intercrop (FYM, MRP and control) at the 1st month. The lowest concentrations of nitrogen was recorded in, chickpea/kale intercrop (FYM, MRP and Control) (3.20%, 2.83%, 2.93%); lupin-kale rotation (FYM, MRP and Control) (3.27%, 2.93%, 2.71%).

Table 5.1: Effects of cropping systems and organic inputs on nitrogen concentration (%) in kale leaves

			Long rain season 2014				Short rain season 2014			
Months of kale growth	Cropping systems	Crop	FYM	MRP	CNTRL	MEAN	FYM	MRP	CNTRL	MEAN
1	Intercrop	Lupin/kale	3.90^{ab}	3.70^{a}	4.00^{ab}	3.87^{a}	4.47^{efg}	4.38^{ef}	3.52^{a}	4.123^{bc}
	Intercrop	Chickpea/intercrop	3.80^{ab}	4.15^{b}	3.75^{a}	3.90^{a}	4.33^{e}	4.38^{e}	4.00^{d}	4.24^{c}
	Monocrop	Kales	4.00^{ab}	4.87^{c}	4.17^{b}	4.35^{d}	4.68^{g}	4.53^{efg}	4.06^{d}	4.42^{e}
	Rotation	Lupin-kale	-	-	-	-	4.60^{fg}	3.58^{ab}	3.87^{cd}	4.02^{b}
	Rotation	Chickpea-kale	-	-	-	-	4.42^{ef}	3.75^{bc}	3.87^{cd}	4.03^{b}
2	Intercrop	Lupin/kale	3.77^{bc}	3.67^{b}	3.41^{a}	3.62^{a}	4.28^{ef}	3.96^{bc}	3.57^{a}	3.93^{b}
	Intercrop	Chickpea/kale	3.77^{bc}	4.09^{d}	3.40^{a}	3.75^{a}	4.05^{cd}	4.36^{ef}	3.80^{b}	4.07^{c}
	Monocrop	Kales	3.99^{cd}	4.47^{e}	4.22^{d}	4.23de	4.29^{ef}	4.74^{h}	4.52^{fgh}	4.52^{e}
	Rotation	Lupin-kale	-	-	-	-	4.45^{fg}	4.19^{de}	3.94^{bc}	4.19^{d}
	Rotation	Chickpea-kale	-	-	-	-	4.36^{ef}	4.34^{ef}	4.63^{gh}	4.44^{de}
3	Intercrop	Lupin/kale	2.92^{bc}	2.97^{bcd}	2.21^{a}	2.70^{a}	3.63^{f}	3.67^{f}	2.91^{ab}	3.4^{d}
	Intercrop	Chickpea/kale	3.00^{cd}	3.10^{cde}	2.70^{b}	2.93^{b}	3.20^{cde}	2.83^{ab}	2.93^{abc}	2.98^{b}
	Monocrop	Kales	3.23^{de}	3.37^{e}	2.90^{bc}	3.17^{c}	4.07^{g}	3.953^{g}	3.60^{f}	3.87^{e}
	Rotation	Lupin-kale	-	-	-	-	3.27^{de}	2.93^{abcd}	2.71^{a}	2.97^{b}

MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea, LUP-lupin .Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$. LRS-long rain season. SRS-short rain season

The high nitrogen contents in the lupin/kale rotation with application of farm yard manure in season two could be attributed to the residues and leaves which dropped from lupin as compared to chickpea. The dropped leaves could have decomposed and released nitrogen as they are attributed to have high contents of nitrogen hence more supply for plant uptake. Previous studies have shown that Lupin has high above ground biomass (Engedaw, 2012).

Previous studies have shown that continuous application of FYM lead to an increase in soil N (Banger, 2008) and this ultimately leads to high Nitrogen contents in the kale tissues. There was no significant difference between the cropping systems during the first growing season (Table 5.1). The nitrogen levels in the leaves of kales kept increasing as the leaves matured. The levels of nitrogen were higher during the 1st month of kale development as it is usually the time when kales produce fresh, lushly leaves.

Kale monocrop in the first season recorded higher levels of nitrogen as compared to the intercrops and rotation. This is because there was no competition for nutrients by the crop. At the 3rd month of both seasons lower levels of nitrogen was recorded as compared to 1st and 2nd month hence can be attributed to the age of the plant and increased canopy. A study by Fageria *et al.*, (2005) reported that nitrogen is lost by plants in the form of $NH^{-}_{3.}$

The kale/lupin intercrop system with application of MRP also depicted higher amounts of nitrogen as compared to other treatments; it can be explained by the availability of phosphorus and the exudates which would have probably ensured the availability of the nutrients from the soil for easier plant uptake. An increased amount of phosphorus plays an important role in nitrogen fixation by legume through the increased number of nodules therefore kale benefited from the fixed nitrogen hence higher nitrogen levels. Similar results done by Ojiem, (2006) reported that P was essential for N2 fixation by common bean.

5.3.1.2 Potassium:

Potassium concentration in kale leaves were significantly ($P \leq 0.05$) increased by the application of organic fertilizers. During the 1st month of season one, kale/chickpea intercrop (FYM, MRP, Control) (0.96%, 1.05%, 0.96%); kale monocrop (FYM, MRP and Control)(0.86, 1.19%, 0.90%) recorded a lower concentration of potassium as compared to 2nd month, kale/ lupin intercrop

(FYM, MRP and control) (1.63%, 0.97%, 1.27%); chickpea/kale intercrop (FYM, MRP and control) and kale monocrop (FYM, MRP and Control) (Table 5.2).

During the second season, the trend in potassium concentration was similar to that of 1st season whereby in the 1st month, lupin-kale rotation (FYM, MRP and Control) and chickpea-kale (FYM, MRP, Control) recorded the highest levels of the potassium as compared to kale monocrop (FYM, MRP and Control); chickpea/kale intercrop and lupin/kale intercrop (FYM, MRP and Control) (Table 5.2). During the 2nd month highest concentrations of potassium was recorded as compared to month 1 and 3.chickpea-kale rotation (FYM, MRP and Control); Lupin-kale rotation (FYM, MRP and Control). The high levels of K in the kale tissues after chickpea-kale rotation systems is because chickpea has a better K mobilization and recycling hence available for subsequent plant uptake.

Table 5.2: Effects of cropping systems and organic inputs on potassium concentration (%) in kale leaves

			long rain season 2014				short rain season 2014			
Months of kale growth	Cropping systems	CROP	FYM	MRP	CNTRL	MEAN	FYM	MRP	CNTRL	MEAN
1	Intercrop	Lupin	0.56^{a}	1.01^{cd}	0.77^{b}	0.780^{a}	0.59^{a}	1.04^{e}	0.79^{b}	0.81^{a}
	Intercrop	Chickpea	0.96^{bc}	1.05^{cd}	0.96^{bc}	0.989^{b}	0.98^{de}	1.06^{e}	0.93^{cd}	0.99^{bc}
	Monocrop	Kales	0.86^{bc}	1.19^{d}	0.90^{bc}	0.984^{b}	0.88^{c}	1.21^{f}	0.89^{cd}	0.99^{bc}
	Rotation	Lupin-kale	-	-	-	-	3.25^{j}	3.47^{k}	2.34^{f}	3.02^{d}
	Rotation	Chickpea-kale	-	-	-	-	2.55^{h}	3.13^{i}	1.23^{f}	2.303^{c}
2	Intercrop	Lupin/kale	1.63^{b}	0.97^{a}	1.27^{ab}	1.28^{a}	2.03^{c}	1.36^{a}	1.67^{b}	1.68^{c}
	Intercrop	Chickpea/kale	1.53^{b}	1.20^{ab}	1.00^{a}	1.24^{a}	1.95^{c}	1.60^{b}	1.43^{a}	1.66^{c}
	Monocrop	Kales	1.26^{ab}	1.53^{b}	1.40^{ab}	1.398^{b}	1.67^{b}	1.96^{c}	1.90^{c}	1.84^{d}
	Rotation	Lupin-kale	-	-	-	-	3.23^{fg}	3.32^{g}	2.31^{e}	2.95^{e}
	Rotation	Chickpea-kale	-	-	-	-	3.47^{h}	3.17^{f}	2.18^{d}	2.94^{e}
3	Intercrop	Lupin/kale	1.12^{b}	1.01^{ab}	0.87^{ab}	1.002^{bc}	1.41^{c}	1.36^{a}	1.17^{abc}	1.31^{e}
	Intercrop	Chickpea/kale	0.91^{ab}	0.76^{ab}	0.69^{a}	0.798^{a}	1.24^{bc}	1.07^{ab}	0.97^{a}	1.09^{c}
	monocrop	Kales	0.80^{ab}	1.07^{b}	0.83^{ab}	0.900^{b}	1.127^{ab}	1.37^{c}	1.22^{bc}	1.239^{d}
	Rotation	Lupin-kale	-	-	-	-	2.96^{fg}	2.76^{f}	2.33^{e}	2.63^{f}
	Rotation	Chickpea-kale	-	-	-	-	3.04^{g}	3.17^{g}	1.96^{d}	2.72^{f}

MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea, LUP-lupin Means followed by the same letters in the same season in a column is not significantly different at ($P \leq 0.05$)

The legume-kale rotations recorded an increase in concentrations of potassium; this may be attributed to some remaining legume stover and leaves which might have been shed. Ahlawat *et al*., (2005) while conducting chickpea-maize cropping studies noted that stover recycling from crops was able to economize 50% of the recommended NPK fertilizers rates.

All plots treated with farm yard manure recorded higher levels of K as compared to the other treatments; farm yard manure had higher amounts of K during the initial analysis. Similar results were recorded by Fageria and Baligar, (2003). During the second season the high concentrations of potassium than first season may be attributed to the high soil temperatures above the optimum as this increases the psychological activities of the roots hence taking up more potassium. Potassium is an indispensible nutrient with its significant role in the synthesis of amino acids and proteins (Malik and Srivastaka, 1983). It has a key role in stomatal functioning and helps the plant lose water more efficiently by promoting turgidity to maintain internal pressure of the plant (Tirasoglu *et al.,* 2003).

5.3.1.3. Phosphorus (ppm)

Phosphorus concentration was at ($P \leq 0.05$) by applications of different organic inputs and the integration of the legumes. During the 1st month of sampling, lupin/kale intercrop (FYM, MRP and Control) and chickpea/kale intercrop (FYM, MRP and Control) recorded higher concentrations of phosphorus as compared to kale monocrop (FYM and MRP). At the 2nd month, the levels of phosphorus in the kale leaves were generally high, kale monocrop (FYM, MRP and Control), chickpea/kale intercrop (FYM, MRP and Control) and lupin/kale intercrop (FYM, MRP and control) (Table 5.3).

During the second season, concentration of phosphorus was highest at the 2nd month in lupin/kale intercrop (MRP) (54.32ppm), same as chickpea/kale intercrop (MRP) (Table 5.3). The lowest levels phosphorus concentration was recorded in kale monocrop across organic fertilizers. The 1st month recorded the lowest concentrations of phosphorus than the 3rd month. There were positive interactions between the cropping systems and organic fertilizers.

Table 5.3: Effects of cropping systems and organic inputs on phosphorus concentration (ppm) in kale leaves

			Long rain season 2014				Short rain season 2014			
Months of kale growth	Cropping system	crop	FYM	MRP	CNTRL	MEAN	FYM	MRP	CNTRL	MEAN
1	intercrop	Lupin/kale	14 ^{a}	17 ^{a}	14 ^{a}	15^{a}	14.76^{cde}	29.83^{f}	14.76^{cde}	19^{a}
	Intercrop	Chickpea/kale	10 ^{a}	19 ^{c}	9.27 ^{a}	12.8^{a}	10.76 ^{ab}	17.76^{e}	10 ^{a}	12^{a}
	Monocrop	kale	8.50 ^{a}	12.83 ^{a}	7.73^{a}	9.7^{a}	16.59^{de}	12.36 ^{abc}	13.72^{bcd}	13.7^{a}
	Rotation	Lupin-kale	-	-	-	-	13.70^{bcd}	14.4^{bcde}	12.59^{abc}	13.6^{a}
	Rotation	Chickpea-kale	-	-	-	-	14 ^{bcd}	14.3 ^{bcde}	12.88^{abc}	13.7^{a}
2	Intercrop	Lupin/kale	30 ^{ab}	44 ^{c}	44 ^{c}	39^{d}	51 ^{j}	54.3^{g}	48 ^{i}	51.1^{d}
	Intercrop	Chickpea/kale	32 ^{bc}	35.67^{bc}	26 ^{ab}	31^{c}	33 ^{abc}	37.2^{bcd}	27 ^{a}	32.4^{b}
	Monocrop	kales	20 ^{ab}	24^{ab}	13.67^{a}	19.3^{b}	31 ^{ab}	25.5^{a}	25 ^{a}	27.2^{b}
	Rotation	Lupin-kale	-	-	-	-	40.08^{cd}	41.9 ^{de}	32.8^{abc}	38^{c}
	Rotation	Chickpea-kale	-	-	-	-	42.32 ^{de}	53.6^{g}	38.63^{bcd}	45^{c}
3	Intercrop	Lupin/kale	32 ^{cd}	38 ^{d}	23 ^{abc}	31^{c}	33.7 ^{bcde}	40.4 ^{ef}	24.5 ^{ab}	32^{b}
	Intercrop	Chickpea/kale	35.33 ^{cd}	31.00 ^{cd}	21 ^{ab}	29^{c}	31.1 ^{abcde}	32.7^{bcde}	23 ^{a}	28^{b}
	monocrop	kale	17.33 ^{a}	23.33^{abc}	14^{a}	18.2^{b}	35 ^{cde}	27 ^{abc}	37.5 ^{def}	33.2^{b}
	Rotation	Lupin-kale	-	-	-	-	37 ^{g}	35 ^{cde}	29 ^{abcd}	33.6^{b}
	Rotation	Chickpea-kale	-	-	-	-	34.7^{cde}	45.1 ^{f}	28 ^{abcd}	36^{c}

MRP-Minjingu rock phosphate, FYM- farm yard manure, CNTRL-control, C/P-chickpea, LUP-lupin Means followed by the same letters in the same season in a column is not significantly different at $P \leq 0.05$

During the 2nd month, phosphorus concentration was high across all treatments and cropping systems (Table 5.3). The highest P concentration was under kale/lupin intercrop (MRP) (54.3ppm). This increase could be attributed to readily available P from MRP which was released by exudates from white lupin. White lupin is also known to release more citric acid compared to chickpea. White lupin has been found to effectively utilize P from MRP particularly when soils are deficient in P (Arcand and Schneider, 2006). Gardner *et al.*, (1983) reported that the proteoid roots of lupin plants secreted large quantities of citric acid. Therefore, the addition of MRP to soil increases total soil P with the potential to replenish labile P and plant-available P (Arcand and Schneider, 2006).

As the sampling times were varying, phosphorus concentration also varied between 1st, 2nd and 3rd month. Phosphorus concentration in plants tissue varies with plant age. As a general rule, phosphorus concentration with the advancement of plant age is associated with increased dry matter yield. The decrease in phosphorus concentration with advancement of plant age is known as the dilution effect. Similar results of the trend in nutrient contents in plant tissue were also recorded by Fageria *et al.,* (2011).

5.3.2 Effects of organic fertilizers and different cropping systems on kale yield

A significant increase in kale yield was recorded in a monocrop system with application of FYM during the 1st month for season one. Similar results were recorded throughout season two, for both the FYM (Monocrop) and MRP (Monocrop) (Fig 5.1). During season two, 1st month, of sampling, highest yields were recorded under; kale monocrop (FYM and MRP) and lupin/kale intercrop (FYM, MRP). In the 2nd month of sampling, highest yields were recorded in, lupin-kale rotation (FYM, MRP), chickpea/kale intercrop (MRP and FYM) and kale monocrop (FYM, MRP) (Fig 5.1). As shown by the previous results on the nutrient status of the kale tissues, the more the nutrients in the leaves it has an effect on the yields of crops.

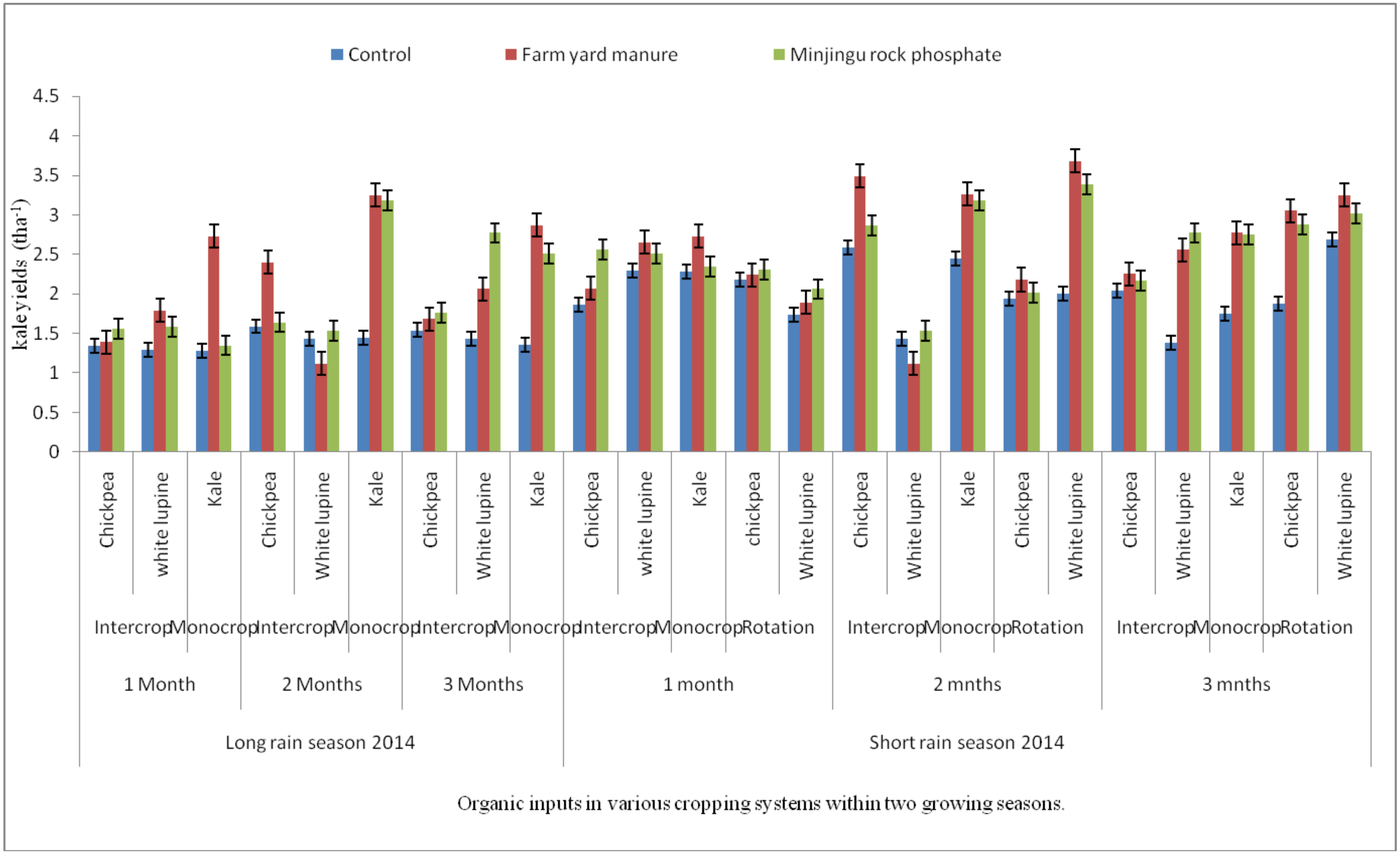

Figure 5.1: Effects of legume integration and application of organic fertilizers on kale yields *C/P-chickpea, LUP-lupin*

Throughout the two seasons, control had lowest yields, during the 1st month of sampling compared to the other months. The reason for the low yields is because of the limited nutrients available for increased yields as no input was applied hence the plants only benefited from the available nutrients found in the soil before planting and as shown by the initial analysis of soils most nutrients were moderately available P (11 ppm) N, (0.25 %) according to descriptions by Landon, 2014. Under the MRP treatment, the yields were high throughout the months although third month the yield reduced.

Chickpea/kale and lupin/kale intercrop with application of MRP, lead to increased yields during the 1st month because legumes have an effect on P solubilisation in the MRP plots thus making the nutrients readily available to the crop. The use of legumes could have also attributed to increased yield due to nitrogen they fixed. Availability of phosphorus and nitrogen contributed to the improved performance of kale. A previous study done by Onwonga *et al*., (2010) recorded improved maize yield where there was cowpea/maize intercrop with application of MRP.

Application of FYM across all cropping systems, recorded high kale yield throughout the two seasons, this could be attributed to the high nitrogen contents as shown in the initial analysis (Table 3.1) which is needed for plant growth**.** The improved yield was due to increased nutrient uptake under the use of FYM. Increased yield by organic manure application has also been reported (Muhammad & Khattak 2009; Akande *et al*., 2010). This might be attributed to more nutrients being released from the application of FYM upon decomposition and activates soil microbial biomass Belay *et al*., (2001).

It is evident that improved yield by addition of organic manures might be attributed to improved nutrient availability of the soil. Similar results were coined by Marschner, (2011). This results conform to the findings of Shirani *et al*., (2002) and Iqbal *et al*., (2005) who concluded that manure application either alone or in combination with different tillage practices and cropping systems improved crop growth and in turn the crop yield. The monocrop system had higher yields as compared to the intercrop, these can be explained by the fact that under the mono cropping system, there was no competition for nutrients hence higher yield as compared to the intercrops where there was a possibility of competition between the crops**.**

The chickpea/lupin-kale rotation had higher yields as compared to the other cropping systems, this could be attributed to the benefits the nitrogen fixed in the soil by the previous legume was available for kale uptake hence the high yields. This is in agreement with Onwonga *et al.,* (2008) noted that legume rotations significantly had higher yields.

5.4 CONCLUSION

This study showed that the application of appropriate cropping system and organic inputs has an influence on kale yield. Integration of kale and with white lupin under with the application of farmyard led to an increase in the nutrient concentrations and yield of kale.

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CHAPTER SIX

6.0 DECOMPOSITION AND MINERALIZATION RATES OF CHICKPEA AND LUPIN RESIDUES INCORPORATED IN A NITISOL OF KABETE, KENYA

Abstract

Asynchrony between nitrogen (N) supply and crop demand is the source of many environmental hazards associated with excess N in the biosphere. We assessed nutrient release rates of chickpea (*Cicer arietinum*) and white lupin (*Lupinus albus L.*) residues with intent of determining the best time to incorporate in the soil such that nutrient release is synchronized with kale (*Brassica oleracea var. acephala*) nutrient uptake. The study was carried out at the University of Nairobi field station, between November 2014 and February 2015. The experimental design was a CRD replicated thrice. The residues used were chickpea and lupin harvested from a previous crop. Residues were weighed, put in litter bags and buried. Litter bags retrieval was done at an interval of 0, 15, 30,45,60,75, 90,105 and 120 days. Weights were taken and residues analyzed in the laboratory for N, P, and K. The decay formula ($y=y_o\ e^{-kt)}$ was used to determine the decomposition and mineralization rates of the residues. The half lives were determined using the formula t1/2=ln (2) /k .The actual measurements of nutrient in kale (nutrient uptake) were measured during the study period at intervals of 30, 60 and 90 days. Weights dropped after each retrieval, the chemical compositions of the residues also declined with time. After 120 days of incubation, the white lupin had 24% of N, 16 %P, 16% K of the initial respective nutrients, whereas for chickpea was 19% N 15% P and 9 % K. A 50 % in weight loss of the legumes was found after 9 days of incorporation in the soils for the two legumes. A 50 % loss in N, P and K release of the legume residues was found at day 18 (N) 23 (P) and 11 (K) for chickpea and day 14(N), 11 (K) and 25 (P) for white lupin. The half life's of both legumes was at day 30. Kale leaves had the highest nutrient concentrations between day 30 for nitrogen and 60 for potassium and phosphorus. For maximum nutrient synchrony between nutrient release and nutrient uptake, chickpea and white lupin residues should be applied when planting kales.

Key words: chickpea residues; decomposition rates; nutrient release rates; kales, white lupin residues, synchrony.

6.1 INTRODUCTION

Few African farmers use adequate inorganic fertilizers because of their limited availability and high cost and it is the same case in Kenya (Kelly, 2006). One of the factors limiting kale production in Kenya is low soil fertility. Nitrogen and phosphorus are identified as the major limiting nutrients for many cropping systems (Kwambiah *et al.*, 2003) and their application from organic and inorganic sources is essential to maximize and sustain crop yield potentials (Hartermink *et al.,* 2000).

A synchrony between nitrogen (N) supply and crop demand is the source of many environmental hazards associated with excess N in the biosphere. An assessment of nutrient release rates of chickpea (*Cicer arietinum*) and white lupin (*Lupinus albus L*) residues with intent of synchronizing with kale (*Brassica oleracea var. acephala*) uptake was carried out.

For one to be able to develop an effective legume following techniques, it is necessary to know their residue decomposition and nutrient-release dynamics. Once this has been known, it is easy to synchronize the period of maximum supply with the period of maximum demand (Delin and Engström, 2010).

Kale takes up nutrients differently at each maturity stage, highest nutrient concentrations in kale tissues was recorded to be at day 60 of their maturity. There is need of synchronizing nutrient released by legume residues with nutrient uptake by kales to match their demand. Legume residues decay rapidly under both field (Onwonga, 1997) and laboratory (Odhiambo, 2010) conditions, which make them useful as short-term fallow cover crops in cereal rotations.

The objective of carrying out the study was to assess the decomposition and nutrient release rates of chickpea and lupin residues to match the nutrient uptake by kale.

6.2 MATERIALS AND METHODS

6.2.1 Study Site

The on-station study was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi. More details are described in chapter three section 3.1.

6.2.2 Treatments and Experimental design

The plant materials were selected from a previous crop. The residues were chickpea (*Cicer arietinum*) and lupin (*Lupinus albus L.*). The chickpea and white lupin residues were weighed and put into litter bags measuring 20cm ×20cm × 20cm (Anderson and Ingram, 1989) without chopping them, and later buried in soil to a depth of 15 cm replicated three times.

The residue retrievals were done after 0, 15, 30, 45, 60, 75, 90, 105 and 120 days after burying. After every retrieval, the residue were washed with distilled water to remove soil particles carefully removed from the litter bag and put in a khaki bag, they were oven dried, grounded to pass through a 2mm sieve and analysis were carried out for C, N, P and K content. Nitrogen content was determined by Kjeldahl method as described by Nelson and Sommers, (2010). The Walkley- black was adapted for carbon (Nelson and Sommers, 2010). Potassium and phosphorus was analyzed using the wet digestion method using the digestion mixture.

$Y = e^{-kt}$ **where y=percent mass remaining at a point**

t=time elapsed since the beginning of the litter decomposition

k=decomposition rate coefficient. (Wielder and Lang, 1982).

The half lives were calculated using;

$T_{1/2} = \ln(2)/k$.

Where $t_{1/2}$ **= time when half of the nutrients or weight is lost**

In(2) = natural logarithm

K=decomposition rate

6.2.3 Plant analysis

Analysis was done for N, P, K and Carbon. Detailed methods are further described in chapter 3, section 3.3.3.

6.3 RESULTS AND DISCUSSION

6.3.1 Effects of incubation days on residue weight loss

The weights of both chickpea and white lupin residues kept declining (Fig 6.1). During the first 30 days of incubation weight decreased with increase in incubation days. The weight loss of the legumes can best be described in four ways, the rapid stage, the moderately rapid stage, the moderate stage and the leveling off. There was a rapid loss in weight within the first 30 days. Between day 30 and 60 the weight loss was moderately rapid, while at 60 to 90 the weight loss was moderate but gradually declined towards the end of the incubation period.

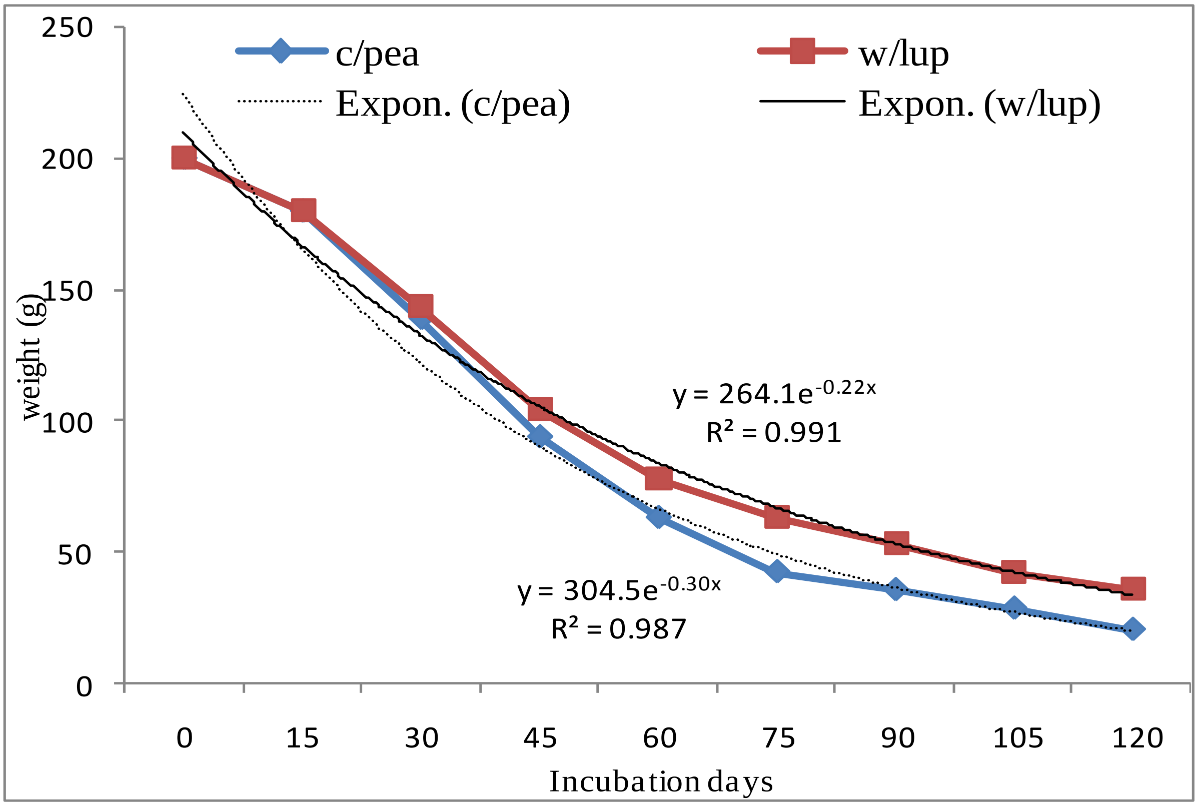

Figure 6.1: Weight losses of chickpea and white lupin within the 120 days study period

There was a 30% loss in weight of both residues after the first 15 days where a further 50 % loss was recorded after 45 days whereas after 120 days of residue incubation, 90 % of weight had been lost for chickpea while while lupin had 83% of weight that had been lost. The drastics weight loss in the first few days could be atrributed to the high content of fast decomposable components such as sugars, amino acids and proteins while as the days of incubation progressed the remnants comprised of the stem and the roots. Similarly, in the later stages, decomposition rates tend to decrease and this have been attributed to due to the accumulation of recalcitrant components such as lignin, tannins and cellulose (Hadas *et al*., 2004; Lupwayi *et al*., 2004). The calculated weight half lifes ($t_{1/2}$) for both legumes was found to be at day 52, this is the day when half of the weight had been lost.

There was a strong correlation between the days of incubations and weight loss of both legumes, as days progressed weight was lost. Chickpea (R^2=0.991) was positively and significantly correlated to whitelupin (R^2=0.987) as shown by the coefficient of correlations in losssing weight , chickpea lost its weight more rapidly during than whitelupin but both followed a similar trend. Decomposition of residues is highly dependent on soil moisture content and soil temperatures, this factors influnences the microbial activity which aids in the decomposition process.

The two legumes had a similar trend in decomposition albeit the different rates. The two residues had a higher decomposition rate within the first few days of decomposition. Differences in decomposition rates among the residues could be attributed to differences in susceptibility to microbial degradation. A rapid decomposition rate of legumes can also be attributed to lower C:N ratio.

Previous studies have shown that, plant materials with low C: N (carbon to nitrogen) ratios decompose faster than those with high C: N ratio (Danga *et al*., 2009, 2010). For example, Onwonga ,(1997) observed rapid secomposition in the fiest ten days of incorporating chickpea green maure with low C:N ratio. Berg and co-workers, (2007) have shown that in the initial stages of leaf breakdown, small soluble carbon molecules, like starches and amino acids, are lost first leaving behind the more recalcitrant molecules like lignin. Decomposition during this first phase is rapid because these molecules are easy to break down and energy rich. The second stage of decomposition (the breakdown of lignin) is much slower because lignin consists of very large and complex molecules.

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6.3.2 Effects of incubation days on nutrient release

6.3.2.1 Nitrogen

There was a rapid release in nitrogen during the fisrt 30 days, between days 30 and 75, the release rate of nitrogen was moderately rapid later levelled off between days 75 to 120 day (Fig 6.2). There was a 33% loss of nitrogen by chickpea within the first 15 days,50% loss after 30 days , after 120 days, 86.7% of nitrogen had been lost. On the other hand , lupin lost 10% of Nwithin the first 15 days of decomposition, a 50% of was lost within the 60 days, while after 120 days, there was a 80% nitrogen losts. The calculated half lifes ($t_{1/2}$=In(2)/k) for both legumes was at day 20.

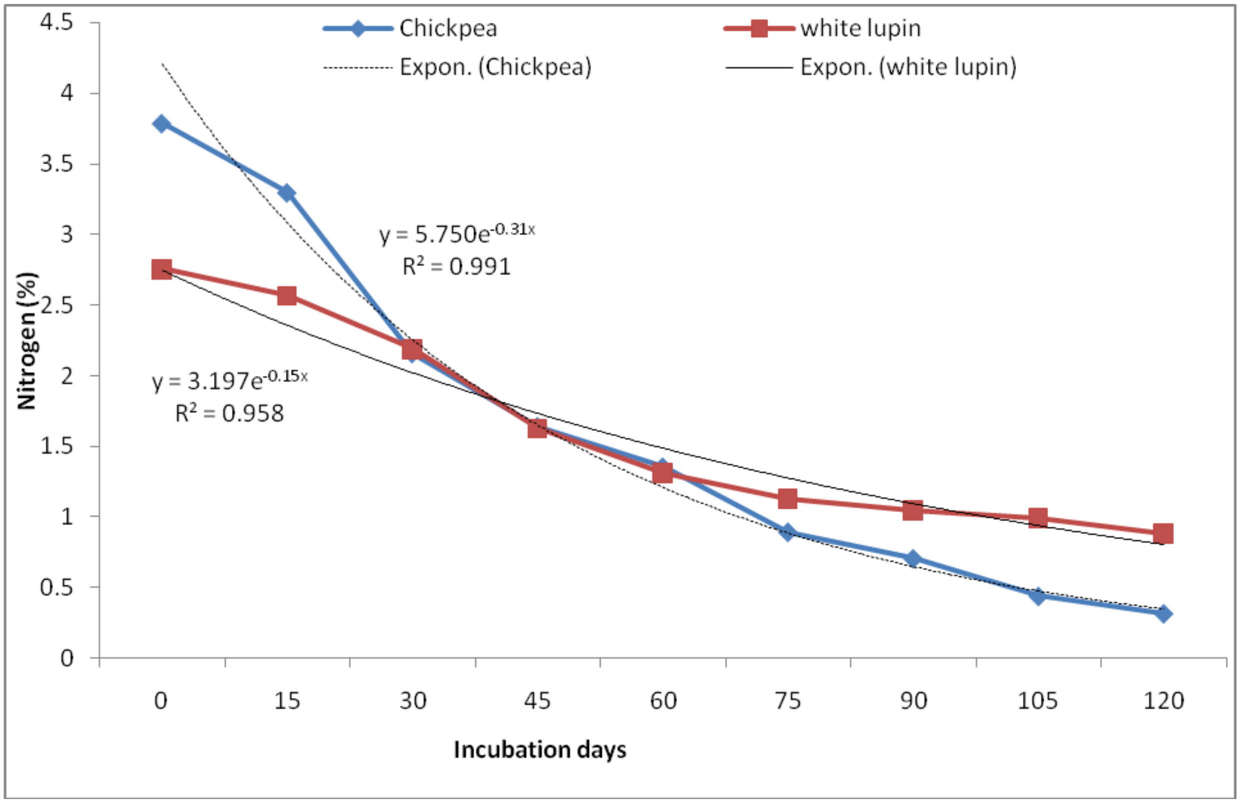

Figure 6.2: Nitrogen release of chickpea and lupin residues in 120 days of incubation.

There was a drastic loss of nitrogen in the first 15 days of decomposition this mainly can be explained by the dissapearance of leaves in the residues as they are attributed to have much nitrogen pools in their tissues. The rates of N release followed the same trend as weight loss. There was a strong and positive coefficient of correlation between days of incubation and nutrient release for both legumes both legumes (Fig. 6.2). This means that as the days of incubation progrssed more nitrogen was lost. Chickpea (r=0.995) was positively and significantly more strongly correlated to whitelupin (r =0.979), this shows that chickpea released nitrogen more rapidly than lupin residues. The rapid release of nitrogen by chickpea residues can be attributed to high initial nitrogen contents amd lower C:N ratio, where chickpea(C/N=24) and whitelupin (C/N=26).

Nitrogen release by legumes is a dependent on the lignin comtent of the residue, high leaf contents leads to high nitrogen release and it declines as the decomposition of the residues advances in the days of incubation. The average percentage of remaining N at day 120, was 16% of total N by chickpea while for lupin it was 28% of the initial nitrogen, which is within the range of 3.84–55.57% of total N as reported by Charoulis *et al,*. (2005).The two legume residues slightly differed in their N release rates due to their different N contents or C: N ratios. These results concur with earlier findings reported by (Trinsoutrot *et al*., 2000) and (Hadas *et al.*, 2004).

6.3.2.2 .Changes in C: N ratio of the legume residues

The Carbon: Nitrogen ratio of the chickpea and lupin reisdues kept decreasing as the days progressed (Fig.6.3). The lower C:N ratio at the start of the study is the main factor in determining the litter quality and the rapid decomposition of the legumes There was a fast decrease within the first 45 days of decompostion of the residues. Between days 45 and 90 the C:N ratio rapidlly decreased whereas between and it leveled off down towards day 120. The was a strong coefficient correlation (R^2 values) between the residues and days of incubation. Chickpea was more positively correlated (R^2 =0.988) to white lupine (R^2 =0.983), chickpea released its nutrients more rapidly than white lupine and it initially had a lower C: N ratio before incubation.

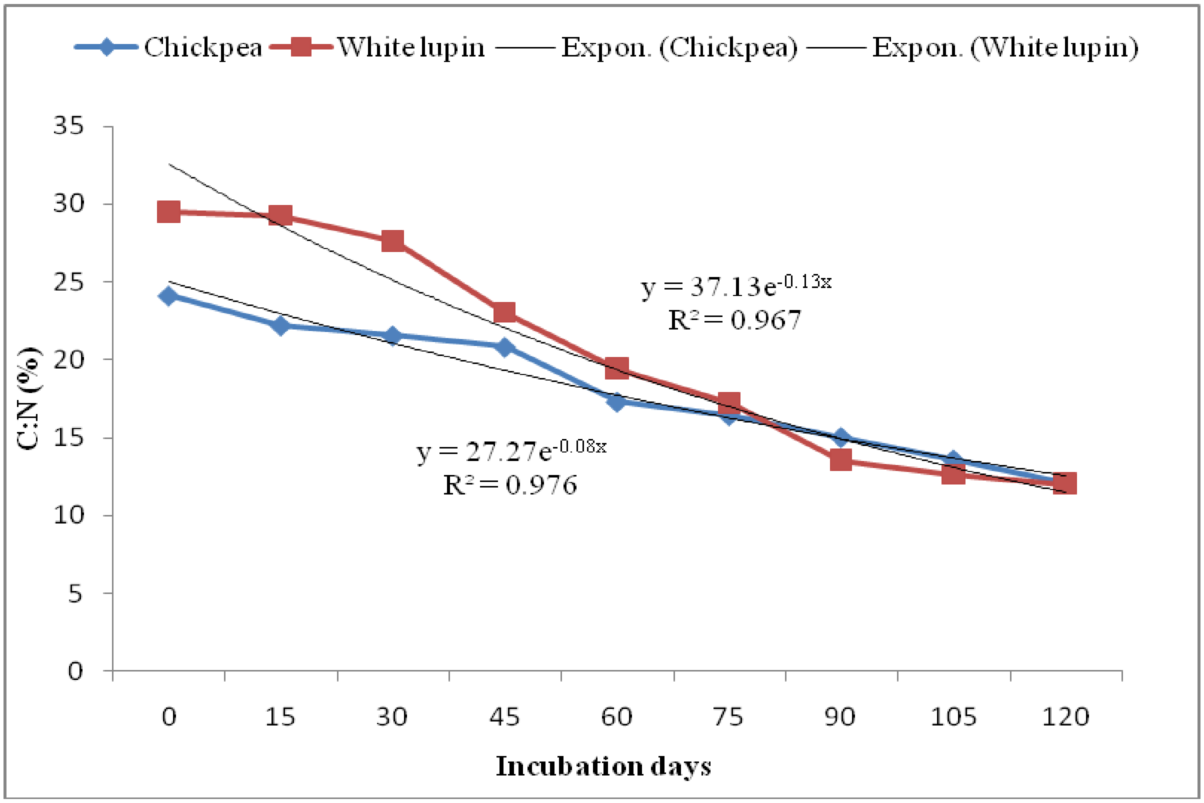

Figure 6.3: Changes in C: N ration of the legume residue in 120 days of incubation

The R^2 value shows that chickpea residues C:N ratio, decreased raidly throughout the decomposition period as compared to white lupine residues which was slow. It futher explains why chickpea decopmosed rapidly as compared to lupin. After 120 days, both legumes had a similar percentage of C:N (12%). This is in agreement with Mubarak *et al.*, (2002), who did a study on decomposition and nutrient releaese of groundnuts and maize stovers and found out that carbon decresaed as the haulms decomposed.

These results are in agreement to those described by (Shi, 2013) who found out that the % Carbon of decomposing residues kept decreasing as the days of incubation increased or advanced. The trend of C:N ratio decreasing with the decomposition period which was 120 days has also been reported by Chemining' wa *et al.*, (2013) who was working on decompostion and nutrient relesease of selecyed legumes in cold semiarid areas of Kenya. Moreover previous studies have shown that plant materials with low C: N ratio decomposes fast (Danga *et al.*, 2010).

6.3.2.3 Phosphorus release

There was a rapid release of phosphorus in the first 15 days, between 15 and 45 days there was moderately rapid release rate whereas between day 45 and 75 the release rate was slow and it later levelled off between days 75 and 120 (Fig. 6.4). The phosporus levels of the legume residues declined in a manner similar to the weight loss. A 50 % loss of the phosphorus was found between day 15 and 30 for both legumes. After 30 days of incubation, there was a 33.3% and 38.8% amount of phosphorus remaining of the initial amounts for lupin and chickpea residues respectively. After 120 days of incubation, the amount of phoshorus remaing was 3.5 % and 1.7% of the initial content. The half lifes ($t_{1/2}$=In(2)/k) for both legumes was found to be at 30 days of incubation.

During the study, phosphorus release rate of chickpea residues was significantly higher as compared to the lupin residues especially towards the 120 day. During the first 15 days the phosphorus release rates of chickpea and white lupin residues was almost similar. There was a strong coefficient of correlation between days of incubation and phosphorus release rates (r=0.988) chickpea and r=0.942 white lupin) (Fig .6.4). On the other hand, chickpea was more strongly correlated to white lupin, as it released phosphorus more rapidly than white lupin and had higher levels of initial phosphorus before incubation.

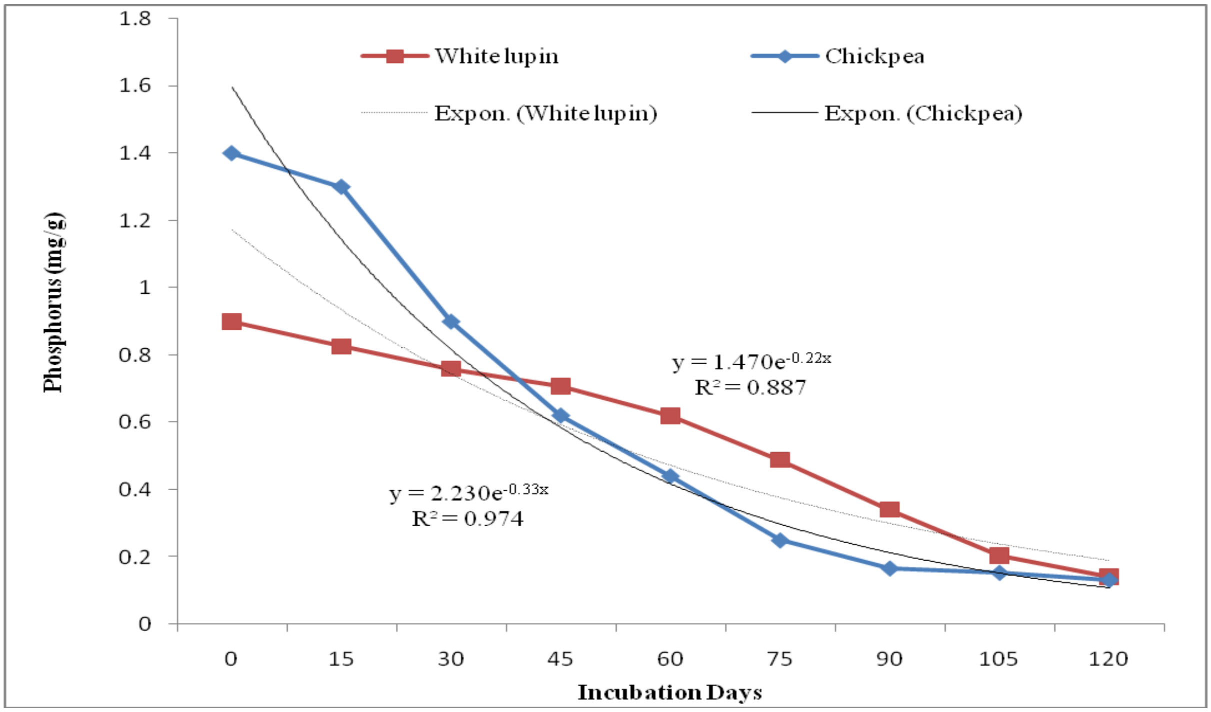

Figure 6.4: Phosphorus release rate of chickpea and white lupin residues in 120 days of incubation

The phosphorus release was similar with the trend followed by the weight loss. The trend of the phosphorus release by the legumes is the same as the trend found by Mburu *et al.*, (2013) on the nutrient disappearance of legumes in Laikipia County. There was a 60 % release of P at day 45 of incubation, phosphorus is known to be not dependent on the rainfall, but to the total inorganic P content and soluble P in the residues as there was limited rainfall during some time in the study period but still the release rate was rapid and this could be attributed to the effective action of microorganisms on the organic fractions. Similar observations by (Giacomini *et al.*, 2003) on the how phosphorus is not dependent on rainfall.

Under the prevailing environmental conditions of this experiment, the release of P was much higher. Climatic variables could play an important role in regulating decomposition and nutrient release from residues (Lindahl *et al*., 2007).

6.3.2.4 Potassium

There was a rapid release of potassium during the first 30 days of the legume incubation. The trend of both legume release rate was the same as that of other nutrients loss (Fig.6.5). Between day 30 and 75 there was a moderately rapid rate of potassium release whereas between days 75 to 120, the release of potassium progressively declined. There was a 5 % loss of potassium by both legumes after the first 15 days, after 45 days, 43% of potassium had been lost by chickpea while lupin had lost 35% , after 120 days of incubation both legumes had released 85% of the original potassium level. The half life's ($t_{1/2}$=In(2)/k) for both legumes was found to be at day 30.

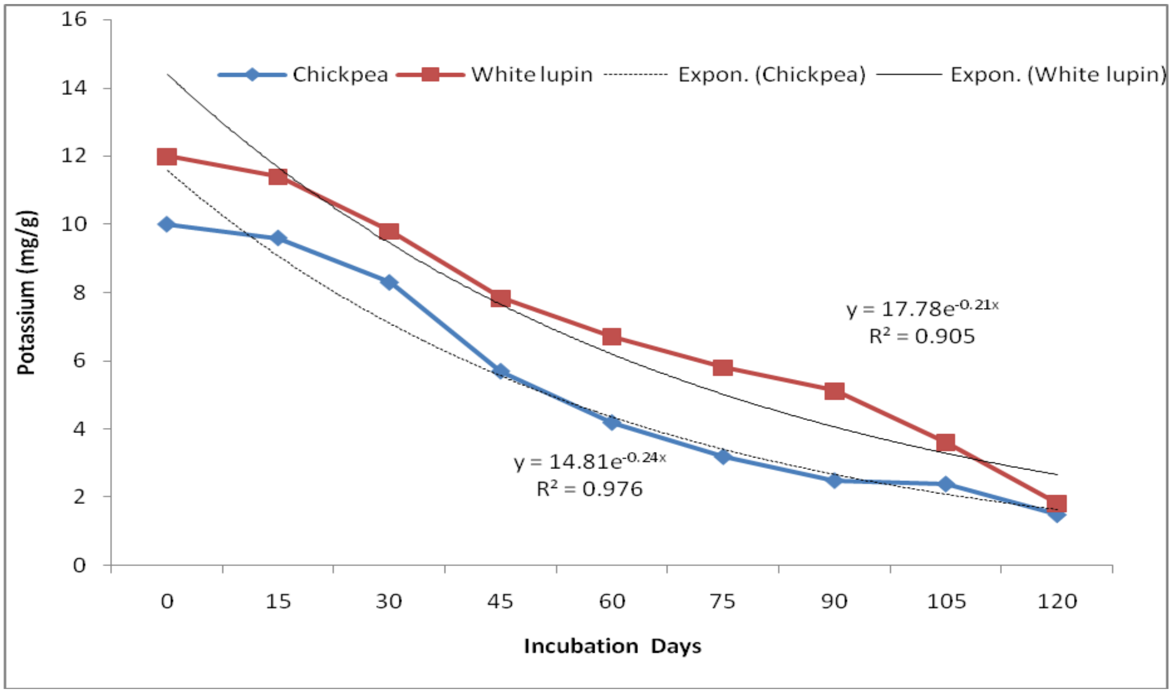

Figure 6.5: Potassium release rate in chickpea and white lupin residues in 120 days of incubation

Both legumes have a strong coefficient of correlation between days of incubation and potassium release. As days progressed more potassium was released, chickpea (r=0.988) was positively and significantly strongly correlated to white lupin (r=0.951) (Fig 6.5), it shows that chickpea released much potassium than white lupin despite having a higher initial potassium. From previous studies, chickpea decomposed faster than white lupin and hence was able to release more potassium.

Potassium release is dependent on soil moisture where, rapid release occurred when there was increased rainfall which could have increased the soil moisture. These results conform to those by Giacomini *et al*., (2003) who documented that the K rate depends on the rainfall during the decomposition process. The release rate pattern of potassium was similar to that of weight loss and the other nutrients. These release patterns indicate the high solubility of K since it is not a structural component of the cell (Mubarak *et al*., 2002). Similar results were reported elsewhere (Attiwill, 1968).

6.3.2.5. Kale nutrient uptake curves

Kales takes up different nutrients at differerent concentrations, at the fisrt 30 days of development, the nutrient uptake was rapid, it later becomes moderate upto day 60, between day 60 and 120, nutrient uptake declines progressively (Fig.6.6). All nutrients were positively and significantly strongly correlated with the days of develoment, nutrient uptake was as dependent on days of growth. Phosphorus (r=0.977) was trongly correlated to potassium (r=0.905) and Nitrogen (r=0.969), phopshorus uptake was almost constant throughout the period. Nitrogen conentration was higher at 30 days. Whereas phopsorus and potassium concentrations were highest at 60 days.

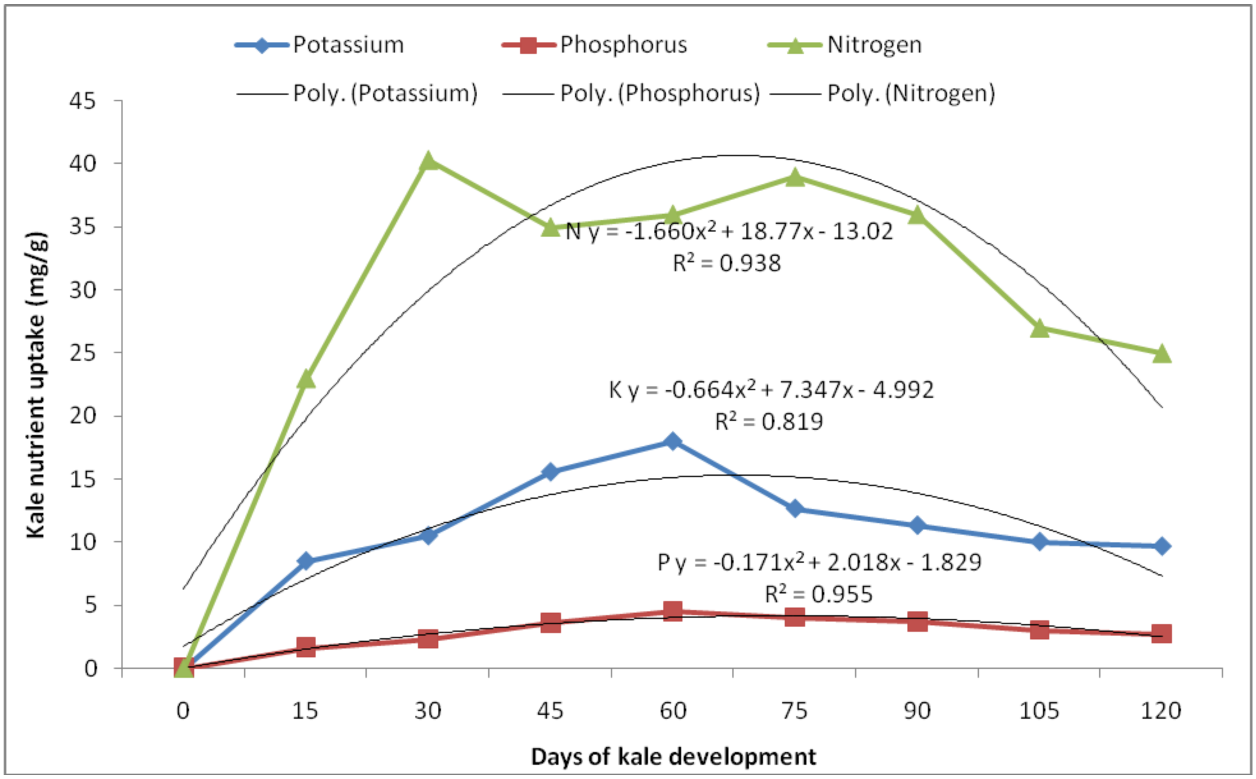

Figure 6.6: Nutrient uptake by kale in 120 days of development

Kales take up nutrients rapidly within the first 30 days of development, as this is the times kales are actively maturing and more leaves are produced, hence need for more nutrients needed. The highest concentration of nutrients was recorded between day 30 and 60 of sampling. As kale became mature, its nutreint contents kept increasing. Salisbury and Ross, (1992) stated that N accumulation exists in young tissue which also receives soluble forms of nitrogen transported from older leaves. In this study, N was found to have the highest concentration in day 30 where the leaves were still younger.

The phosphorus and potassium concentrations in kale leaves were found to be highest at day 60. After day 60, the concentration progressively declined at the third sampling (Fig 6.6). These results conform to those by Miller-Cebert *et al*., (2009) who found highest P at the budding stage as 0.42 g 100 g. K was determined as 18 mg/g for the 60 day of development. Miller-Cebert *et al*., (2009) also stated that the levels of K in canola increased with growth.

6.3.2.6 Legume nutrient loss compared with the kale nutrient uptake.

Both legumes released nutrients at same rates, the kale nutrient uptake also varied with the development stage. In a study carried out, it was found that kale leaves had varying nutrient concentrations at different times, where nitrogen was more concentrated at day 30, while phosphorus and potassium was at day 60 (Fig. 6.6). The nutrient uptake by kale and release by lupine curves intersected at specific days (Fig, 6.7 & 6.8).

6.3.2.6.1 Phosphorus

Phosphorus release by chickpea in relation to kale phosphorus uptake showed that the curves met at day 30. Phosphorus release and uptake was strongly correlated with days of development and incubation (Fig 6.7a). The release rate was more correlated to uptake; much phosphorus was released as compared to the rate by which kales took up the nutrient. Phosphorus release and uptake intersected at day 30. Nutrient uptake and release strongly correlated to days, whereas white lupin phosphorus release (R^2=0.970) was more correlated to phosphorus uptake kales (R^2=0.955), white lupin released its phosphorus more rapidly as compared to the phosphorus uptake rate by kale (Fig 6.8a).

6.3.2.6.2 Potassium

Potassium release and uptake by chickpea was strongly correlated with days. Chickpea potassium release was more strongly correlated to kale potassium uptake; chickpea release rate was more rapid as compared to uptake by kale (Fig 6.7b). The potassium uptake and release curves intersected at day 30, potassium uptake (R^2 =0.819) and release rates (R^2 =0.969) strongly correlated to days, lupin release rate was more correlated to kale uptake, shows that there was a rapid potassium release as compared to the uptake rate(Fig 6.8b).

6.3.2.6.3 Nitrogen

In the case of nitrogen, the release and uptake curves intersected at day 25 and there was a strong correlation between nitrogen uptake/ nitrogen release with days. Kale nitrogen uptake was strongly correlated to chickpea nitrogen release; kale nitrogen uptake was more rapid at the initial development stages as compared to chickpea nitrogen release rates (Fig 6.8c). Timing of residue application to match the kale nutrient uptake is important so as to avoid nutrient loss.

The nutrient release by white lupin in relation to kale nutrient uptake curves intersected at specific times. Nitrogen release and uptake curves were intercepted at day 30, there was a strong correlation between nitrogen release/uptake and days, as days progressed nitrogen was released and kale took up nitrogen. Nitrogen release by white lupin was strongly correlated to kale nitrogen uptake, lupin released nitrogen more rapidly than the rate at which kales would take up (Fig 6.8c).

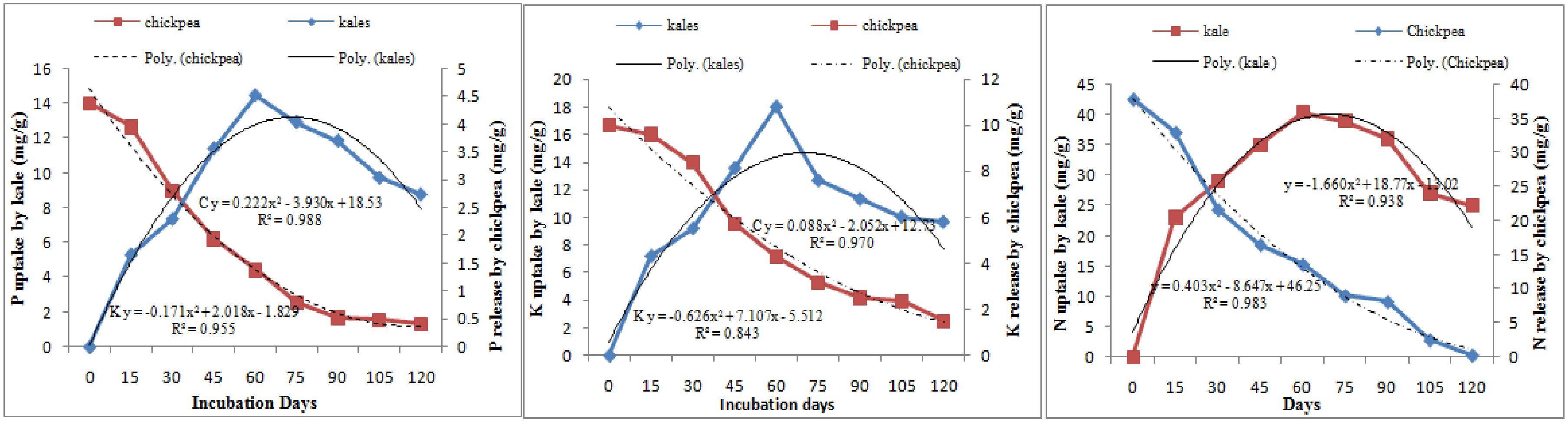

Fig 6.7a Fig.6.7b Fig 6.7c

Figure 6.7 a, b and c: Kale nutrient uptake in relation with nutrients release by white lupin.

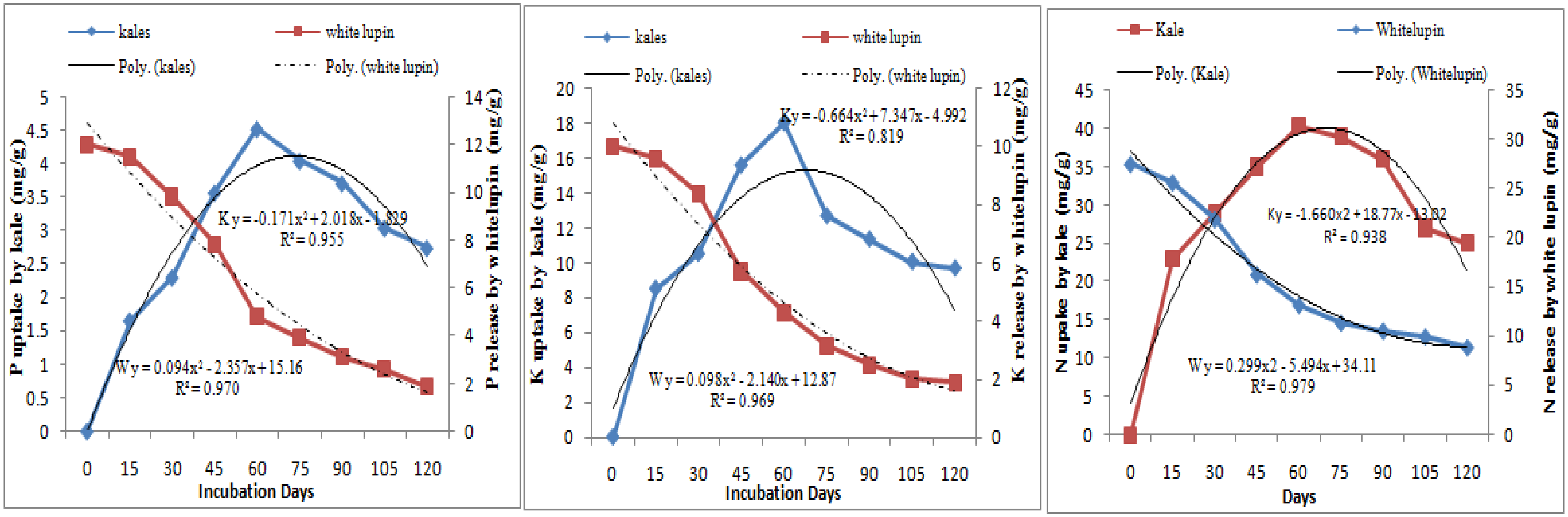

Fig 6.8a

Fig 6.8b

Fig 6.8c

Figure 6.8 a, b and c: Kale nutrient uptake in relation with nutrient release by chickpea.

The time when the two curves intersect shows the point of maximum synchrony between nutrient release and uptake. Most of the curves intersected before or at day 30 of kale growth, the day of maximum synchrony are important as it helps in knowing the exact timing of application to match nutrient uptake and avoid loss of nutrients.

From the calculated half life's by all the nutrients where nitrogen was at day 20, potassium at day 30 and phosphorus was day 30 for all the nutrients, the calculated days match with the days of intersection between nutrient release by the legumes and uptake by kale.

Form the experiments carried out, it was found that the point of the maximum nitrogen synchrony was at day 20 of kale growth, at this point, is where the kale will be able to benefit from the nitrogen released by the lupin and chickpea residues. Application of the residues should be done at day 40 to 45 to match the highest nitrogen concentrations in the kale tissues.

As described by Palm *et al.*, (2001) and Rowe *et al.*, (2004), strategies in legume-based systems to potentially reduce the rate of N supply around periods of potential asynchrony include changing the timing and placement of legume residues, manipulating residue quality through choice of legume tissue or species.

6.3.3. Legume residues weight loss and cumulative nutrient release

6.3.3.1. Phosphorus

The cumulative phosphorus release by legumes residues increased with time of incubation (Fig 6.9.1). During the first 15 days of decomposition, the cumulative nutrient release was rapid, between day 30 and 75 therefore cumulative phosphorus release became moderate, whereas between days 75 and 120 the curve leveled off as there was a slow phosphorus release. The rate of cumulative phosphorus release was polynomial.

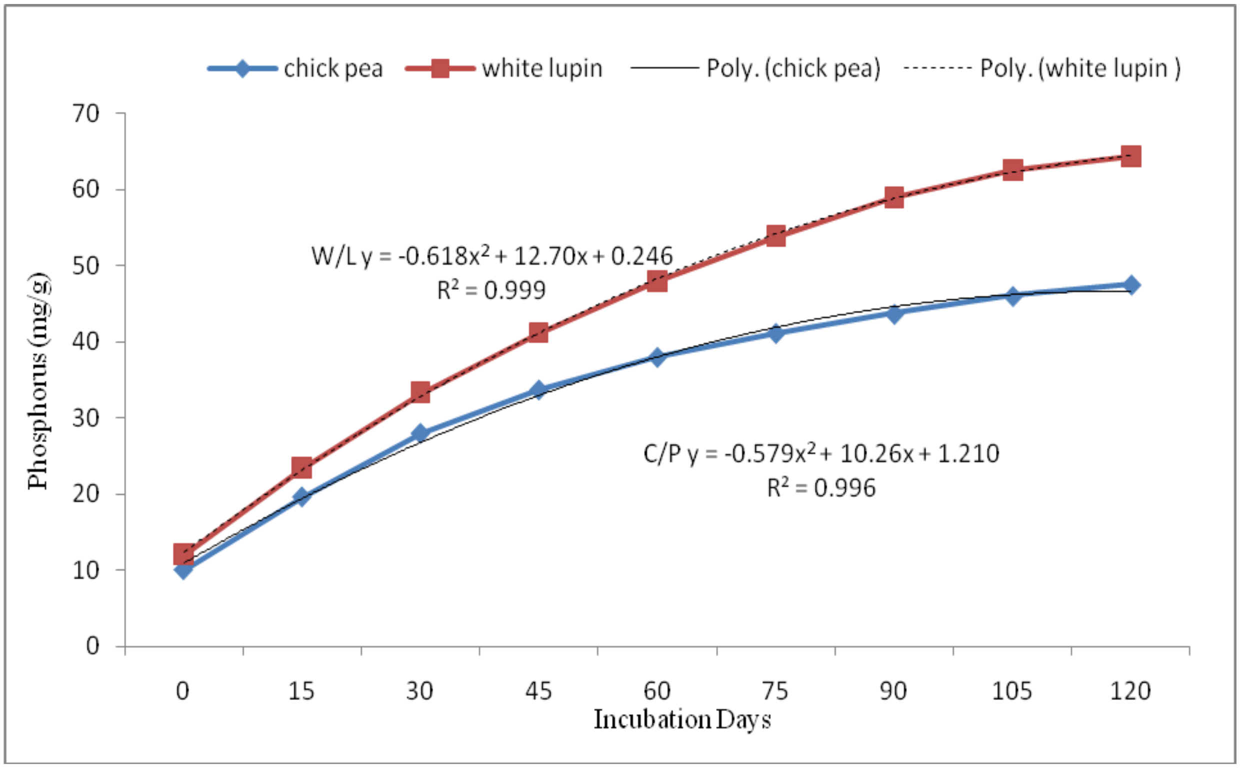

Figure 6.9: Cumulative phosphorus release by legumes in 120 days of incubation

There was a strong correlation between cumulative phosphorus release and days of incubation as shown by the (R^2 values) (Fig 6.9.1). White lupine (R^2=0.999) was strongly correlated to chickpea (R^2=0.996), it had more cumulative phosphorus release than chickpea.

6.3.3.2 Potassium

White lupine had a rapid cumulative potassium release throughout the incubation days as compared to chickpea (Fig 6.9.2). During the first 30 days of incubation both legumes had a 60% cumulative potassium release. White lupine residues showed a linear curve as it released potassium rapidly throughout the period. As for white chickpea, between day 30 and 75 there was a moderate cumulative potassium release, while between days 75 to 120 the cumulative potassium release was progressively slow (Fig 6.9.2).

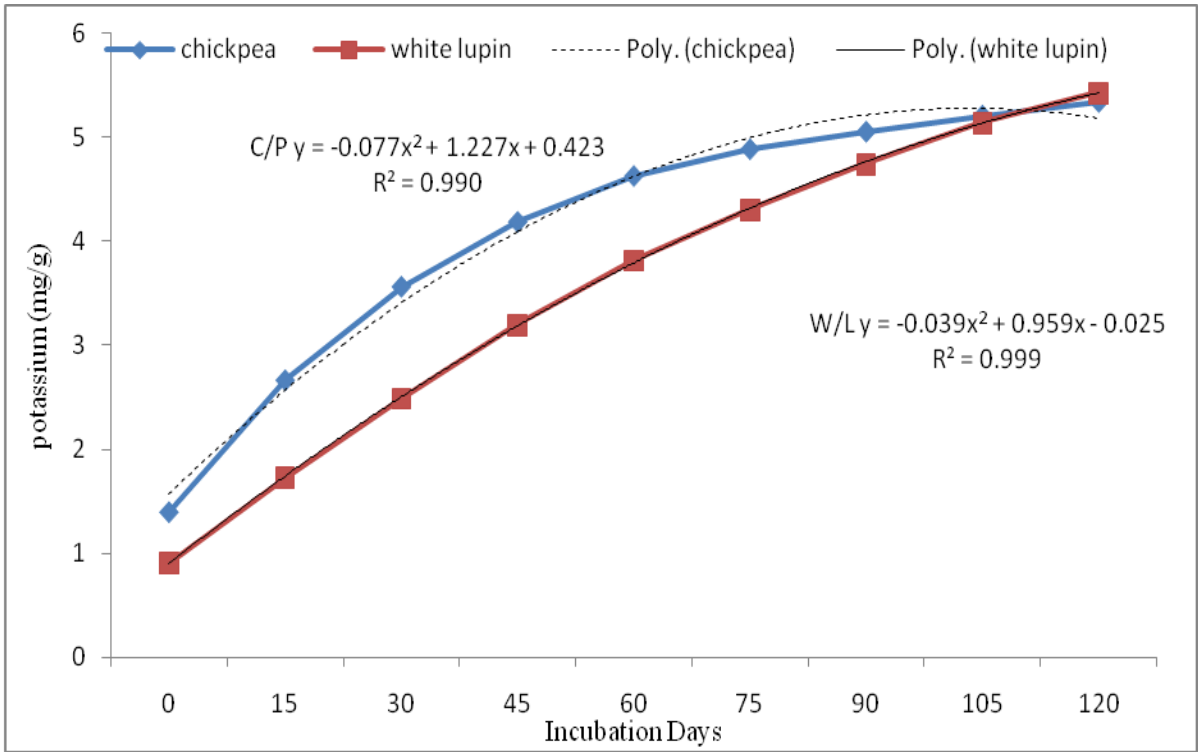

Figure 6. 9.2: Cumulative potassium release by legumes in 120 days of incubation

Both legumes were stongly correlated to the days of incubation as shown by the R^2 values. Chickpea had high initial amounts of potassium and had a slightly lower cumulative than whitelupine. White lupine was strongly correlated to chickpea, as it had a rapid rate of cumulative potassium release while chicpea was progressively fast. At the end of the incubation period, white lupin had more cumulative potssium released than chickpea.

6.3.3.3Nitrogen

Chickpea had higher initial nitrogen, as compared to white lupine residues (Fig 6.9.3). The cumulative nitrogen release by both legumes followed a trend similar that of potassium. The first 30 days of incubation showed a rapid rate, between days 30 to 60 there was a moderate rate of cumulative nitrogen release and it later became slow towards the 120 days (Fig.6.9.3). After 120 days both legumes had the same amounts of cumulative nutrient loss (145mg/g).

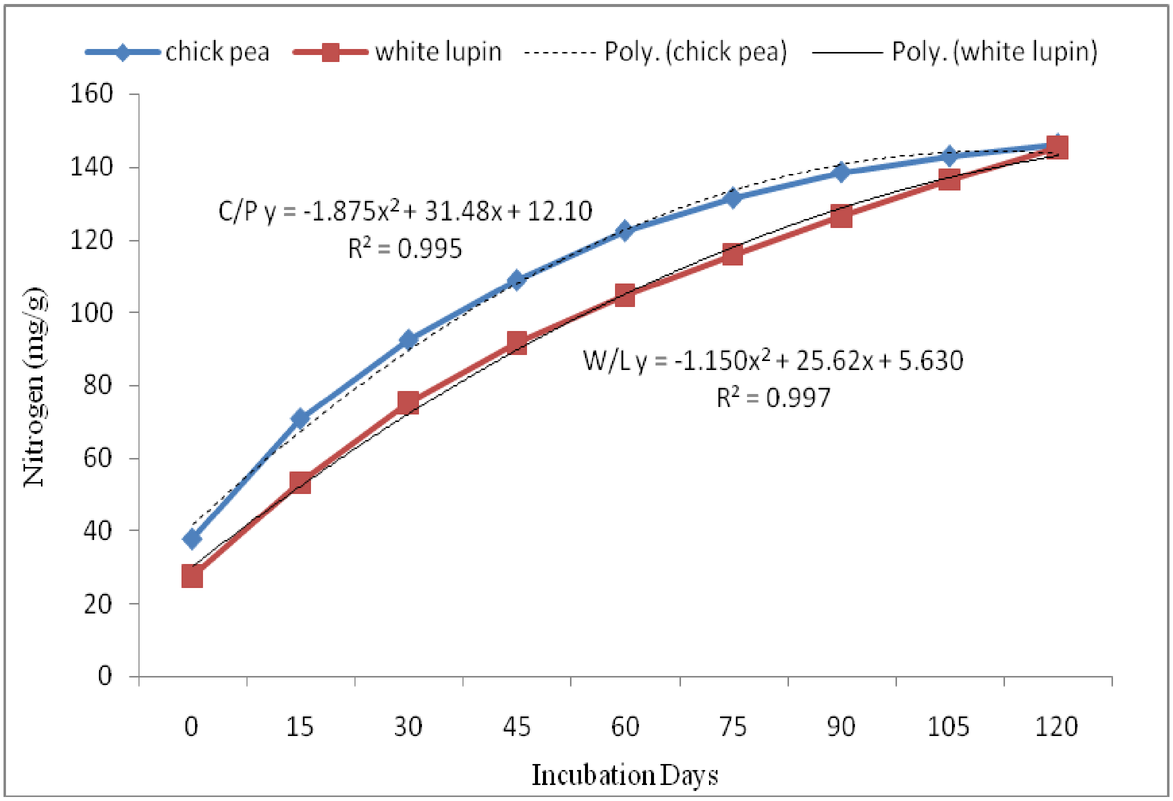

Figure 6.9.3: Cumulative nitrogen release of legumes in 120 days of incubation

Similar results of the cumulative nitrogen release was recorded by Odhiambo, (2010), who reported that N recovered as mineral N in the soil increased consistently by between 18.6 and 38.5, 15.9 and 22.1 and 17.1 and 30.3% of the initial added N contined in the sunhemp, mucuna and lalblab residues respectively across all the soils. Both legumes showed a strong correlation to incubation days, cumulative nitrogen was an effect of incubation days. white lupin was strongly correlated to chickpea. It had a higher cumulative rate than chickpea. Chickpea previously had a rapid nitrogen release than white lupine.

6. 3.3.4 Cumulative Weigh losst.

The cumulative weight loss of legumes follwed a trend similar to that of the nutrients (Fig. 6.9.4). Both chickpea and white lupine showed a similar trend in cumulative weight loss. At the first 30 days there was rapid cumulative weight loss whereby, both legumes had a cumulative of 60% weight loss **(**Fig 6.9.4). Between day 45 to 75 there was a moderate cumulative weight loss, whereas between days 75 to 120 the cumulative rate (Fig 6.9.4). The rapid cumulative weight loss in the initial stages may be attributed to presence of leaves which decomposed rapidly, while as the days progressed the remnants comprised of lignin and polyphenol materials which are not readily decomposed. Cumulative weight loss strongly correlated with days of incubation as shown by the R^2 values (Fig 6.9.4).

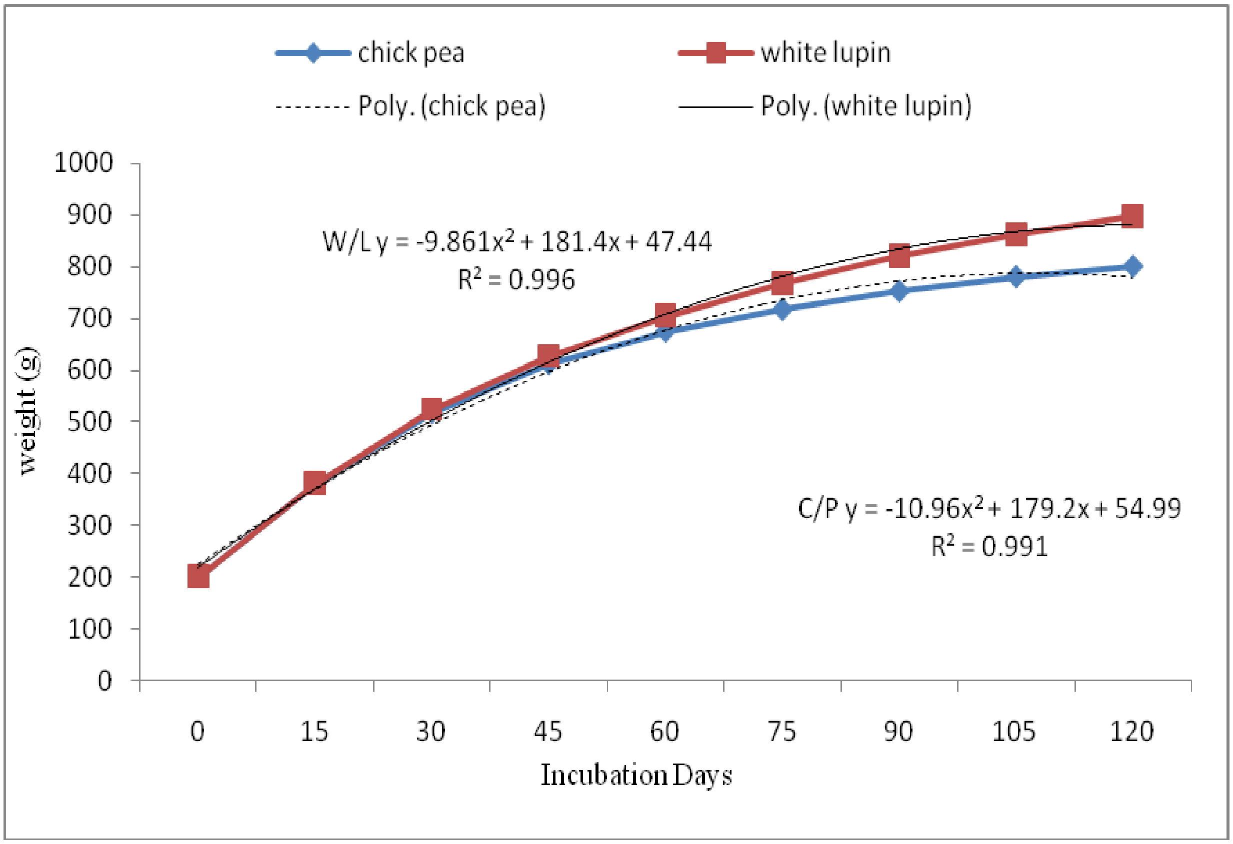

Figure6.9.4 Cumulative weight loss of legumes in 120 days of incubation

White lupine (R^2 =0.996) was strongly correlated to chickpea (R^2=0.991) in cumulative weight loss. Chickpea showed a more rapid rate in weight loss resulting to a lower cumulative weight loss,as some of its nutrients night have been lost to the soil, while lupin had a less rapid weight loss, leading to a higher cumulative weight loss.

6.3.4: Effects of weights loss and nutrient release rates of chickpea and white lupin residues

6.3.4.1 Chickpea.

Chickpea residues had a similar pattern of weight loss and nutrient release. The first 30 days of decomposition, the residues showed a rapid rate of weight loss and nutrient release (Fig. 6.10.1). Between days 30 and day 75 the release rate was moderate while towards day 120 the rate slowed down for both weight loss and nutrient release (Fig 6.10.1).

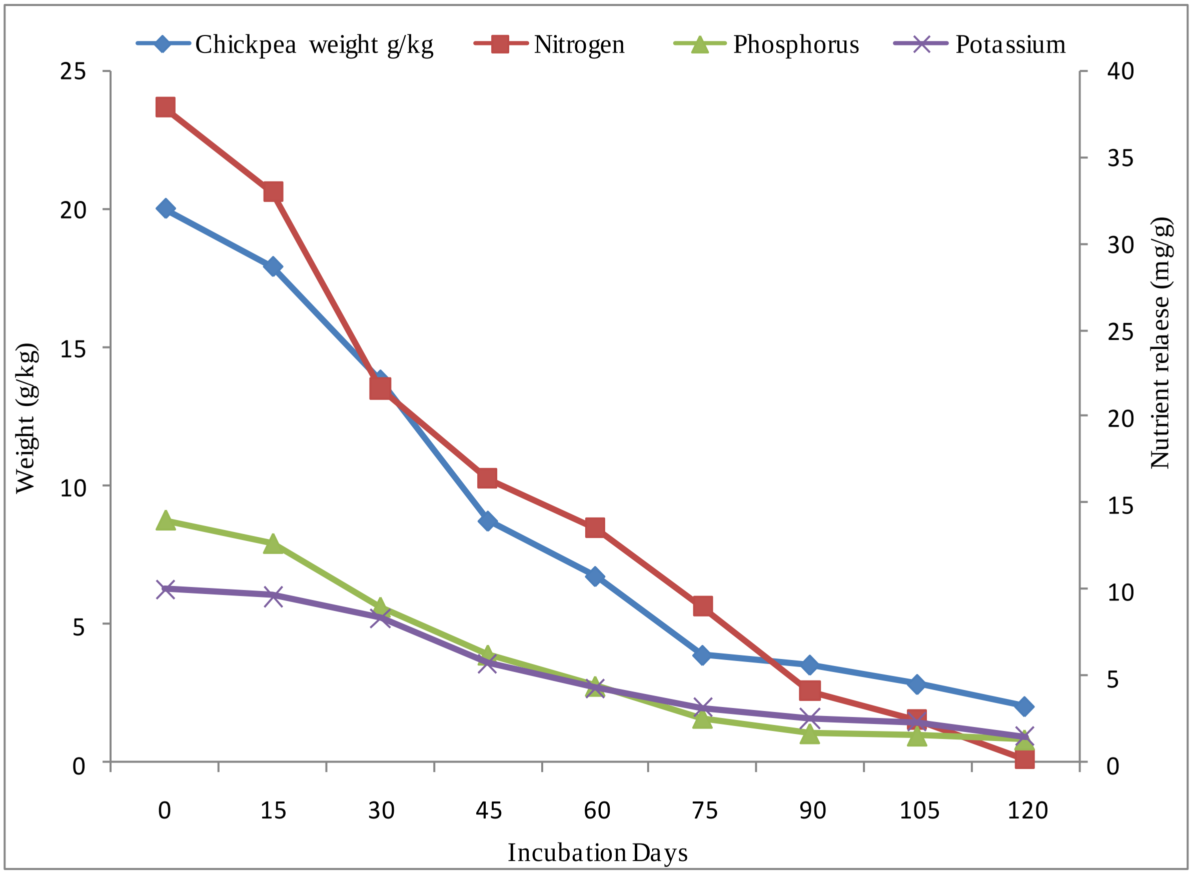

Figure 6.10: Nutrient release by chickpea residues in relation to weight loss

As weight was lost, nutrients were also released, loss of weight entails decomposition of plan parts, which releases nutrients, the rapid loss and release rates during the first 30 days could be attributed to presence of leaves which decomposes rapidly than the stems and roots. There was equilibrium between weight loss and nitrogen release at day 30. The other equilibriums between weight loss and potassium and phosphorus were attained at 105 days of decomposition. These points show where weight loss has an effect on nutrient release rate.

The coefficients of correlations were highly significant R^2=0.823 between weight loss and nutrient release, each nutrient released was strongly correlated to the rate of weight loss. As weight was lost more nutrients were released.

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The equations may be used to extrapolate days of what will happen at other times. Similar results were recorded by (Wang *et al*., 2011).

6.3.4.2 White lupine

The trend of weight loss and nutrient loss was similar to that of chickpea (Fig.6.10.1). the rate at which weight was lost was similar to that of the nutreints released. At the first 15 days of decomposition, there was a rapid rate of weight loss and nuterint release, between days 15 and 60 the reate was fast and it became moderate and progressivley slow towards 120 days (Fig 6.10.2). There was a strong correlation between days of incubation and weight loss and nutrient release. Days of incubation significantly affected the weight loss and nutrient release.

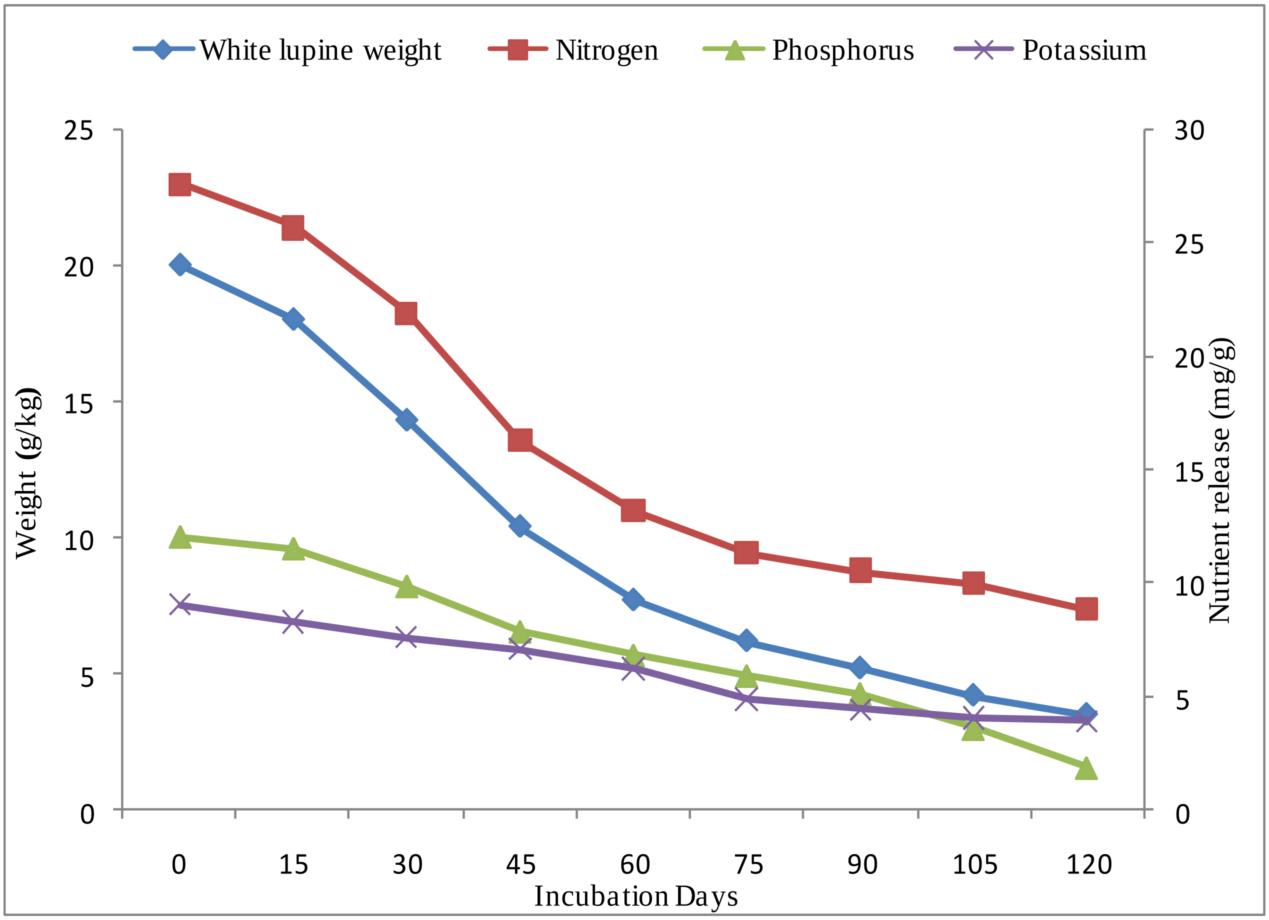

Figure 6.11: Nutrient release by white lupin residues in relation to weight loss

Nitrogen release by white lupine was independent o weight loss. There is no point of intersection. Whereas, potassium had a point of intersection with weight loss at 120 days, while phosphorus release also like nitrogen had no point of intersection.

Weight loss and nutrient release rates were strongly correlated to days of incubation as shown by the R^2 values. Potassium release was strongly correlated to the other nutrients ($R^2=0.97$). A similar example was done (Wang *et al.*, 2011) on cumulative nutrient release by polymer coated urea (PCU) and polyner coated in water at 25 ^{0}C and 100 ^{0}C.

6.4 CONCLUSION

Chickpea and white lupin residues have the potential to provide nutrients to smallholder farmers in Kabete Kenya through decomposition. Decomposition and mineralization indicated that both legumes had lost half of the weights after 52 days and half of the nutrients after 30days. Kale on the other hand had higher nutrient concentrations from day 3o to 60 as it varied with the nutrients. For higher opportunities of matching nutrient release by legumes and nutrient uptake by kale, the exact days of residues application needed to be known.

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CHAPTER SEVEN

7.0 BIOLOGICAL NITROGEN FIXATION OF CHICKPEA AND WHITELUPIN INTEGRATED IN A KALE CROPPPING SYSTEM WITH APPLICATION OF ORGANIC FERTILIZERS

Abstract

Information on BNF of chickpea and White lupine integrated into kale cropping systems with application of organic fertilizers is not well documented. A study to determine the amounts of nitrogen fixed by chickpea and lupine cultivated on the nitisol of Kabete, Kenya was carried out. The experimental design was a Randomized Complete Block Design with a split plot arrangement. The main plots were the different cropping systems (monocrop (kale), intercrop-chickpea/kale; lupine/kale and rotation- chickpea-kale; lupine-kale) the sub plots were the organic fertilizers (Minjingu Rock Phosphate and Farmyard Manure). Soil and plant samples were collected at the maturity stage of the legumes, and analysis was done for soil and plant available N. BNF was determined using the extended difference method. The biomass, yields and number of nodules were determined. Lupin significantly ($P \leq 0.05$) fixed higher amounts of N_2 (58-86 kgha^{-1}) as compared to chickpea (55.1 - 82.76 kgha $^{-1}$) in both seasons with significantly higher amounts fixed in white lupine/kale intercrop (FYM and MRP), chickpea/kale intercrop (FYM and MRP). White lupin-kale rotation (FYM, CNTRL) (3076.8kgha^{-1}, 2348.9kgha^{-1}) yield was higher as compared to white lupine/kale intercrop (MRP) (1798.44kgha^{-1}), chickpea had significant high yields chickpea-kale rotation (MRP, FYM) (1024kgha^{-1}, 845 kgha^{-1}) in season one and a similar trend in season two. Above ground biomass (tha^{-1}) across treatments and cropping systems increased, white lupine-kale rotation (CNTRL, FYM, MRP) (15.37 tha^{-1}, 13.53 tha^{-1} and 13.13 tha^{-1}), chickpea-kale rotation (MRP, FYM and CNTRL) (9.31tha^{-1}, 6.05 tha^{-1} and 6 tha^{-1}) while intercrops recorded lower biomass during both seasons. Number of nodules was significantly affected by application of organic fertilizers in the different cropping systems, white lupine-kale rotation (Control (32); white lupine/kale intercrop (Control) (31) and the chickpea/kale intercrop (MRP) (27). Intercropping white lupin with kale with application of MRP is a cheaper alternative of enhancing soil N through BNF.

Key words: Biological nitrogen fixation, chickpea, farm yard manure, Minjingu rock phosphate, wheat.

7.1 INTRODUCTION

Kale (*Brassica oleracea acephala group*) is an important vegetable in Kenya found at most households tables, consumed with maize meal (*ugali)* or as a salad. Despite its importance, production of kale is greatly hindered by several factors which include soil fertility depletion (Bationo *et al.,* (2004) and Kimani *et al*., (2004). Most small scale farmers planting kales, plant them as a monocrop, and practice continuous cropping which excludes crop rotation or intercropping that includes legumes in combination with inappropriate soil conservation practices has depleted soil fertility (Njeru *et al.*, 2015).

A study by Gachimbi, (2002) revealed that the rising cost of inputs has resulted in many smallholder farmers reducing or abandoning the use of chemical fertilizer altogether in Central Kenya. This aggravates the soil infertility situation and results in further decline in crop yields since for a majority of farms, the available manure is not enough to fertilize the whole farm in addition to the limited access to sufficient inorganic fertilizer.

Introduction of legume plants like chick pea (*Cicer arietinum L.*) and white lupine (*Lupinus albus cv Amiga*) as an intercrop or in rotation system with kale, has the ability of improving soil available Nitrogen through their ability to fix N (Tilak *et al.*, 2002). There is also need to utilize the locally available resources to improve soil fertility and supply more mineral nutrients for crop uptake include use of farm yard manure and Minjingu Rock Phosphate (Gichagi *et al.,* 2007).

The benefit of including legume crops in cropping systems is mostly associated with their ability to biologically fix atmospheric N, (Cheminig'wa *et al.,* 2006; Walley *et al.,* 2007). The use of chickpea and white lupin with application of MRP has the ability to dissolve the unreadily available from the rock. The said legumes release exudates which aids in the solubilization process. The integration of chickpea and white lupin with application of Minjingu Rock Phosphate (MRP) and farm yard manure (FYM) to address soil infertility is however not common in this region partly due to lack of awareness and empirical data to support the need for the same.

Thus current study was aimed at determining the amount of nitrogen fixed by the chickpea and white lupine under application of various supplies of organic fertilizers when intercropped or in rotation with kale.

7.2 MATERIALS AND METHODS

7.2.1 Study Site

The on-station study was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi. More details are described in chapter three section 3.1.

7.2.2 Treatments and Experimental design

For the estimation of biological nitrogen fixation, the reference method was used whereby a reference crop which was wheat was sown at the end of each block. The design was a completely randomized block design with a split plot arrangement. Wheat was sown as a monocrop under the different organic inputs.

The amounts of N_2 fixed by the legumes were determined at the late pod fill stage and at the flowering stage. The extended difference method (the fourth extension, (Bergersen *et al.*, 1985) was used. The method is assumed that the uptake of soil-derived N will be the same in the legume and the reference crop. Wheat was the chosen reference crop (Jensen, 1986; Reining, 2006). The biological nitrogen fixation (BNF) by legumes was calculated using the formula:

$$\textbf{BNF (kg ha0}^{-1}\textbf{) = (shoot N}_{leg}\textbf{+root N}_{leg}\textbf{) - (shoot N}_{ref}\textbf{+root N}_{ref}\textbf{) + (N}_{in}\textbf{ in soil }_{leg}\textbf{-N}_{in}\textbf{ in soil }_{ref}\textbf{).}$$

Where; leg=legume; ref=reference crop; in=mineral N (Hauser 1987).

7.2.3 Plant sampling and analysis

Plant sampling of the roots and shoots was done by harvesting within the middle rows and two rows left on the sides for (chickpea, white lupin and wheat). The grain yield and green matter was determined by weighing the fresh grain whereas the nodules were physically counted.

7.2.5 Statistical analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne *et al.,* 2006). Least significant difference (LSD) test was used to identify significant differences among treatment means (P≤0.05).

7.3 RESULTS AND DISCUSSION

7.3.1 Lupine and chickpea green matter

There was a significant ($P \leq 0.05$) increment in legume fresh weights with application of organic fertilizers. There was an increase in lupin fresh weights in white lupin-kale rotation across all treatments and chickpea-kale rotation upon application of organic fertilizers during the first season. The second season recorded significant increases in both legumes biomass where there was a chickpea/kale intercrop across all treatments similarly to white lupin/kale intercrop (Fig 7.1).

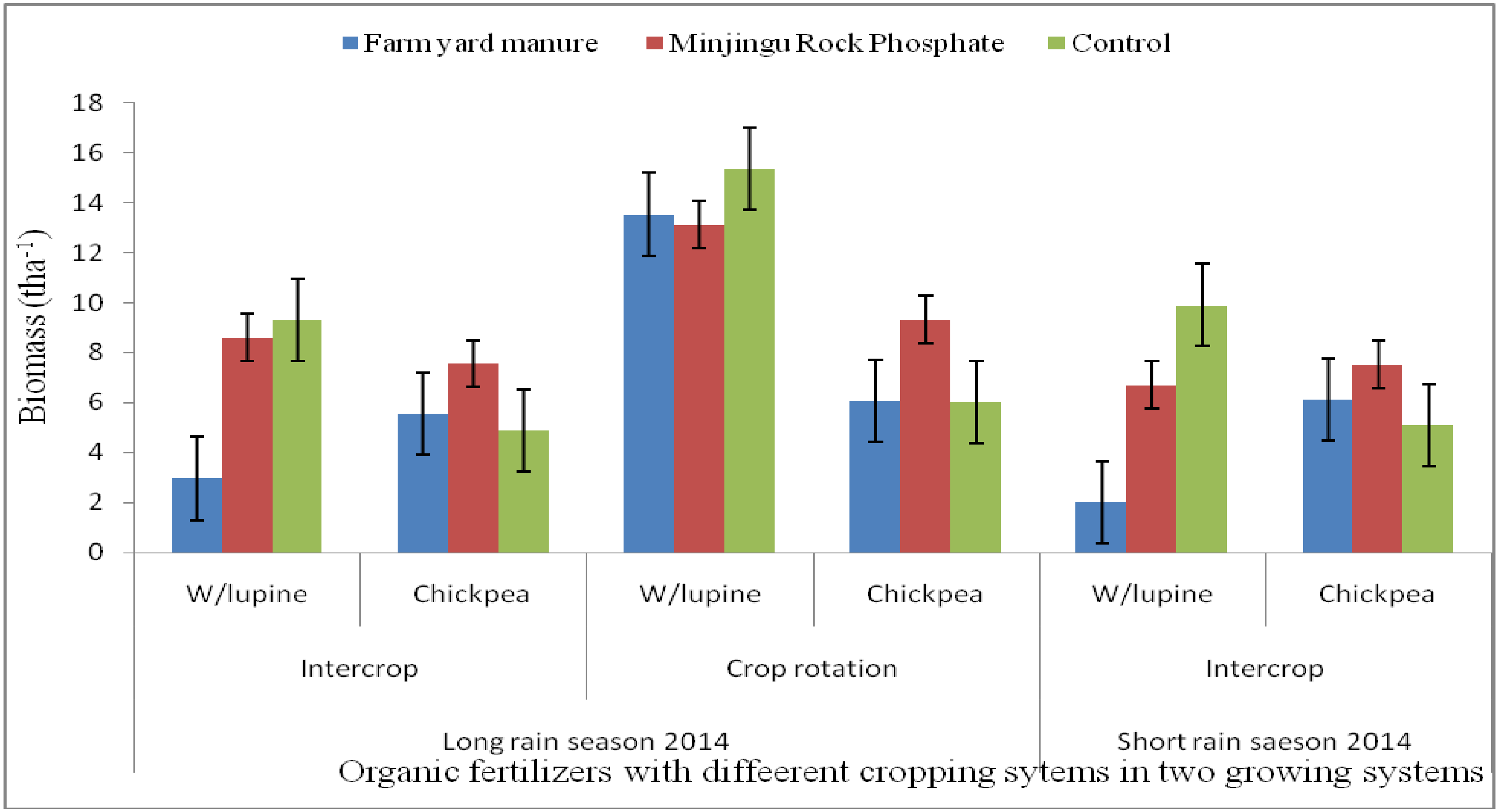

Figure 7.1: Effects of organic fertilizers application with cropping systems on legume fresh weight

The highest biomass of white lupine may be attributed to their rapid growth and more leaves as compared to chickpea. It also had the highest biomass under the control, because it performs better in P deficient soils, (Gilbert *et al.*, 1999) those under the rock phosphate had the lowest biomass 13.13 tha^{-1}. Previous studies have shown that legumes with high nitrogen fixed also had high biomass (Chemining'wa *et al.,* 2013).

7.3.2 Lupine and chickpea grain yields

There was a significant P (≤ 0.05) increase of legume yields upon application of organic fertilizers (Fig 7.2). There was a significant interaction effects between cropping systems and organic fertilizers (Fig 7.2) and hence, the chickpea-kale rotation (MRP) recorded highest yields of chickpea as compared to chickpea-kale rotation (FYM and CNTRL).White lupine/kale intercrop (CNTRTL, FYM) recorded higher yields as compared to White lupine/kale intercrop (MRP) in season one. During the second season, white lupine/kale intercrop (CNTRL, FYM) recorded a significant increase in yields as compared to those under MRP, whereas chickpea/kale intercrop (MRP) recorded a 50% increase in yields as compared chickpea/kale intercrop (CNTRL).

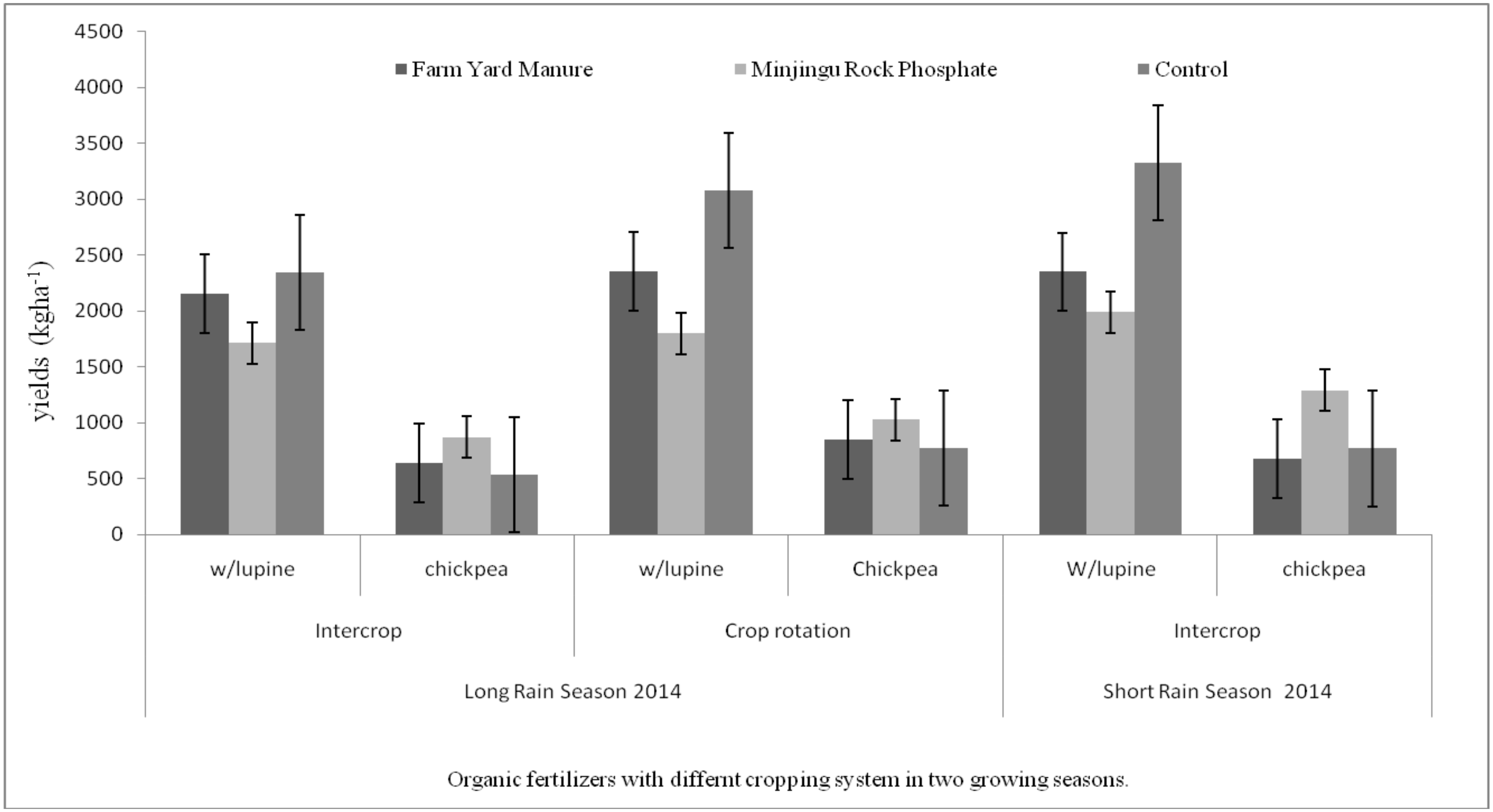

Figure 7.2: Effects of organic fertilizers application and different cropping systems on legume yield

The higher yields recorded by white lupin as compared to chickpea could be attributed to the organic fertilizers applied. All plots applied with FYM recorded higher yields of chickpea as compared to the controls could be attributed to availability of nutrients from the decomposing manure. Due to decomposition of the FYM the mineralized nutrients are then made available for crop uptake, thus contributing to yield increase. Similar arguments were documented by (Kanyanjua *et al*., 2002) on application of organic manures.

7.3.3 Biological nitrogen fixation

White lupine fixed significantly higher amounts of nitrogen than chickpea (Fig 7.3). The N fixed by white lupine and chickpea significantly increased with application of MRP. With improving P supply, through use of organic fertilizers, the N fixation by the legumes was accordingly enhanced. During the 1st season, the chickpea/lupin-kale rotation fixed more nitrogen was fixed as compared to the intercrop systems. Also noted was that white lupin out performed chickpea in the amount of nitrogen fixed (Fig 7.3). During the second season, white lupine fixed significantly higher amounts of N_2 than chickpea across all treatments (Fig 7.3).

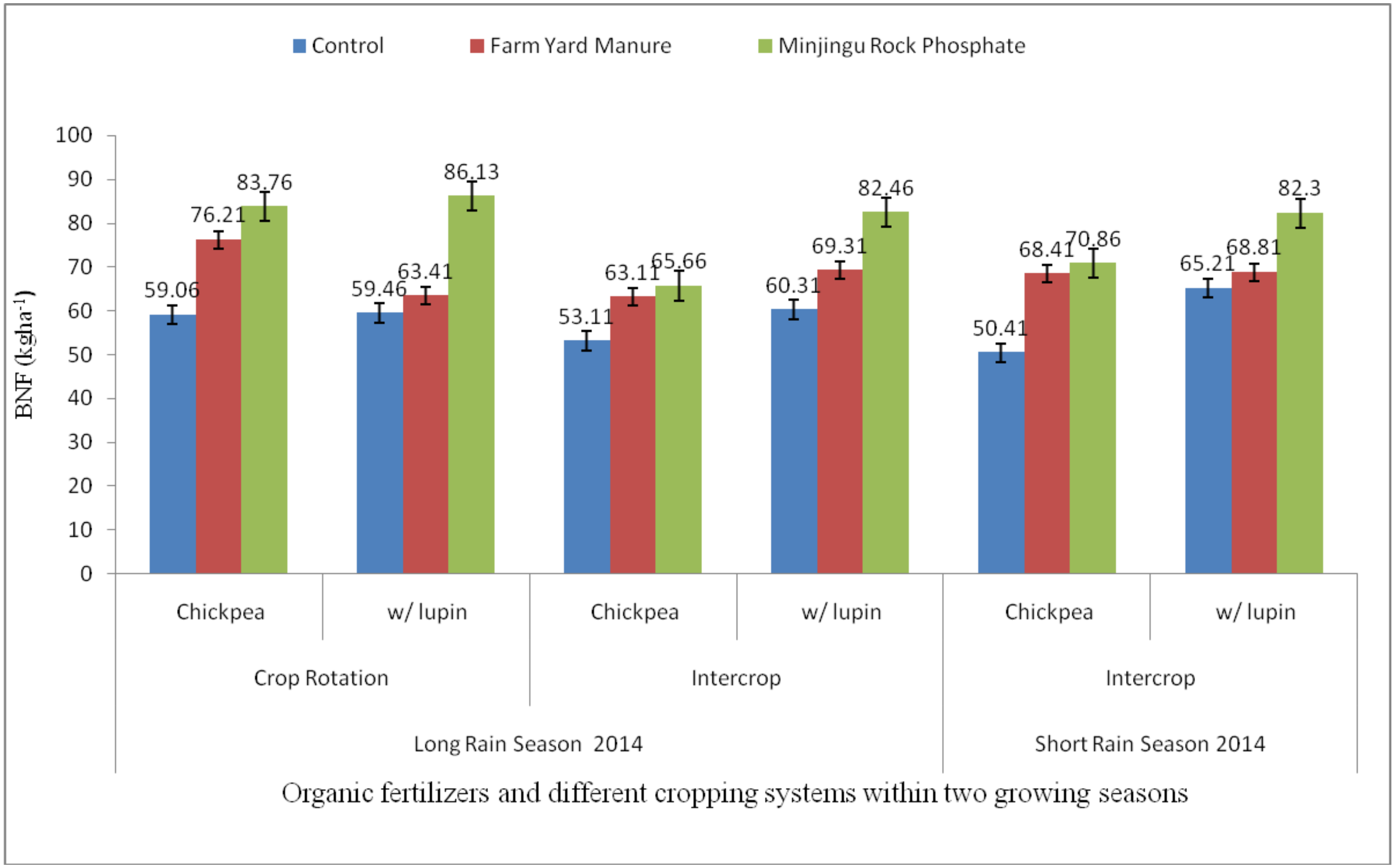

Figure7.3: Effects of organic fertilizers with different cropping systems on Biological nitrogen fixation.

The highest amount of N fixed by lupine than chickpea could be attributed to better genetics potential and adaptation to environmental conditions. The said legume also fixed significant higher amounts where no input was applied and this could be explained by the fact that lupine is tolerant to low plant available P as compared to chickpea. This is in agreement with Ramaekers *et al.,* (2010) who documented that lupine may be more tolerant low plant available P content in the soil.

The higher amounts of nitrogen fixed after application of MRP could be attributed to availability phosphorus which enhances nitrogen fixation, previous studies have shown that low P availability also has a negative effect on legume nodulation (Kidd and Proctor, 2001). Whereas, the slightly lower levels of fixed nitrogen where FYM was applied was due to the additional N supply. Studies have shown that when soil N levels are high, nodule number and activity decreases and hence roots do not attract bacteria or allow infection hence N fixation is limited (Fening *et al.,* 2002).

The amount of N fixed by the legumes is dependent on the genetic of the legume and the nutrient availability for the legume growth and development. Studies done previously (Giller, 2001; Lelei *et al*., 2009; Walley *et al.,* 2007; Yusuf *et al.,* 2008) showed that genetic variations among legumes influences the amount of nitrogen fixed. Graham *et al*., 2004) also reported that nitrogen fixation in legumes is a quantitatively inherited trait.

7.3.4 Number of Nodules per plant

The number of nodules were significantly ($P \leq 0.05$) different between legumes (chickpea and lupine with 26 and 31 nodules per plant respectively white lupine had higher number and proportion of active nodules (Fig 7.4). In the White lupine-kale rotation across all treatments significant a nodule count was recorded as compared to chickpea across all treatments. White lupine/kale intercrop under FYM and MRP recoded more nodule numbers than chickpea/kale intercrop during season one. Season two, the trend was similar to that of season one, whereby white lupine showed higher numbers than chickpea (Fig 7.3). White lupines had more nodule numbers and most were active which led to fixing significantly more atmospheric N and had higher percentage of N derived from the atmosphere (Fig 7.3).

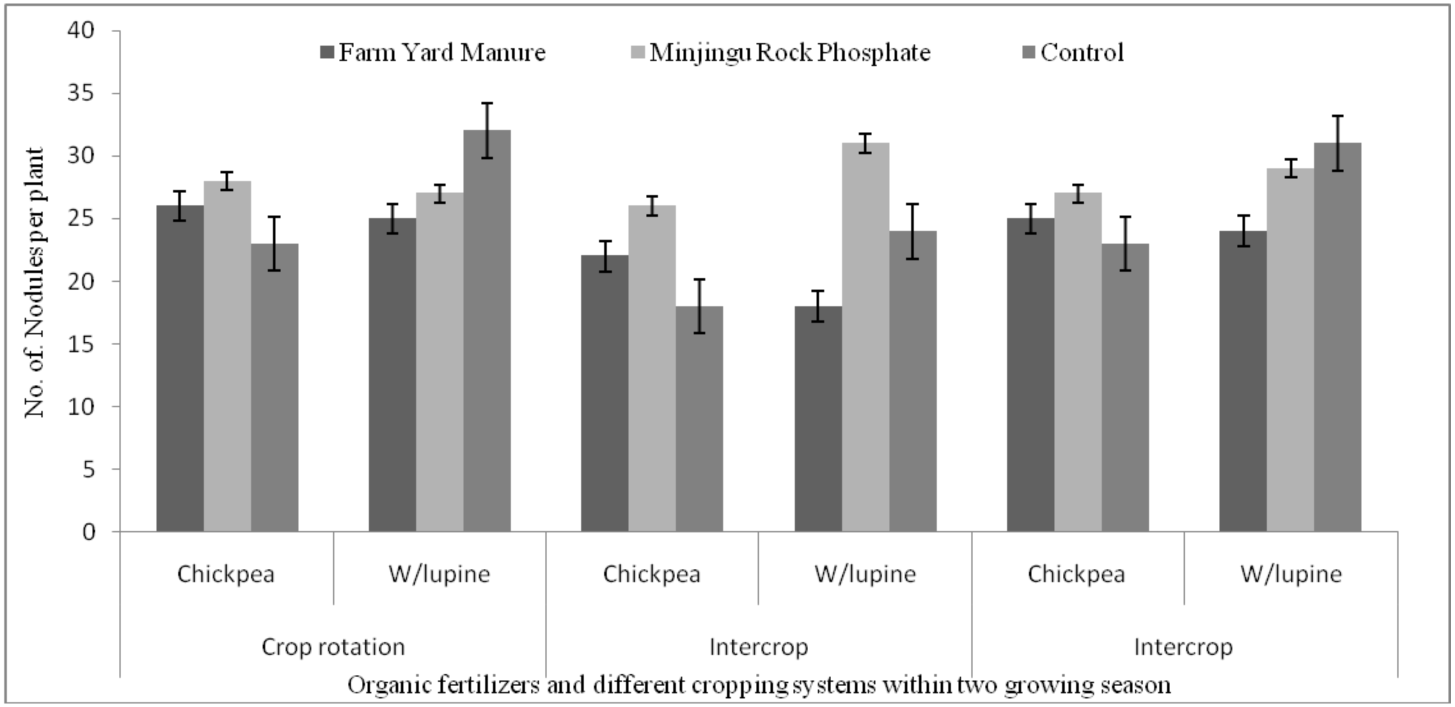

Figure 7.4: Effects of organic fertilzers application and different cropping sytems on legume number of nodules

Both legumes when under rotation systems had the highest number of nodules as compared to the intercropping systems. Application of rock phosphate led to a significant increase in the number of nodules by chickpea while white lupine recorded higher numbers of nodules under the control. The high number of nodules presented by chickpea with application of MRP could be attributed to the presence of nutrients which aided in developing of more nodules while white lupine is known to adapt well in P deficient soils and hence it forms many nodules. A study done by Neumann & Martinoia, (2002); Lamont, (2003); Shane &Lambers, (2005) supports the same findings. Previous studies have demonstrated the widespread presence in Kenyan soils or rhizobial strains that are compatible with a cross range of legume crop species (Cheminig'wa *et al.*, 2006; Mburu *et al.*, 2013; Karanja *et al.*, 2000).

7.4 CONCLUSION

Application of the MRP enhanced N2 fixation by legumes with superior fixation realized in white lupine throughout the two seasons. Similarly chickpea also fixed higher amounts of nitrogen upon application of organic fertilizers as compared to where no input was applied. Crop rotations were more superior to intercrops with application of MRP in Nitrogen fixation. Kale is able to benefit from higher nitrogen concentration after a rotation with application of MRP.

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CHAPTER EIGHT

8.0 GENERAL DISCUSSIONS, CONCLUSION AND RECCOMENDATIONS

8.1 General Discussion

Integration of white lupin with kale and application of farm yard manure lead to a significant increase in soil total N and total organic carbon. The noted increase in soil available N upon application of FYM could be attributed to the organic materials which underwent decomposition. Previous studies done have shown that continuous application FYM lead to an increase in soil available N (Kapkiyai *et al.,* 1999). The high N in the rotation was attributed to nitrogen fixed by the legume previously and any remaining residues which might have decomposed. White lupine is known to have more above ground biomass as compared to chickpea (Engedaw, 2012), which explains why after a white lupine rotation, there was an increased level of nitrogen as a result of the residues which possibly dropped.

Application of MRP with white lupin intercropped recorded a significant increase in soil available Phosphorus. Lupins are known to have exudates which dissolve the P held up by MRP making them readily available (Weisskopf *et al*., 2006. Carbon increase is a long term process but application of farm yard manure under kale-white lupin rotation led to a slight increase which is important in crop production. Legume rotation cropping system had a significant effect on both soil nitrogen and carbon. Similarly, the use of white lupin as an intercrop with application of MRP not only improved kale yield, it also fixed higher amounts of nitrogen. Whereas, the slightly lower levels of fixed nitrogen where FYM was applied was due to the additional N supply. Studies have shown that when soil N levels are high, nodule number and activity decreases and hence roots do not attract bacteria or allow infection hence N fixation is limited (Fening *et al*., 2002).

Improved soil nutrients lead to improved nutrient concentrations and increase in kale yield. For increased yield one has to supply the soil with amendments which can be achieved through decomposition of legume residues to supply nutrients for kale production. During the decomposition of legumes, White lupine and chickpea residues decomposed in a similar exponential manner which was similar to the nutrient release pattern. Both legumes had their half lives after day between days 30 to 50 days of decomposition. The timing of the maximum synchrony of nutrients by the kales is important, the legumes to match the nutrient uptake by kales.

8.2 Conclusions

The soil organic fertilizers MPR and FYM are viable alternatives to the expensive inorganic fertilizers for improving the soil nutrient status which will intern improve kale nutrient concentration and yield in Kabete sub County. Intercropping of kale with white lupin and application MRP significantly increased soil phosphorus and enhances N2 fixation whereas, rotating kale with white lupin with application of FYM lead to an increase in soil % carbon, total nitrogen , improved kale nutrient concentrations and yield. Moreover, the MRP, FYM are locally available, thus making it an ideal source of nutrients for smallholders economically and the famers get to enjoy a diversity of crops to harvest from same piece of land. Both legumes had similar decomposition and mineralization rates. For higher opportunities of matching nutrient release by legumes and nutrient uptake be kale application of the residues should be done during planting of kales.

8.3 Recommendations

Integration of white lupin with application of FYM is a viable approach towards improving soil total N and organic carbon. Similarly, applications of MRP under the same cropping system will improves soil phosphorus which at the end improves the phosphorus concentration of kales. Under the same setup, more nitrogen is fixed which leads to also improves soil nitrogen which leads to improved nitrogen concentration on kale leaves.

For maximum asynchrony of nutrient loss and uptake, application of residues should be done at planting of kale.

I would also recommend that more studies be done on decomposition and mineralization rates of other legumes and under a different soil.

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APPENDICES

Appendix 1: Analysis of variance for soil available Nitrogen

```
Variate: total_N_1_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.      m.s.     v.r.      cov.ef. F pr.

ReP stratum     2          0.00204          0.00102          1.68

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM          10        0.91182          0.09118          150.17            1.00    <.001
Residual          20        0.01214          0.00061          1.25     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          0.02162          0.01081          22.25   1.00    <.001
CROPPING_SYSTEM.treatm          20        0.14011          0.00701          14.42   1.00    <.001
Residual          44        0.02138          0.00049          0.01     1.00

ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
          9          0.29207          0.03245

Total    107       1.40116


Analysis of variance

Variate: total_N_2_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.      m.s.     v.r.      cov.ef. F pr.

ReP stratum     2          0.00824          0.00412          1.49

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM          10        1.71793          0.17179          62.21   1.00    <.001
Residual          20        0.05523          0.00276          0.89     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          0.08238          0.04119          13.28   1.00    <.001
CROPPING_SYSTEM.treatm          20        0.71984          0.03599          11.60   1.00    <.001
Residual          44        0.13650          0.00310          0.07     1.00

ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
          9          0.39785          0.04421
```

```
Total    107       3.11796


Analysis of variance

Variate: total_N_3_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.       m.s.     v.r.       cov.ef. F pr.

ReP stratum     2          0.00006          0.00003          0.20

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM          10        2.28993          0.22899          1540.17          1.00    <.001
Residual         20        0.00297          0.00015          0.41     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          0.22766          0.11383          313.95           1.00    <.001
CROPPING_SYSTEM.treatm           20        0.42863          0.02143          59.11   1.00    <.001
Residual         44        0.01595          0.00036          0.01     1.00

ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
         9          0.33381          0.03709

Total    107       3.29902
```

Appendix 2 : Analysis of variance for soil available phosphorus

```
Variate: P_ppm_1_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.       m.s.     v.r.       cov.ef. F pr.

ReP stratum     2          1.17     0.58     1.41

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM          10        876.29           87.63   211.67           1.00    <.001
Residual         20        8.28     0.41     1.20     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          13.90   6.95     20.18   1.00    <.001
CROPPING_SYSTEM.treatm           20        179.96           9.00     26.12   1.00    <.001
Residual         44        15.16   0.34     0.01     1.00
```

```
ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
          9          502.40          55.82

Total   107       1597.15


Analysis of variance

Variate: P_ppm_2_mnths
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.      m.s.     v.r.      cov.ef. F pr.

ReP stratum    2          0.29     0.15     0.33

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM         10        1762.10          176.21           399.80           1.00    <.001
Residual         20        8.81     0.44     0.64     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          191.00          95.50   139.45           1.00    <.001
CROPPING_SYSTEM.treatm          20        480.92           24.05   35.11   1.00    <.001
Residual         44        30.13   0.68     0.01     1.00

ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
          9          559.59          62.18

Total   107       3032.84


Analysis of variance
 Variate: P_ppm_3rd_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.      m.s.     v.r.      cov.ef. F pr.

ReP stratum    2          2.91     1.46     2.14

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM         10        2331.72          233.17           342.73           1.00    <.001
Residual         20        13.61   0.68     1.01     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          105.04          52.52   78.17   1.00    <.001
CROPPING_SYSTEM.treatm          20        419.81           20.99   31.24   1.00    <.001
Residual         44        29.56   0.67     0.01     1.00
```

```
ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
          9          407.12            45.24

Total   107       3309.76
```

Appendix 3: Analysis of variance for soil organic Carbon

```
Variate: organic_C_1mnth

Covariate: treatm*CROPPING_SYSTEM

Source of variation                  d.f.             s.s.            m.s.         v.r.    cov.ef.     F pr.

ReP stratum                              2          0.002          0.001        1.09

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM         10        33.075           3.308   3417.53          1.00    <.001
Residual         20        0.019   0.001   1.63     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          0.042   0.021   35.14   1.00    <.001
CROPPING_SYSTEM.treatm          20        0.338   0.017   28.53   1.00    <.001
Residual         44        0.026   0.001   0.00     1.00

ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
          9          34.314            3.813

Total   107       67.817

Analysis of variance
 Variate: organic_c_2_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation     d.f.      s.s.      m.s.     v.r.      cov.ef. F pr.

ReP stratum    2          0.064   0.032   2.33

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM         10        52.349           5.235   382.07           1.00    <.001
Residual         20        0.274   0.014   2.13     1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2          0.994   0.497   77.34   1.00    <.001
CROPPING_SYSTEM.treatm          20        6.969   0.348   54.23   1.00    <.001
Residual         44        0.283   0.006   0.00     1.00
```

```
ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
        9       34.893          3.877

Total   107     95.825



Analysis of variance

Variate: organic_c_3_mnth
Covariate: treatm*CROPPING_SYSTEM

Source of variation    d.f.    s.s.    m.s.    v.r.    cov.ef. F pr.

ReP stratum   2       0.197   0.099   1.48

ReP.CROPPING_SYSTEM stratum
CROPPING_SYSTEM       10      65.590          6.559   98.23   1.00   <.001
Residual      20      1.335   0.067   0.87    1.00

ReP.CROPPING_SYSTEM.treatm stratum
treatm  2       1.160   0.580   7.52    1.00    0.002
CROPPING_SYSTEM.treatm        20      9.016   0.451   5.84    1.00   <.001
Residual      44      3.396   0.077   0.02    1.00

ReP.CROPPING_SYSTEM.treatm.SEASON.*Units* stratum
        9       36.677          4.075

Total   107     117.372
```

ANALYSIS OF VARIANCE TABLES FOR KALE NUTRIENT CONCENTRATIONS

Appendix 4: Analysis of variance for kale nitrogen concentration

```
Variate: %_N_1_month

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum       2          0.00809          0.00404          0.16

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2          1.00827          0.50413          20.08   0.008
Residual          4          0.10044          0.02511          1.09

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          1.49642          0.74821          32.41  <.001
CROPPING_SYSTEMS.TREATMENTS
          4          0.16884          0.04221          1.83     0.188
Residual          12         0.27700          0.02308

Total    26         3.05907


Analysis of variance

Variate: %_N_2_month

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum       2          0.30907          0.15454          1.86

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2          1.28074          0.64037          7.73     0.042
Residual          4          0.33148          0.08287          3.71

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          0.57352          0.28676          12.85   0.001
CROPPING_SYSTEMS.TREATMENTS
          4          1.12037          0.28009          12.55  <.001
Residual          12         0.26778          0.02231

Total    26         3.88296

Analysis of variance
```

```
Variate: %_N_3_month

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum      2          0.00897          0.00449          0.32

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS        2          1.85868          0.92934          67.09  <.001
Residual          4          0.05541          0.01385          0.73

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          0.74041          0.37020          19.54  <.001
CROPPING_SYSTEMS.TREATMENTS
          4          0.53814          0.13453          7.10     0.004
Residual          12         0.22735          0.01895

Total    26         3.42896
```

Appendix 5: Analysis of variance for kale potassium Concentration

```
Variate: K_%_1_mnth

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum      2          0.03327          0.01663          3.56

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS        2          0.25636          0.12818          27.40   0.005
Residual          4          0.01871          0.00468          0.30

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          0.40542          0.20271          12.91   0.001
CROPPING_SYSTEMS.TREATMENTS
          4          0.11742          0.02936          1.87     0.181
Residual          12         0.18849          0.01571

Total    26         1.01967

Analysis of variance

Variate: K%_2_mnths

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum      2          0.19736          0.09868          1.24
```

```
 REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2        0.11203        0.05601        0.70    0.547
Residual        4        0.31810        0.07953        1.72

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS        2        0.36892        0.18446        3.98    0.047
CROPPING_SYSTEMS.TREATMENTS
        4        0.84761        0.21190        4.57    0.018
Residual        12        0.55627        0.04636

Total    26        2.40030


Analysis of variance

Variate: K%_3_mnths

Source of variation    d.f.    s.s.    m.s.    v.r.    F pr.

REPLICATIONS stratum    2        0.01130        0.00565        0.43

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2        0.20927        0.10464        7.96    0.040
Residual        4        0.05259        0.01315        0.32

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS        2        0.13105        0.06553        1.59    0.243
CROPPING_SYSTEMS.TREATMENTS
        4        0.16770        0.04193        1.02    0.436
Residual        12        0.49351        0.04113

Total    26        1.06543
```

Appendix 6: Analysis of variance for kale phosphorus concentration

```
Variate: p_ppm_1_mnth

Source of variation    d.f.    s.s.    m.s.    v.r.    F pr.

REPLICATIONS stratum    2        264141.        132070.        0.72

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2        3098719.       1549359.       8.48    0.036
Residual        4        730815.        182704.        0.99
```

```
REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          4367607.        2183804.        11.81   0.001
CROPPING_SYSTEMS.TREATMENTS
          4          2838281.        709570.          3.84     0.031
Residual          12        2219244.        184937.

Total    26        13518807.

Analysis of variance

Variate: p_ppm_2_mnth

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum      2          7.166E+07      3.583E+07      0.73

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2          2.206E+08      1.103E+08      2.26     0.221
Residual          4          1.953E+08      4.884E+07      0.88

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          9.410E+07      4.705E+07      0.85     0.452
CROPPING_SYSTEMS.TREATMENTS
          4          1.862E+08      4.656E+07      0.84     0.526
Residual          12        6.652E+08      5.544E+07

Total    26        1.433E+09

Analysis of variance

Variate: p_ppm_3_month

Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.

REPLICATIONS stratum      2          20000.           10000.           0.27

REPLICATIONS.CROPPING_SYSTEMS stratum
CROPPING_SYSTEMS       2          5580000.        2790000.        76.09  <.001
Residual          4          146667.          36667.           0.37

REPLICATIONS.CROPPING_SYSTEMS.TREATMENTS stratum
TREATMENTS         2          6268889.        3134444.        31.70  <.001
CROPPING_SYSTEMS.TREATMENTS
          4          1344444.        336111.          3.40     0.044
Residual          12        1186667.        98889.
Total    26        14546667.
```