MONITORING CHANGES IN SOIL ORGANIC CARBON, MOISTURE CONTENT, NUTRIENT BALANCES AND MAIZE (*Zea Mays* L.) YIELD FOLLOWING DOLICHOS (*Lablab purpureus* (L.) INTEGRATION AND FERTILIZER APPLICATION IN MAIZE SYSTEMS OF NAIROBI COUNTY, KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR AWARD OF DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE IN THE DEPARTMENT OF LAND RESOURCE MANAGEMENT AND AGRICULTURAL TECHNOLOGY, UNIVERSITY OF NAIROBI

DECLARATION/APPROVAL

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

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DEDICATION

This work is dedicated to my Dad Sitienei Jacob K and Mum Lagat Christine for their commitment to my education and mentorship throughout my academic life. I Love you and May God bless you abundantly.

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To the Almighty God, All be Glory to Thee, I owe it all to God!

GENERAL ABSTRACT

Decline in soil nutrients and organic levels due to continuous cultivation practices combined with erratic rainfall patterns has led to soil fertility decline posing a serious threat to long-term maize (*Zea mays* L.) production in Nairobi County, Kenya. The current study monitored changes in soil organic carbon, moisture content, nutrient status and maize yield following dolichos (*Lablab purpureus* (L.) integration and application of fertilizers, as basis for developing sustainable soil fertility management strategies. Field experiments were conducted at the University of Nairobi field station, Kabete Sub-County for two seasons during the mid-March to May 2015 (long rain season; LRS) and October to December 2015/2016 (short rain season; SRS). The experiment layout was a Randomized Complete Block Design with a split-plot arrangement replicated three times. The cropping systems were the main plots; (i) mono-cropping (sole maize) (*Zea mays* L.), (ii) intercropping (dolichos (*Lablab purpureus* (L.) /maize) and (iii) rotation (dolichos-maize). The sub-plots were fertilizer types: (i) organic (farmyard manure; FYM), (ii) inorganic (triple superphosphate (TSP) and urea), (iii) integrated fertilizer (FYM +TSP + Urea) and (iv) no fertilizer input (control). Soil moisture, organic Carbon (OC), nitrogen (N), phosphorus (P), and potassium (K) levels were determined at the end of each cropping season. Assessment of ecological sustainability of the technologies being tested was determined by calculating nutrient balances. Soil carbon stocks were also calculated and their changes over a 20-year period projected using Roth-C. Soil carbon (C) inputs were obtained from crop residue and FYM inputs and converted into t C/ha. The C inputs were calculated from grain yield data using a harvest index (HI). The highest levels of soil moisture and organic carbon were respectively observed in maize/dolichos intercrop with application of FYM (31.8% and 2.6%) and FYM + TSP + Urea (30.1% and 2.5%) during the SRS. The same trend was observed in maize/dolichos intercrop with application of FYM and FYM + TSP + Urea in LRS with no significant differences between seasons. Similarly, significantly ($P \leq 0.05$) high soil N and P levels were obtained in maize/dolichos intercrop with application of FYM (0.3% and 22.6 ppm; 0.29% and 19.6 ppm) and TSP+FYM+Urea (0.28% and 22.5 ppm; 0.3% and 16.5 ppm) during the LRS and SRS respectively. The soil K levels were significantly ($P \leq 0.05$) higher in maize/dolichos intercrop with FYM (1.3 cmol/Kg and 1.8 cmol/Kg) application during the SRS and LRS respectively. Averaged across the two seasons, less negative N balances (kg $ha^{-1}yr^{-1}$) were obtained in maize/dolichos intercrop with FYM (-9.1) application. Pronounced losses realized in maize/dolichos intercrop with TSP/Urea (-20.1) application. P losses were higher in maize/dolichos with TSP+FYM+Urea (-2.2) and TSP+Urea (-2.4) application. Less negative P balances (kg $ha^{-1}yr^{-1}$) were obtained in dolichos-maize rotation with the application of FYM (-0.4) and TSP+FYM+Urea (-0.5). Significantly ($P<0.5$) higher K losses (kg $ha^{-1}yr^{-1}$) occurred in dolichos/maize intercrop with TSP+Urea (-6.7), dolichos-maize rotation with TSP+Urea (-4.9) and in maize monocrop with TSP+Urea (-4.5) application. Dolichos-maize rotation with FYM application resulted in reduced K losses (-0.2) compared to monocrop with FYM (0.4) and intercrop with FYM (-1.1) application.

Significant ($P \leq 0.05$) high SOC (t C ha^{-1}) density and stocks were respectively, obtained in maize/dolichos intercrop with FYM (60.7 and 56.2) and TSP+FYM+Urea (59.6 and 55.2) application compared to sole maize and dolichos-maize rotation during SRS. Higher soil organic carbon (t C ha^{-1}) stocks were obtained in maize/dolichos intercrop with TSP+FYM+Urea (140) application as compared to dolichos-maize rotation (120) and sole maize (110). Over a 20-year period, SOC stocks maintained a significant increase with application of TSP+FYM+Urea and FYM in the order maize/dolichos intercrop, rotation and sole maize system. Maize grain yields (t ha^{-1}) in the SRS were significantly ($P \leq 0.05$) higher in dolichos/maize intercrop with application of TSP+FYM+Urea (7.1) and FYM (7.0). Similarly, significantly ($P \leq 0.05$) high maize grain yields were obtained in dolichos/maize intercrop with TSP+FYM+Urea (5.2) and TSP+Urea (5.2) during the LRS. Dolichos-maize rotation with TSP+FYM+Urea application resulted in significantly higher dry matter yields (17.9 t ha^{-1}) compared to intercrop with TSP+Urea (19.6 t ha^{-1}) application in the SRS. When compared across the two seasons, soil moisture content, organic carbon and N, P and K levels were consistently high in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea in SRS. Negative N and P balances were pronounced in maize/dolichos intercrop and dolichos-maize rotation with application of FYM and TSP+FYM+Urea. Significant ($P \leq 0.05$) higher dry matter yields were obtained in dolichos-maize rotation with FYM application and higher grain maize yields were realized in intercrop with application of FYM and TSP+FYM+Urea in SRS as compared to the LRS. It is evident that improved soil moisture, organic carbon, nutrient status and carbon stocks in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea translated into increased maize yields. With the increase in yields, significant nutrient losses were realized. Projected carbon stocks increased in maize/dolichos with continuous application of TSP+Urea and FYM thus replenishing nutrient losses in the long run. Adoption of the best performing technology; maize/dolichos intercrop combined with application of 5 t ha^{-1} FYM and 60 kg ha^{-1} TSP+Urea ought therefore to be tapered (in the short run) with prudent nutrient management strategies to minimize nutrient losses through harvested products for system sustainability.

Key words: Cropping System, *Lablab purpureus,* Nutrient balances, Organic and inorganic fertilizers, Roth-C, Soil Carbon stocks, *Zea mays L.*

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
DST	Decision Support Tools
FYM	Farm Yard Manure
ISFM	Integrated Soil Fertility Management
LSD	Least Significant Difference
LRS	Long Rain Season
NUTMON	Nutrient Monitoring
RCBD	Randomized Complete Block Design
ROTH-C	Rothamsted Carbon Model
SOC	Soil Organic Carbon
SRS	Short Rain Season
SSA	Sub Saharan Africa
TSP	Triple Superphosphate

CHAPTER ONE: GENERAL INTRODUCTION

1.0 Background Information

Maize is one of the most important cereals widely adapted worldwide (Christian, 2012). In Kenya, maize is a major staple food and food security crop grown by every smallholder farmer (KARI, 2002). Its production is however on a downward trend with declining soil fertility as the most widespread, dominant limitation on yields of Maize (Z*ea mays L)* (Mugwe *et al.*, 2009). The soil fertility decline and dynamics of soil organic carbon is as a result of a combination of processes such as continuous cropping with little or no replenishment of nutrients removed through either crop harvests or other losses such as leaching (Kibunja *et al.*, 2007), use of inadequate fertilization and abandonment of fallowing (Njeru *et al.*, 2011; Okalebo *et al.*, 2006). Additionally, the natural physical and chemical features of soils in relation to climatic patterns also contribute significantly to the observed trend of soil fertility decline of countries in SSA. Moreover the low quality of soil resource base as a result of inherent and induced deficiencies of major nutrients N, P and K or low nutrient holding capacity and low organic matter (Okalebo *et al.*, 1992; Kaolo 2003) negatively affect crop production. Consequently, poor soil fertility has emerged as one of the major biophysical constraint to increasing agricultural productivity hence threatening food security in Kenya (Mugwe *et al*., 2009). To address the problems of declining soil fertility various efforts involving the use of organic and inorganic fertilizers has been advocated. Continuous use of inorganic fertilizer has achieved a considerable level of success over the years by increasing crop production at accelerated and balanced rates (Omotayo and Chukwuka, 2009). Inorganic fertilizers provide nutrients in soluble forms and hence readily taken up by plants. However the use of inorganic fertilizers alone has not been helpful under intensive agriculture because their continued use aggravates soil degradation (Sharma and Mittra, 1991). The degradation is brought about by loss of organic matter which consequently results in soil acidity, nutrient imbalance and low crop yields (Gruhn *et al.*, 2000). Application of inorganic fertilizers has also faced important limitations due to high costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007). The high cost has led to non-use or use of suboptimal quantities of fertilizer to avoid crop failure, thus posing a threat to food security (Onwonga *et al.*, 2008).

As a result, average fertilizer use rates for countries in sub-Saharan Africa (SSA) are considered too low to sustain crop and soil fertility (Gruhn *et al.* 2000). Consequently, crop yields are low and are decreasing in many areas, and the sustainability of the current farming system is at risk (Vanlauwe *et al.* 2011). Parallel to the use of inorganic fertilizers, majority of small-scale farmers use organic based technologies such as crop residues, leguminous cover crops and animal manure (Onwonga *et al.,* 2008). Organic techniques have been identified as reliable alternatives to reduce continued large scale use of inorganic fertilizers and have found great application in agricultural development of SSA due to relatively easy access and availability from the local environments (Rigby and Caceres 2001). However, as much as most farmers use organic fertilizer which is mostly available to maintain soil fertility, its quality is usually low because of poor quality livestock feeds and poor practices in manure handling and storage (Lekasi *et al.,* 1998). Furthermore, different organic resources have differing chemical compositions that determine residue decomposition rates, consequently affecting nutrient release rates and patterns, which are in part controlled by the resource quality of the materials (Giller and Cadisch, 1997). As a result integrated soil fertility management (ISFM) is becoming more accepted by development and extension programs in SSA and most importantly by smallholder farmers. Consequently, there is growing need to develop techniques for improving soil fertility without causing damage to the environment (Topliantz *et al.,* 2005). Several researchers have recommended ISFM options for increasing soil fertility and agronomic efficiency of applied inputs (Sanginga and Woomer, 2009; Vanlauwe *et al.,* 2010) in order to maximize crop productivity. These practices include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm, and must be adapted to the local conditions (Vanlauwe *et al.,* 2010; Fairhurst, 2012). Among the common ISFM practices in SSA are intercropping and rotation of cereals with legumes, manure application, and application of both organic and inorganic materials either simultaneously or sequentially to the same crops.

Legumes are important components of farming systems in the East African highlands because they are major protein sources for animals and humans, in addition to their role in the restoration of soil fertility (Amede and Kirkby 2004). Cereal-grain legume intercropping has potential to address the soil nutrient depletion on smallholder farms (Sanginga and Woomer, 2009) through nitrogen fixation (Peoples and Craswell, 1992).

In the central highlands of Kenya, cereal-legume intercropping is already being widely practiced by the smallholder famers. However, most of the ISFM techniques tested and recommended are inconclusive since they are field based and conducted under changing climate conditions (Scoones, 2001). Moreover, field experiments require resources and time under unpredictable climate conditions to arrive at valid, reliable conclusions and recommendations that can stand the taste of time (Bouma and Jones, 2001). Further, field research in agriculture has been largely empirical and site-specific and conducted without the active help of agricultural system models. Integration of this system models (Decision Support Tools) with field research will make easy interpretation of results and will eliminate the critical knowledge gaps (Struif Bontkes *et al.*, 2001). Decision support tools (DSTs) allow for the analysis, comprehension of the existing situation and subsequently offer alternatives to solve problems or explore opportunities without need for repeated field experiments (Bontkes and Wopereis, 2003; Walker, 2002*)*. Key DST and/or biophysical models have been developed to track dynamics and elements such as N, organic carbon and calculating nutrient balances. The important DSTs that have significantly enhanced understanding of characteristics and functioning of smallholder farming systems in Sub Saharan Africa and the suitability of integrated soil fertility management technologies include the NUTrient MONitoring (NUTMON) Toolbox, used to monitor nutrient balances at different spatial scales (Giller *et al.,* 2006). The NUTMON toolbox (now called MONQi), is a static model that calculates nutrient flows of tropical farming systems has been widely applied in several nutrient balance studies (De Jager *et al.* 1998; Van Beek *et al.* 2009). The use of MONQI toolbox in a maize-legume based system may allow a quick diagnosis of farmers' nutrient management strategies to support decisions related to nutrient management (Van den Bosch *et al.* 2001) thus amelioration of soil quality and fertility. On the other hand, there's need to understand the dynamics of soil organic carbon (SOC) which is important for the prediction of the carbon sequestration potential of soils as climate change mitigation strategy. The turnover of SOC can be quantified and simulated with the help of organic matter turnover models (Coleman and Jenkinson 1996; Franko *et al.* 1997) using Rothamsted carbon model (Roth-C) that allow the prediction of changes in soil carbon stock arising from agricultural management practices or from rising temperatures due to climate change (Paul *et al*. 2004; Knorr *et al.* 2005).

It is therefore against this background that the current study monitored changes in soil organic carbon, moisture content, nutrient balances and maize yield following dolichos (*Lablab purpureus* (L.) integration and fertilizer application in maize systems as basis for developing sustainable soil fertility management strategies.

1.1 Statement of the Problem

Soil fertility in the central highlands of Kenya is on the decline (Jaetzold and Schmidt 2006), with an annual net nutrient depletion exceeding 30 kg/ha (Smaling 1993). Further, crop residue removal together with continuous cropping exacerbates depletion of soil nutrients and soil organic matter stocks due to accelerated mineralization (Xiang *et al.,* 2005). The situation is further aggravated by the fact that even the farmers using mineral fertilizers rarely use the recommended rates (60-100kg) of N, P and K per hectare each year in the area, where most of them apply less than (20kg/ha) (Adiel 2004), thus posing a threat to food security. Additionally, in most smallholder farms, fertilizer is not readily available and when available the cost is often limiting to small scale resource poor farmers (Smestad *et al.,* 2002). This leads to non-use or use of suboptimal quantities of fertilizer to avoid crop failure, thus posing a threat to food security. Additionally the single use of organic materials that is commonly available to farmers is insufficient to supply nutrient for crop production and thus maize yield decline (Nziguheba *et al.,* 2002; Vanlauwe *et al.,* 2002). In most cases, where strategies aimed at soil fertility management are embraced, the quantitative assessment of their effects has rarely been satisfactory (Murage *et al.,* 2006). Information on the extent to which integration of legumes into maize based cropping system with combined application of fertilizers contribute to sustainable soil management and increased agricultural productivity in the face of climate change and land use is scanty (Yudelman, 2000). Moreover the long term benefits of the practice with respect to carbon sequestration as an adaptation strategy to climate change and nutrient balances as a measure of sustainability is not known.

1.2 Justification

Due to increased soil fertility decline under unpredictable weather conditions, an alternative and innovative approaches that take into account farmers' socio-economic status and environment under which they operate in are imperative. Techniques such as crop rotations, intercropping and application of fertilizers enhance soil fertility and increase stability and resilience of the soil to droughts. This has an effect on soil organic carbon content, which has major implications on soil structure and soil moisture as well as improving availability of organic matter that acts as the active source of plant nutrients. Intercropping maize with legumes will stabilize yield, promotes dietary diversity and maximize returns even when low levels of technology and resources are used. Additionally this practice with retention of residues will help buffer farmers from climate variability while increasing farm yields and sequestering carbon in the soil. Furthermore, techniques that combine mineral fertilizers with organic nutrient sources can be considered as better options in increasing fertilizer use efficiency, and providing a more supply of nutrients. Combination of organic and mineral fertilizer nutrient sources has been shown to result in synergistic effects and improved synchronization of nutrient release and uptake by crop leading to higher yields. Testing of the said techniques under field conditions will however require time and resources to arrive at appropriate conclusions and recommendations on their suitability and sustainability. In this context, the need of appropriate decision support tools will become handy for farmers, decision makers and other stakeholders' to address declining crop production in smallholder farming systems. NUTtrient MONitoring toolbox (NUTMON) and Rothamsted carbon model (Roth-C) are key DST for monitoring nutrient balances at different spatial scales and quantification of SOC turnover driven by a range of climate models, respectively.

It is envisaged that this study once successfully implemented, would contribute towards enhancing the long-term sustainability of agricultural production system while mitigating climate change. Food security will be improved due to sustainable production practices. Additionally, improved social welfare due to maximized returns and human health as a result of enhanced dietary diversity will be realized.

1.3 Research objectives

1.3.1 Broad objective

To monitor changes in soil organic carbon, moisture content, nutrient balances and maize yield following dolichos (*Lablab purpureus* (L.) integration and fertilizer application in maize systems as basis for developing sustainable soil fertility management strategies.

1.3.2 Specific objective

i. To determine the effect of dolichos integration with farmyard and, combined triple superphosphate and Urea application on soil organic carbon and moisture content in maize cropping systems.
ii. To determine the effect of dolichos integration with farmyard and, combined triple superphosphate and Urea application on N, P and K balances in maize cropping systems.
iii. To determine the effect of dolichos integration with farmyard and, combined triple superphosphate and Urea application on soil nutrient status, maize grain and dry matter yield in maize cropping systems.
iv. To simulate the long term effect of dolichos integration with farmyard and, combined triple superphosphate and Urea application on soil organic carbon stocks in maize cropping systems.

1.4 Hypotheses

i. Dolichos integration with farmyard and, combined triple superphosphate and Urea application will increase soil organic carbon and soil moisture content in maize cropping systems.
ii. Dolichos integration with farmyard and, combined triple superphosphate and Urea application will result in less negative NPK balances in maize systems.
iii. Dolichos integration with farmyard and, combined triple superphosphate and Urea application will lead to an increase in soil nutrient status, maize dry matter and grain yield.
iv. Simulated soil organic carbon stocks over a 20-year period will show an increase following dolichos integration with farmyard and, combined triple superphosphate and Urea application in a maize cropping system

CHAPTER TWO: LITERATURE REVIEW

2.1 Integration of legumes into cereal cropping systems

2.1.1 Importance of Dolichos (*Lablab purpureus*)

Dolichos lablab (*Lablab purpureus*) is a grain legume that is fairly tolerant to high temperatures and drought (Muchow, 1985). It has the capacity to replace these common legumes which are more vulnerable to low rainfall and higher temperature occurring in the arid and semi-arid areas. Dolichos is as a multipurpose crop utilized as a pulse, green vegetable and animal feed (Maass, 2007). It is mainly grown by small scale farmers mainly in Eastern, Central and Coast provinces as an intercrop with maize or pure stand. It can also be utilized as short fallow in order to maintain soil fertility and organic matter (English *et al.*, 1999). Dolichos can fix up to 235 kg N/ha and produces more N per unit area from plant biomass than many other legumes (Peoples *et al*., 1995). Apart from its ability to fix nitrogen, dolichos also has the ability to bring minerals from the deeper soil horizons to the surface as well as improving soil air circulation (Kumar Rao *et al*, 1983). Excessive mono-cropping of legume may result in accumulation of nitrates in the root zone hence reduce N fixation. Therefore, to enhance nitrogen fixation, it is important that a nitrogen fixing legume should be associated with a cereal crop that utilizes the excess nitrate in the root zone (Fujita *et al.,* 1992).

2.1.2 Maize production status

Maize is a major staple food for most households in Kenya and main source of income and employment for majority of rural households (Mantel and Van Engelen, 1997). It constitutes 3% of Kenya's Gross Domestic Product (GDP), 12% of the agricultural GDP and 21% of the total value of primary agricultural commodities (Government of Kenya, 2002). Maize is both subsistence and a commercial crop, grown on an estimated 1.4 million hectares by large-scale farmers (25%) and smallholders (75%). Maize is also important in Kenya's crop production patterns accounting for about 20% of gross farm output from the small-scale farming sector (Mugwe *et al.,* 2001). The maize growing areas of the country are located in ecological zones that allow the maize to grow irrespective of limiting temperature and rainfall environments.

It is grown in a wide range of soils including Andosols, Vertisols, Phaeozems, Cambisols, Luvisols, Nitisols, Acrisols and Ferralsols (Muchena *et al*., 1988). Food security and welfare of the farming population are dependent on productive capacity of maize farmers. More than 70% of maize area in Kenya is cultivated on farms of less than 20 acres (Mantel and Van Engelen, 1997). Total maize production and yield per unit area in Kenya has been affected by many different factors including total planted area and productivity. Moreover there is limited scope for expanding cultivated land under maize production since unused land is diminishing or is of marginal quality or just unsuitable for maize production (Muchena *et al*., 1988). Small farms tend to use more labor per acre than large farms. About 25% more labor is required for organic grain production than for conventional; expect about 2 to 2½ hours per acre (Watson *et al*., 2002). The bulk of the small-scale farmers who do not apply chemical fertilizers or manure obtain yields ranging between 1.1 and 2.5t tons per hectare. Technologies that combine mineral fertilizers with organic nutrient sources can be considered as better options in increasing fertilizer use efficiency, and providing a more balanced supply of nutrients (Donovan and Casey 1998). Combination of organic and mineral fertilizer nutrient sources has been shown to result in synergistic effects and improved synchronization of nutrient release and uptake by crop (Palm *et al.* 1997) hence increasing yields. This is especially when the levels of mineral fertilizers used are relatively low as is the case in most smallholder farms of central Kenya (Kapkiyai *et al.*, 1998).

2.2 Interventions in soil fertility management under maize cropping system

2.2.1 Application of inorganic fertilizers in a maize-based system

Inorganic fertilizers have a high concentration of nutrients that are rapidly available for plant uptake and they can be formulated to supply the appropriate amount of nutrients to meet plant growth requirements (Ngo *et al.,* 2012). Today, a wide range of inorganic fertilizers are required to maintain soil fertility and sustainable agricultural systems. Non-application or sub-optimal use of inorganic fertilizers will lead to soil nutrient levels decline rapidly and crop productivity decrease (Waswa *et al.*, 2007). Chemical fertilizers have achieved a considerable level of success over the years and have been widely used all over the world by enhancing crop production (Ngo *et al.,* 2012).

However many studies have shown that the use of mineral fertilizers can have negative effects on soil such as acidification, increased leaching losses and decline of organic matter contents (Marschner, 2002; Adjei-Nsiah, 2012). Additionally, in Sub-Saharan Africa, sufficient mineral fertilizers are not available at the right times during the year due to high costs and inefficiencies in the production-consumption chain (Nyamangara *et al.*, 2009). An alternative to mineral fertilization is the amendment of soil with organic matter. Organic residue addition has been shown to improve soil fertility (Caravaca *et al.,* 2002), plant nutrition and vegetation cover (Larcheveque *et al.,* 2005). Organic residues addition also helps in reducing nutrient losses through leaching and also improves soil organic matter content. Organic residue amendments have long term advantages of soil improvements while over short-term and medium-term use, synthetic chemical fertilizers are attractive due to their convenience, ease of application, and reliable high yield. Hepperly *et al.,* (2009) reported that although synthetic chemical fertilization is able to stimulate high short-term maize yields, it will not be able to support sustainable crop productivity, crop health, or soil health over longer time periods. However other studies have shown that combining both the organic residues and inorganic residues to be more advantageous in terms of nutrient synchrony and soil fertility improvement hence increased maize yields (Sakala *et al.,* 2000; Vanlauwe *et al.,* 2001; Nyamangara *et al.,* 2003; Mugwe *et al.,* 2008; Nyongesa *et al.,* 2009).

2.2.2 Application of organic fertilizers in a maize-based system

Farm-yard manure offers a natural means to cycle plant nutrients as it forms an important part of organic soil fertility programs (Parr *et al.,* 1992). FYM application is common in central highlands of Kenya and has been estimated that more than 95% of smallholder farmers growing maize use it (Harris, 1998). The application of manures to soil provide potential benefits including improving the fertility, structure, increasing soil organic matter, water holding capacity and supplementing the amount of synthetic fertilizer needed for crop production (Phan *et al.*, 2002). Farm yard manure is known to increase crop yield by its favorable effect on physical, chemical and biological factors that determines the productivity and fertility status of soil and supply nutrients in the readily available form to plants. High quality cattle manure can contain up to 23kg of nitrogen, 11kg of phosphorus and 6kg of potassium (Vasundhara *et al.*, 2006).

Organic residues can increase maize yields more than or similar to application of inorganic fertilizers (Nziguheba *et al.,* 2000). The increase in yields is associated with increased nutrient uptake and also mulching effects (Tian *et al.*, 1993). The yield response to organic residues is dependent on the amount of organic matter, quality of organic residues and method of application (Mutegi *et al.*, 2012). Organic inputs can alleviate constraints to crop growth other than N depletion and, as such, improve the use efficiency of N fertilizer (Vanlauwe *et al.,* 2001). Organic residues which undergo rapid mineralization produce higher grain yield and stover in maize as compared to those organic residues which undergo slow mineralization during early stages of maize growth (Nyongesa *et al.*, 2009). In the long run, continuous application of organic inputs may improve soil physical and chemical characteristics such as soil structure, bulk density, porosity, and nutrient retention among others, and consequently lead to better crop growth (Vanlauwe *et al.*, 2001). Many studies have shown that organic amendments can increase maize yields and other crops significantly (Marschner 2002 and Mekuria 2012).

2.2.3 Dolichos in intercrop and rotation system

Dolichos integration can be through crop rotation and intercropping practices. Intercropping is the practice of cultivating two or more crops in the same space at the same time (Anil *et al.*, 1998). It usually involves one main crop (of primary importance for economic or food production reasons) and one or more added crops. The crops in an intercrop are normally from different species or plant families. Intercropping is most common among small holder farmers in tropical countries (Altieri, 1991) and has the advantage of being more efficient in utilization of available resources and increased productivity compared to the sole crop (Mucheru *et al.,* 2010). According to Sanginga and Woomer (2009), intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as soybean and dolichos accumulate from 80 to 350kg nitrogen (N) ha^{-1} (Peoples and Craswell, 1992). Nzabi *et al.*, (2000) working in Kisii ditrict at two sites (Nyamionyo and Nyatieko) found that dolichos when intercropped with maize and the residue incorporated into the soil showed that dolichos lablab/ maize intercrop could give maize yield of 3,350 kg/ha and 3,320kg/ha in Nyamionyo and Nyatieko respectively. This yield was higher than maize sole crop with residue incorporation which gave a yield of 3,061kg/ha and 3,345kg/ha for the same sites.

Crop rotation is a system where different plants are grown in a defined recurring sequence. This temporal diversity within cropping systems has the principal objectives of providing crop nutrients and breaking the life cycles of several insect pests, diseases, and weed life cycles. Crop rotations are the main avenue for supply of nitrogen in organic cropping systems especially when they include a mixture of leguminous and cash crops. Rotations are divided into nutrient building and nutrient depleting phases which must be in balance or show a slight surplus to ensure long-term fertility (Altieri, 1995). By in influencing soil structure and crop growth conditions, rotations play a critical role in sustainable crop production (Ball *et al.,* 2005).

2.2.4 Integrated Soil Fertility Management

Integrated soil fertility management (ISFM) refers to the application of soil fertility management practices, and the knowledge to adapt these to local conditions, which maximize fertilizer and organic resource use efficiency and crop productivity (Sanginga and Woomer 2009. It is achieved through efficient management of all nutrient sources. ISFM is a sustainable approach that acknowledges the need for both organic and mineral inputs to sustain soil health and crop production due to positive interactions and complementarities between them (ASHC, 2012). It is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences; biological, physical and chemical of soil degradation (Barrios *et al*. 2006). Strategically targeted fertilizer use together with organic nutrient resources to ensure fertilizer use efficiency and crop productivity at farm scale are basic principles of ISFM (Vanlauwe and Giller, 2006). Although ISFM recognizes the absolute necessity of mineral fertilizer use (Vanlauwe *et al.,* 2010), it advocates the best combination of available nutrient management technologies that are economically profitable and socially acceptable to different categories of farmers (Vanlauwe, 2004). It is rapidly becoming more accepted by development and extension programs in SSA, and, most importantly, by smallholder farmers (Place *et al.*, 2003). Beneficial effects of ISFM on soil fertility have been shown to increase nutrient use efficiency associated with combined nutritional and non-nutritional effects of organic and inorganic inputs compared to inorganic fertilizer applied alone (Fofana *et al.,* 2005; Wopereis *et al.,* 2005). Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of soil nutrients.

Research has shown that combinations of organic and inorganic fertilizers result in higher crop yields compared with sole inorganic or sole organic fertilizers (Chivenge *et al*., 2009). Based on the evaluation of soil quality indicators, Dutta *et al*., (2003) found out that organic fertilizer use combined with mineral fertilizers, compared to the addition of sole organic fertilizers had a higher positive effect on microbial biomass and leading to enhanced soil health. Vanlauwe *et al.* (2002) reported that maize grain yield increases of up to 400% over the control due to improved N synchrony with combined fertilizers through direct interactions of the organic and chemical N fertilizers. Dunjana *et al.,* (2012) found a positive correlation between the application of farm yard manure and inorganic fertilizer on soil organic carbon (SOC), bulk density and aggregate stability and application of animal manure combined with inorganic fertilizer led to increase in maize yields. Therefore, a combination of both organic and inorganic fertilizer may prove to be more effective than sole application.

2.3 Maize based cropping systems and contribution to soil carbon sequestration

Carbon sequestration can be defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. It is estimated that 2500 gigatons (Gt) of carbon are stored in the soil as soil organic carbon (1550 Gt) and soil inorganic carbon (950 Gt) (Lal, 2004). Carbon levels maintenance in agricultural soils is enhanced through addition of crop residues, manure and nitrogenous fertilizers (Lal, 2004). The soil organic carbon sequestration is caused by those management systems that add high amounts of biomass to the soil, conserved soil and water and improved soil structure (Lal, 2004; Marland *et al.,* 2004). However, activities such as continuous unsustainable practices and nutrient mining lead to soil carbon loss (Lal, 2004). Therefore, adopting alternatives such as crop residue incorporation on the soil surface are effective in reducing soil CO_2 emission thus improving soil C sequestration (Al-Kaisi and Yin (2005). Long-term experimental studies have shown that soil organic carbon is highly sensitive to land use changes from native ecosystems, such as forest or grassland and agricultural systems resulting in loss of soil organic carbon. Management of soils to increase SOC levels can therefore increase the productivity and sustainability of agricultural systems. A significant correlation between soil organic matter and cereal productivity in China was reported (Pan *et al.,* 2009).

The study suggested that enhancing carbon sequestration in croplands enhances crop productivity and stabilize yields hence offering sound basis for greenhouse gases (GHGs) mitigation by increasing the capacity to store more organic carbon in soil.

2.4 Decision Support Tools and their use in Agriculture

Improving soil fertility in farming relies on improved understanding of the effects of management practices on soil fertility and also on improved technology transfer of research results into practice (Scoones, 2001). This requires the provision of good on-farm advice by advisors who fully understand the complexity of managing soil fertility in various farming systems. The development and widespread accessibility of appropriate tools to support decision-making is also important (Wander & Drinkwater 2000). Decision Support Tools (DSTs) can be defined as any guidance, procedure or analysis tool that can be used to help support a decision. DSTs allow the decision making process to be made more transparent and allows for the quantitative assessment of effects of any uncertainty on the decision (Sullivan, 2004). The dynamic environment in which the farmer operates implies that effective solutions of the past may not work in the present situation (Bouma and Jones, 2001). This situation calls for tools that can support decision making in smallholder agriculture in sub-Saharan Africa. Such decision support tools (DSTs) can assist with the diagnosis and analysis of problems and opportunities related to soil fertility and identify options for improved ISFM. Several DSTs have been developed over the past decade including NUTMON/MONQi (Monitoring for quality improvement) used to help quantify the resource flows at the field and farm level. The use of NUTMON/MONQI toolbox in maize-based systems may allow a quick diagnosis of farmers' nutrient management strategies to support decisions related to nutrient use (Van den Bosch *et al.* 2001). Roth-C model is also an important DSTs used for the turnover of organic carbon in non-waterlogged top soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process (Coleman and Jenkinson 1990). RothC model was used in estimating the effects of the application of fertilizers under maize based cropping systems on soil carbon stocks and projections over a 20-year period.

2.4.1 Calculation of Nutrient balances using NUTMON/MONQi

Sustainability of an agricultural system can be quantified using nutrient balances as an indicator (Smaling *et al.,* 1996). Soil fertility management decisions to improve sustainability are determined by the available resources, the socioeconomic environment and the objectives such as food security of the household (Van den Bosch *et al.,* 1998). Strategies to manage soil fertility therefore require a long term holistic approach which accounts for nutrient stocks within the farm and their flow between the farm activities as well as the nutrient balances resulting from differences in nutrient exports and imports into the farm (Vlaming *et al.*, 2001). Bio-economic models such as NUTMON are meant to examine the interaction between agro-ecological and socioeconomic processes (Reuben *et al.,* 2000). NUTMON is useful in assessing the effect of introduced nutrient management initiatives on the soil nutrient stocks and flows (Van den Bosch *et al.,* 1998). This helps in making decisions that will ensure long term sustainability of the farm (Brown, 2000).

2.4.2 Quantification and prediction of carbon stocks using Roth-C

Soil organic carbon (SOC) turnover simulation models have been widely used to predict SOC change with changing environmental and management conditions, (Skjemstad, 2004). These models include the Rothamsted (Jenkinson 1990), Century (Parton et al. 1987), and APSIM (McCown *et al.* 1996) models. These are indirect types of models that conceptualize the natural system of carbon pools to be measure different SOC turnover rates, (Xu et al., 2010; Coleman and Jenkinson, 1999; Jensen *et al.,* 1997; Li *et al.,* 1997; Parton *et al.,* 1995). These models can be run in equilibrium in different types of scenarios thereby giving the pool under different conditions. Roth-C is among these models, and it has been widely used for arable soils, grassland soils and forest soils (Falloon & Smith, 2002). The RothC-26.3 model (Coleman and Jenkinson, 1995) translates information on quality and quantity of plant litter, entering the soil, into changes of SOC contents (Mg C/ha), thereby accounting for the influence of soil moisture content, temperature, clay content and litter quality on the rate of decomposition.

CHAPTER THREE: GENERAL MATERIALS AND METHODS

3.1 Site Description

The field experiment was conducted at Kabete field station of the University of Nairobi, located about 10 km north of Nairobi, during the short (SRS) of 2015/2016 and long rain (LRS) seasons of 2015. The station which is about 1940 m above sea level, is located at latitude 1° 15’ S and longitude 36° 41’ E and is categorized under agro-ecological zone III (Sombreak *et al*., 1982). The climate is typically sub humid with minimum and maximum mean temperatures of 13.7°C and 24.3°C respectively. The site has a bimodal rainfall distribution (mid-March to May, long rains and October to December, short rains). The average annual precipitation is 1000 mm (Jaetzold *et al*., 2006). During the experimental period a total of (478mm) of rainfall distributed across two seasons was recorded (Figure 1).

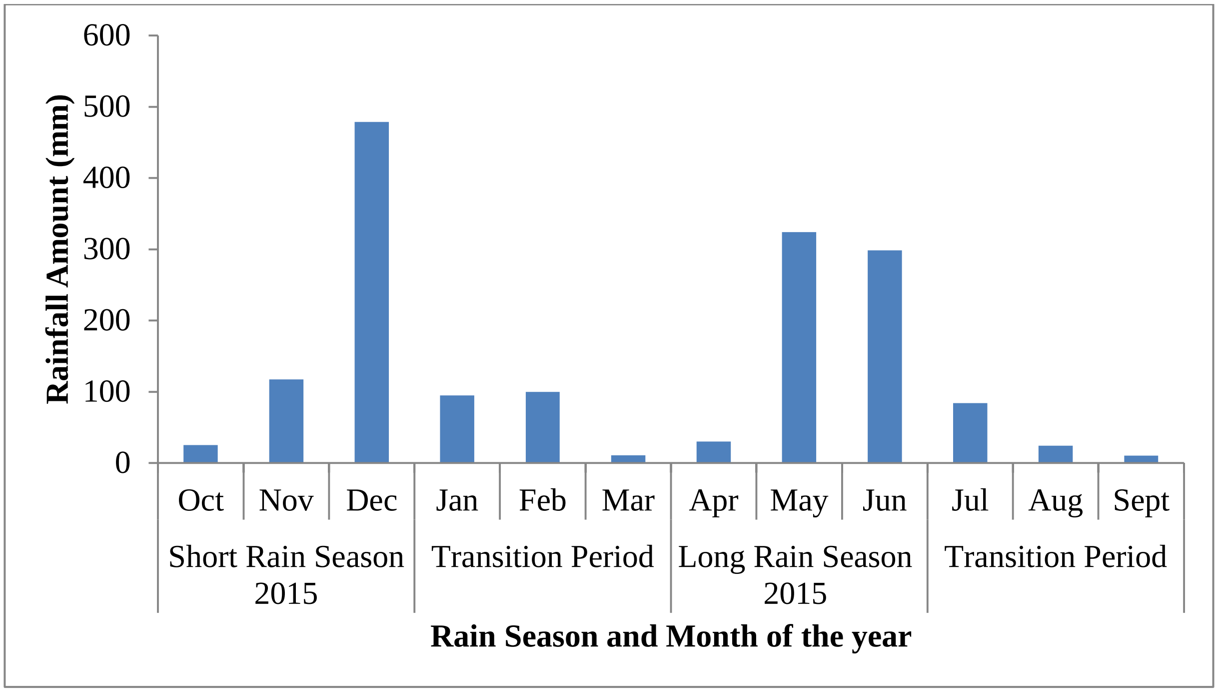

Figure 1: Total monthly rainfall received during the experimental period (mm).

Soils at the research site are predominantly deep red Humic Nitisols containing 60-80% clay (FAO, 1990; KSS, 2004; WRB, 2006). The measured initial soil characteristics (0-20 cm depth), (Table 1) indicated; clay texture, moderate acidity, moderate organic carbon, moderate nitrogen, high potassium and low available P levels according to Landon (1991) soil nutrient classification method.

Table 1: Initial physical and chemical soil properties at experimental site (0-20 cm depth)

Soil property	Units	Value	Soil Property	Units	Value
Soil pH (H_20)	-	6.1	Ca	Cmol Kg^{-1}	8.22
Soil pH ($CaCl_2$)	-	5.7	Mg	Cmol Kg^{-1}	1.6
Available P	Mg Kg^{-1}	11	% Sand	%	6
Total N	%	0.28	% Silt	%	28
Organic C	%	1.96	% Clay	%	62
Potassium	Cmol Kg^{-1}	1.07	Textural Class	-	Clay

The main crops grown in the LRS include maize, potatoes, beans, carrots, tomatoes and limited temperate fruits such as avocados and grapes. Maize, often intercropped with beans, dominates the cropping pattern. Most of the cultivation in Kabete Sub-county is done by large scale farmers who concentrate mainly on coffee. Coffee and horticultural products (flowers and cabbages) are the main income earners. Of the whole households' population in the county, 44% derive their income from agriculture while 45% rely on urban self-employment (FAO, 2010).

3.2 Experimental design and Treatments

The on-station field experiment was conducted during the LRS of (mid-March-May) 2015 and SRS of (October-December) 2015/2016. The experimental design used was a randomized complete block design (RCBD) with split-plot arrangement that was replicated three times. The main plots (4.5m x 8.2m) were cropping associations; (i) dolichos (*Lablab purpureus*)-maize (Z*ea mays* L.) rotation, (ii) dolichos/maize intercrop and (iii) sole maize (Table 2). The sub-plots (4.5m x 2.4m) consisted of fertilizers; (i) (farmyard manure; FYM 10 t ha^{-1}) (ii) (triple superphosphate (TSP) and urea) applied at the rate of 60 kg ha^{-1} (iii) combined inorganic and organic fertilizer (TSP+FYM+Urea) at half the full rate and (iv) control (no fertilizer).

3.3 Agronomic practices

Land was prepared manually using hand hoes followed by secondary cultivation which involved leveling. Planting was done by placing seeds directly into the soil. Two maize (Duma 43 variety) seeds were planted per hill at a depth of about 5cm with a spacing of 75cm between the rows and 30 cm between plants (Table 2).

Table 2: Treatments and crop sequence during the LRS and SRS of 2015/2016

Cropping System	Treatments	Description	Fertilizers	Crop/Season	
				LRS	**SRS**
Monocrop	1	Maize Monocrop	Control	Maize	Maize
	2	Maize Monocrop	FYM	Maize	Maize
	3	Maize Monocrop	TSP+FYM+Urea	Maize	Maize
	4	Maize Monocrop	TSP+Urea	Maize	Maize
Rotation	5	Lablab-Maize	Control	Lablab	Maize
	6	Lablab-Maize	FYM	Lablab	Maize
	7	Lablab-Maize	TSP+FYM+Urea	Lablab	Maize
	8	Lablab-Maize	TSP+Urea	Lablab	Maize
Intercropping	9	Lablab/Maize	Control	Lablab/Maize	Lablab/Maize
	10	Lablab/Maize	FYM	Lablab/Maize	Lablab/Maize
	11	Lablab/Maize	TSP+FYM+Urea	Lablab/Maize	Lablab/Maize
	12	Lablab/Maize	TSP+Urea	Lablab/Maize	Lablab/Maize

Key: FYM – Farm Yard Manure; TSP – Triple Superphosphate; Control – no fertilizer; LRS – Long Rain Season; SRS – Short Rain Season.

Farm yard manure at (10 t ha^{-1}), TSP and Urea (60 kg ha^{-1}) were placed in the planting holes (banding) about five cm deep between the maize and maize/dolichos rows in each plot at planting in both seasons. Dolichos *black* variety was planted in the intercrops as well as in the rotation with Maize. In rotation, two seeds of dolichos were planted at a depth of about 5 cm with a spacing of 75 cm by 30 cm. In the intercrop, dolichos was planted in between maize rows at the same inter-plant spacing as in pure stands at the start of the LRS of 2015 and SRS of 2015/16. Sole dolichos was planted during LRS and rotated with maize in the LRS. Thinning to one seedling per hill was done four weeks after planting. Weeding was done by hand hoeing at 3 weeks after germination and also at the flowering stage.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 INTERACTIVE EFFECTS OF DOLICHOS (*Lablab purpureus* (L.) INTEGRATION AND FERTILIZERS APPLICATION ON SOIL MOISTURE AND ORGANIC CARBON IN MAIZE (*Zea mays* L.) CROPPING SYSTEMS OF NAIROBI COUNTY, KENYA

Abstract

Decline in soil organic carbon levels due to continuous cultivation practices combined with erratic rainfall patterns has led to soil fertility decline posing a serious threat to food security. The current study investigated the interactive effects of of dolichos (*lablab purpureus* (L.) integration and fertilizers application n soil organic carbon and soil moisturein maize systems of Kabete Sub-county, Nairobi County. The study was carried out between mid-March to May 2015 long rain season (LRS) and October to December 2015/16 short rain season (SRS). The experimental design was a Randomized Complete Block Design with a split plot arrangement replicated three times. The main plots were cropping systems; (i) mono-cropping (sole maize) (*Zea mays* L.), (ii) intercropping (dolichos (*Lablab purpureus* (L.) /maize) and (iii) Rotation (dolichos-maize). The sub-plots were fertilizer types: (i) (farmyard manure; FYM), (ii) (triple superphosphate (TSP) and urea), (iii) combined fertilizer (FYM+TSP+Urea) and (iv) no fertilizer input (control). Soil samples were taken at the end of each cropping season from 0-20 cm for determination of soil moisture content (%) and soil organic carbon levels (%).The highest levels of soil moisture and soil organic carbon were respectively, observed in maize/dolichos intercrop with application of FYM (31.8% and 2.6%) and FYM+TSP+Urea (30.1% and 2.5%) as compared to crop rotation and monocrop during the SRS. The same trend in soil moisture and organic C levels were observed in maize/dolichos intercrop with application of FYM and FYM+TSP+Urea during LRS albeit with no significant differences compared with the SRS. Soil organic carbon levels and moisture content increased in maize/dolichos intercrop with FYM and TSP+FYM+Urea application in both seasons. Application of FYM and TSP+FYM+Urea to maize/dolichos is therefore a viable and sustainable practice to enhanced organic C and soil moisture content levels in smallholder farming systems..

Keywords: Fertilizers; Cropping systems; Maize; Soil moisture; Soil organic carbon

4.1.1 Introduction

Soil is the largest terrestrial organic carbon pool (Schmidt *et al.*, 2011). It contains twice as much C as in the atmosphere or vegetation (Lal, 2004). Hence, small changes in rates of mineralization of this pool due to climate or land use and management change will directly affect atmospheric CO_2 concentrations (Stockmann *et al.*, 2013). For both climate mitigation and amelioration of soil quality and fertility, there is a growing interest in adapting agricultural soil management to stabilize or increase soil organic carbon (SOC) contents (Lal, 2007; Stockmann *et al.*, 2013). In recent decades, unsustainable land practices such as soil nutrient mining have led to accelerated depletion of the natural soil base available for food production (Hossner and Juo, 1999). Soil productivity maintenance remains a major environmental issue in sub Saharan Africa (SSA) (Oyetunji *et al.*, 2001). Woomer *et al.* (1994) also reported that continuous cropping with its associated tillage practices provokes an initial rapid decline in SOM which then stabilizes at low levels. The dynamics of SOC are also influenced by agricultural management practices such as mulching, removal of crop residues and fertilization (Duiker and Lal, 2004). Additionally, the natural physical and chemical features of soils in relation to climatic patterns also contribute significantly to the observed trend of soil fertility decline of countries in SSA. This includes low erratic rainfall patterns together with its unreliability and poor distribution limiting crop production (KARI, 1996). Moreover the low quality of soil resource base as a result of inherent and induced deficiencies of major nutrients N, P and K or low nutrient holding capacity and low organic matter (Okalebo *et al.*, 1992; Kaolo 2003) negatively affect crop production. Proper soil conservation becomes imperative when considering issues regarding soil fertility improvement in SSA. Sustainable agricultural production incorporates the notion that natural resources be used to increase agricultural output and income without depleting the natural resource base (Gruhn *et al.*, 2000). The demand for increased agricultural production requires improved use efficiency of natural resources such as water and nutrients (Gao *et al.,* 2010). This combined with intercropping often leads to better use of land and other resources (Willey, 1990). The small holder farmers of Central Highlands of Kenya intercrop cereals with grain legumes, such as dolichos Lablab (*Lablab purpureus* (L.) as a strategy for diversifying food production and household income since legumes are both cash and food crops (Mafongoya *et al.*, 2006).

Legumes have the ability to suppress the growth of weeds, recover deeply leached nutrients and add organic material to the soil, consequently improving soil chemical and physical properties (Nyambati *et al.* 2006; Maass *et al.* 2010). In addition to intercropping, farmers practice well-managed crop rotations with the aim of increasing soil organic matter to sufficient levels that also tend to help to moderate and retain soil moisture under dry conditions, and allow excess moisture to drain away in wet seasons thus recharging the ground water aquifers. Agronomic practices aimed at improving soil organic matter and reducing moisture stress offer greater potential benefits to improving crop productivity in rain fed agriculture compared to improved crop varieties (Lobell, 2009). These practices include the interaction between organic and inorganic sources of nutrients (Palm *et al.,* 1997) which have proven to be successful in improving the physical productivity of soil (Weil and Magdof, 2004). The application of sole animal manure applied or in combination with chemical fertilizers, improves soil organic carbon concentration (Manna *et al.,* 2007; Cong *et al.,* 2012). On the other hand, application of farm yard manures to soil provide benefits such as soil fertility, soil structure improvement, increased soil organic matter, better water holding capacity and organic carbon content (Sharif *et al.,* 2004). The use of organic manures generally ensures effective and efficient management of soil by providing nutrients in correct quantity and proportion in environmentally beneficial forms (Gruhn *et al.,* 2000). Despite their obvious utility to small-scale farmers, the ability of fertilizer resources to supply nutrients to crops has not been fully integrated. Consequently, there is a need to understand and improve the efficiency of soil nutrient sources under site specific conditions. There is also insufficient information on the responses of soil combined effects of legume integrated in maize cropping systems with application of organic and inorganic fertilizers. The current study evaluated the interactive effects of maize grown in rotation and/or intercropped with dolichos with application of FYM, TSP+Urea and TSP+FYM+Urea on soil organic carbon and soil moisture content in Nairobi County, Kenya.

4.1.2 Materials and Methods

The study was conducted at the University of Nairobi field station during the LRS of mid-March to May 2015 and SRS of October to December 2016. The experimental design was laid out in a randomized complete block design (RCBD) with split plot arrangement replicated three times.

Detailed descriptions of the site, experimental design, treatment and agronomic practices are as described in chapter 3 of this thesis.

4.1.3 Soil sampling and analysis

Soil samples for organic carbon determination were collected within the 0.2m depth between the plants in a row in every plot, using a 5 cm diameter soil auger at harvest time of each cropping season. The samples were air-dried for one week and sieved through 2 mm mesh and analyzed for soil organic carbon. The Walkley-Black wet oxidation method (Nelson and Sommers, 1982) was used. The percent soil organic carbon was determined using the following formulae:

$$\text{Organic carbon (\%)} = \frac{0.003\text{g} * N * 10\text{ml} * (1-T/S) * 100}{ODW}$$

Where:

N = Normality of K2Cr2O7 solution
T = Volume of FeSO4 used in sample titration (mL)
S = Volume of FeSO4 used in blank titration (mL)
ODW = Oven-dry sample weight (g)

Soil moisture (%) content was determined using the gravimetric method by (Black, 1965). Soil samples were collected at maize harvest using an auger within the 20 cm depth. Samples were put in a pre-weighed metal can and sealed tightly to minimize evaporation. They were then weighed (*mass of wet soil + container*). In the laboratory, the moist samples were placed in an oven at 105 ^{o} C for 24 hours. The dried samples were removed from the oven allowed to cool and re-weighed (*mass of dry soil + container).* The percent soil moisture content was determined using the following formulae:

$$\text{Moisture content \%} = \frac{(M_w + M_c) - (M_d + M_c)}{(M_d + M_c) - M_c}$$

Where: M_w - mass of wet soil
M_d – mass of dry soil
M_c – mass of container

4.1.4 Statistical Analysis

The effects of cropping system and application fertilizers on soil moisture and organic carbon were compared by analysis of variance (ANOVA) at plot level. The significant treatment means were separated using the Fisher's Protected Least Significant Differences $P \leq 0.05$.

4.1.5 Results and Discussion

4.1.5.1 Soil moisture as influenced by legume integration and fertilizer application in maize systems

There were significant increases in soil moisture content in maize/dolichos with application of FYM+TSP+Urea and FYM as compared to dolichos-maize and sole maize (Table 3) in the LRS. Higher moisture content was obtained in maize/dolichos with FYM application of which was not significantly different from dolichos-maize with FYM+TSP+Urea application in the SRS. Sole maize had significantly ($P \leq 0.05$) low moisture content across fertilizer inputs (Table 3).

Table 3: Effects of cropping systems and fertilizer application on soil moisture (%) content

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize	Mean
LRS	CONTROL	24.877^{ab}	25.745^{abc}	23.483^{a}	24.701^{a}
	FYM	30.091^{cd}	30.218^{d}	29.778^{cd}	30.033^{c}
	TSP/FYM/UREA	29.922^{cd}	30.385^{d}	29.562^{c}	29.961^{bc}
	TSP/UREA	28.502^{bcd}	28.167^{bcd}	27.639^{bcd}	28.101^{b}
	Mean	28.348^{a}	28.629^{a}	27.616^{a}	
SRS	CONTROL	22.354^{a}	22.646^{a}	23.106^{a}	22.702^{a}
	FYM	30.835^{cd}	31.769^{d}	31.329^{d}	31.311^{c}
	TSP/FYM/UREA	30.877^{d}	30.999^{d}	31.414^{d}	31.103^{c}
	TSP/UREA	27.816^{bcd}	27.734^{bcd}	29.435^{cd}	28.332^{b}
	Mean	27.971^{a}	28.287^{a}	28.821^{a}	

LSD: Cropping system*Treatment = 2.63
Season* Cropping system*Treatment = 3.72

Note: Within rows means followed by the same letters are not significantly different at P = 0.05 according to Fisher's Protected Least Significant Difference Test.

The increased soil moisture content with application of FYM and combined FYM+TSP+Urea in the intercropping system is attributable to addition to improved ground cover and increased amount of organic matter that results into improved soil structure and reduced water losses through soil erosion, reduced evapotranspiration following intercropping and moisture conservation by application of FYM. Wortman *et al.* (2012) reported increase in soil moisture under legume based plots only in the subsequent seasons. He attributed this to the improved soil physical properties such as improved water retention, good water holding capacity, increase in porosity and aggregate stability resulting in better soil moisture retention. This is also in agreement with Boateng *et al.* (2006) and Adeleye *et al.* (2010) who found out that higher level of FYM increased the soil water content. Higher soil moisture when intercropping with dolichos could also be as a result of increased shading provided which reduced evaporation from the soil surface. This is in agreement with (Ghanbari *et al.*, 2010) who reported improved soil moisture in intercropping compared with sole cropping due to increased shading hence reducing water loss through evaporation. There was reduced soil moisture in dolichos-maize rotation with TSP+FYM+Urea and TSP +Urea application in the SRS as compared to sole-maize. This could be attributed. This could have been possibly caused by the dolichos in rotation utilizing moisture for development hence depleting the soil profile of moisture. Hoyt and Leich (1983) observed lower soil moisture in plots following legumes attributing this to moisture depletion by legumes. Another reason could have been that dolichos developed ground cover more rapidly but maintained it for a shorter time hence protects the soil least at harvest Maina *et al.* (2000). The increase in soil moisture in the subsequent season was mainly because of increased amount of received rainfall (Table 3). Ngeve (2003) had also indicated that soil moisture is primarily determined by amount and intensity of received rainfall. This could also be explained in terms of increase in organic matter buildup due to slow nutrient release to the soil obtained from FYM addition thus improved soil structure and tilth, water retentions. This finding is similar with that of Wang *et al.*, (2012) also observed that organic manure application significantly ($P<0.05$) increased total porosity, field capacity and water retentions.

4.1.3.2 Soil organic carbon as influenced by legume integration and fertilizer application in maize systems

Significantly ($P \leq 0.05$) high soil organic carbon (SOC) content were obtained in dolichos/maize intercropping system with application of FYM and FYM+TSP+Urea having no significant difference in crop rotation as compared to monocrop in the LRS (Table 4).

However, the SOC content with application of FYM was not significantly different from that of combined application of FYM+TSP+Urea across dolichos/maize intercrop, dolichos-maize and sole maize. The sole maize had the lowest SOC across with application of fertilizers (Table 4). SOC was higher in dolichos/maize intercrop with FYM and TSP+FYM+Urea application although not significantly difference from dolichos-maize and sole maize in the SRS (Table 4).

Table 4: Effects of cropping systems and fertilizer application on soil organic carbon (%)

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize	Mean
LRS	CONTROL	1.961^{a}	1.963^{a}	1.925^{a}	1.949^{a}
	FYM	2.405^{efg}	2.487^{gh}	2.318^{def}	2.403^{de}
	TSP/FYM/UREA	2.341^{def}	2.414^{efgh}	2.284^{cde}	2.346^{d}
	TSP/UREA	2.158^{bc}	2.221^{cd}	2.149^{bc}	2.176^{b}
	Mean	2.216^{ab}	2.271^{bc}	2.169^{a}	
SRS	CONTROL	2.032^{ab}	2.006^{a}	2.004^{a}	2.014^{a}
	FYM	2.493^{gh}	2.555^{h}	2.449^{fgh}	2.499^{f}
	TSP/FYM/UREA	2.449^{fgh}	2.509^{gh}	2.420^{efgh}	2.459^{ef}
	TSP/UREA	2.241^{cd}	2.284^{cde}	2.221^{cd}	2.249^{c}
	Mean	2.304^{c}	2.338^{c}	2.273^{bc}	

LSD: Cropping system*Treatment = 0.02
Season* Cropping system*Treatment = 0.13

Note: Within rows means followed by the same letters are not significantly different at P = 0.05 according to Fisher's Protected Least Significant Difference Test.

The high soil organic carbon obtained across maize system with integration of dolichos and application of FYM and TSP+FYM+Urea in the SRS can be attributed to direct C input from manure and indirect C input through increased net primary production as crop residue incorporation into the plots, which lead to gradual buildup of SOC over time. These findings are in agreement with those of Whalen and Chang, (2002); Bhattacharyya et al., (2010) who reported high soil organic carbon levels in manured treatments under legume integration based systems. Higher SOC in soil realized with application of FYM can also be attributed to its slower decomposition rate and hence SOC build up. Ghimire *et al.* (2012) had also observed a buildup of soil organic carbon levels with organic fertilizer addition and incorporation of residues over time. There was no significant increase in SOC levels across intercrop, dolichos-maize and sole maize with FYM and TSP+FYM+Urea in the two seasons.

Buildup of organic carbon in soil can take a long time and this may partly explain lack of significant differences across the two seasons. Changes in soil organic carbon are slow and can take up to five years (Baldock, 2009). Kouyate *et al.* (2012) and Myaka *et al.* (2006) had also observed that integration of legumes within cropping systems did not improve SOC. Significant increase of SOC in dolichos/maize intercrop with combined fertilizer application TSP+FYM+Urea can be explained in terms of readily available nutrients supplied by TSP+Urea leading to increase uptake by crops hence enhanced yields. Crop yield enhancement translates to high biomass production and hence leaf senesce that contributes to soil organic matter. This is in agreement with Goyal et al. (1992) who found that addition of mineral fertilizers resulted in increased SOC contents. In their study, they also observed greater SOC contents following combined fertilizer application and this was mainly attributed to increased root growth associated with greater organic matter inputs. Additionally, higher organic C under dolichos/maize could be attributed to its higher biomass production offering less competition to the companion crop. This may have, as well, allowed the companion crop to develop more biomass. Cheruiyot *et al.* (2001) also observed greater increases in biomass production in maize following dolichos compared to other legumes.

4.1.4 Conclusion

The current study was carried out to investigate the effect of inorganic and organic fertilizers and cropping systems on soil organic carbon and moisture content in Kabete, Kiambu County during the 2015/2016 long-short rains. The highest levels of soil moisture and soil organic carbon were observed in maize/dolichos intercrop with application of FYM TSP+Urea as compared to Crop rotation and Monocrop during the SRS. The same trend in soil moisture and organic carbon levels was observed in LRS albeit with no significant differences compared with the SRS. Integration of legumes into cropping systems and combined application of fertilizers proved better at enhancing soil organic carbon levels and moisture content compared to other cropping systems. Improved soil moisture content and organic carbon translates into improved soil structure with good water holding capacity which enhances soil fertility and thus increased crop productivity.

To enhance soil fertility dolichos/maize intercrop alongside application of FYM and combined FYM TSP+Urea is the best bet technological package for increased productivity and sustainability of the smallholder farming systems of Kabete of Nairobi County.

4.2 EFFECT OF DOLICHOS (*Lablab purpureus* (L.) INTEGRATION WITH FERTILIZER APPLICATION ON N, P AND K BALANCES IN MAIZE (*Zea mays* L.) CROPPING SYSTEMS OF NAIROBI COUNTY, KENYA

Abstract

Calculation of soil nutrient balances is imperative in ascertaining effect of innovative technologies on soil fertility and sustainable crop production. A field experiment was carried out to evaluate the effect of dolichos integration and fertilizer application on soil N, P and K balances in a maize (*Zea mays* L.) cropping systems of Kabete Sub-county, Nairobi County. The experimental set up was a Randomized Complete Block Design with a split-plot arrangement replicated three times conducted between mid-March to May 2015 long rain season (LRS) and October to December 2015/16 short rain season (SRS). The main plots were the cropping systems; (i) mono-cropping (sole maize), (ii) intercropping (dolichos (*Lablab purpureus* (L.)/maize) and (iii) rotation (dolichos-maize). The sub-plots were fertilizer types: (i) farmyard manure; FYM), (ii) triple superphosphate (TSP) and urea, (iii) combined fertilizer (FYM +TSP + Urea) and (iv) no fertilizer input (control). N P and K balances were calculated using NUTrient MONitoring (NUTMON) Tool box. Averaged across the two seasons, less negative N balances (kg $ha^{-1}yr^{-1}$) were obtained in intercrop with FYM (-9.14) application and pronounced losses realized in maize/dolichos intercrop with TSP/Urea (-20.1) application. P losses (kg $ha^{-1}yr^{-1}$) were higher in maize/dolichos with TSP+FYM+Urea (-2.2) and TSP+Urea (-2.4) application. Less negative P balances (kg $ha^{-1}yr^{-1}$) were obtained in dolichos-maize rotation with the application of FYM (-0.4) and TSP+FYM+Urea (-0.2). Significantly ($P<0.5$) higher K losses (kg $ha^{-1}yr^{-1}$) were calculated across cropping systems; dolichos/maize intercrop with TSP+Urea (-6.7), dolichos-maize rotation with TSP+Urea (-4.9) and in monocrop with TSP+Urea (-4.53) application.

Dolichos-maize rotation with FYM (-0.2) application resulted in reduced K losses as compared to monocrop with FYM (0.4) and intercrop with FYM (-1.1) application. Negative N and P balances were pronounced in maize/dolichos intercrop and dolichos-maize rotation with application of FYM and TSP+FYM+Urea. Maize/dolichos intercrop with combined application of 5 t ha^{-1} FYM and 60 kg ha^{-1} TSP+Urea) ought to therefore be recommended, in the short run, with prudent nutrient management strategies for system sustainability.

Keywords: Fertilizers, Cropping systems; NUTMON; Nutrient Balances; Soil fertility

4.2.1 Introduction

In large parts of Kenya, declining soil fertility as a result of continuous cropping with little or no replenishment of nutrients removed through either crop harvests or other losses such as leaching has led to downward trend in food crop yields (Kibunja *et al.,* 2007). Consequently, poor soil fertility has emerged as one of the major biophysical constraint to increasing agricultural productivity hence threatening food security in Kenya (Mugwe *et al*., 2009). The Central highlands smallholder farmers in particular have been experiencing declining soil fertility and crop productivity (Kibunja and Mugendi 2010). This has led to emphasis to prioritize research on increasing crop productivity and alleviation of poverty among the smallholder farmers. Furthermore, the majority of the farmers of this region lack financial resources to access sufficient amount of chemical fertilizers to replace soil nutrients removed through harvested crop products (Jama *et al*., 2000) and crop residues. Additionally, application of mineral fertilizers has also faced important limitations due to high costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007). On the other hand, the use of organic fertilizer which is mostly available to maintain soil fertility is usually low in quality due to poor quality feeds offered to livestock (Lekasi *et al.,* 1998). Therefore, it is necessary to adopt improved and sustainable technologies in order to improve food productivity and thereby food security (Landers, 2007; Goletti and Yudelman, 2000). Such improved technologies include the use of integrated soil fertility management practices (ISFM) which involve intercropping cereals with legumes as one of its main components (Sanginga and Woomer, 2009).

This practice is an attractive strategy to smallholder farmers for increasing productivity and land labor utilization per unit area of available land through intensification of land use (Seran and Brintha, 2010). Furthermore, intercropping cereals with legumes have huge capacity to replenish soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen (Giller, 2001). To assess the impact of agricultural technologies on soil fertility and ensure future sustainability, calculation of nutrient balances is necessary (Vlaming *et al*., 2001), especially in Sub Saharan Africa where it is becoming increasingly difficult to satisfy short term production needs and long term sustainability demands concurrently (de Jager *et al*., 1998). Farm productivity can be measured by quantifying nutrient balances (Segala *et al*., 2010), which are useful indicators in assessing the sustainability of farming systems (de Jager *et al*., 1998). A soil nutrient balance is a commonly used indicator to assess changes in soil fertility (Roy et al. 2003). Stoorvogel and Smaling (1990) introduced a soil nutrient balance as a net balance of five inflows and five outflows, which indicates whether an agricultural system is a net winner or loser in terms of soil fertility. NUTMON (now known as MonQi), a nutrient monitoring tool, has been applied to study ecological sustainability of various nutrient management strategies in different environments (Priess et al., 2001; Onwonga *et al.*, 2015). The current study monitored effects of fertilizer application and legume integration in maize systems on soil nutrient flows and balances as a basis for determining their system sustainability.

4.2.2 Materials and Methods

The study was conducted at the University of Nairobi field station during the LRS of mid-March to May 2015 and SRS of October to December 2016. The experimental design was laid out in a randomized complete block design (RCBD) with split plot arrangement, replicated three times. Detailed descriptions of the site, experimental design, treatment and agronomic practices are as described in chapter 3 of this thesis.

4.2.2.1 Soil sampling and analysis

Soil samples for quantification of nutrient flows was randomly collected within the 0.2m depth between the plants within a row in every plot, using a 5cm diameter soil auger.

Samples for nutrient content N, P and K analysis were thereafter collected at harvest from each plot. The samples were air-dried and sieved through 2 mm mesh before laboratory analysis. Soil P was determined using the Mehlich III Double Acid method (Mehlich *et al.,* 1984). Total N was determined by Kjeldahl digestion method (Black, 1965; Anderson and Ingram, 1993) and K was measured by Flame Emission Spectrophotometry (Jonca and Lewandoski, 2004). Soil texture was determined using hydrometer method (Black et al., 1965). Undisturbed core samples were used in bulk density determination (Blake and Hartge, 1986).

4.2.2.2 Plant sampling and analysis

Grain and stover samples were oven dried at 70 ^{o}C to a constant weight. Grain and dry matter (DM) yields were determined at harvest, within a quadrat area of 1m^2 from three center rows of each sub plot. For dry matter measurement, plant stems were cut immediately above ground and weighed to determine fresh weight. Sub-samples were taken to the laboratory and oven dried at 70°C for 48 hours and thereafter weighed for dry matter determination.

4.2.3 Quantification of Nutrient Balances

The NUTmon MONitoring (NUTMON) Tool box was used in quantification of nutrient (N, P and K) flows and balances. NUTMON-Toolbox is user friendly computerized software for monitoring nutrient flows and stocks especially in tropical soils (Vlaming *et al.,* 2001). The toolbox has within it a structured questionnaire, a database and a simple static model. Data entry and extraction is possible from the database through a user interface to produce inputs for the model. A detailed description of the model is provided in the NUTMON manual (Vlaming *et al*. (2001); Surendran and Murugappan, (2006) and also on www.monqi.org website.

4.2.3.1 Farm Conceptualization

In NUTMON, farms are conceptualized as a set of dynamic units depending on management, from the source and destination of nutrient flows. Consequently, the following units relevant to the current study are defined: Farm Section Unit (FSU), these are areas within the farms with relatively homogenous properties; Primary Production Unit (PPU)/crop activities, formed the piece of land with different possible activities such as one or more crops which are either annual or perennial. These units are located within FSUs; Stock, the amount of staple crops, residues and fertilizers temporarily stored for later use; Outside (EXT): external nutrient pool consisting of markets (de jager et al., 1998). The study as presented aims to assess the nutrient balances at primary production unit and the method used was adjusted to enable generation of output within an experimental area. Consequently, the blocks/replicates involving either of the legumes were the equivalent of the FSU, the primary production units (PPUs) were the plots comprising of the 12 treatments (Table 2). In line with De Jager *et al*. (1998), the modified concept upheld nutrient inputs (Table 5) through mineral fertilizer (IN 1) but omitted that through subsoil exploitation (IN 6) because of the shallow to moderate rooting depths (0-20cm) of the crops involved. Fertilizers (IN 1-TSP/Urea and IN 2-FYM) were identified as nutrient flows into PPU, (IN 3) atmospheric deposition and (IN 4) biological nitrogen fixation and returned plant residue (OUT 2). Nutrient output flows were identified as crop harvest (OUT 1), leaching (OUT 3), volatilization (OUT 4) and soil erosion (OUT 5) Flows and balances of N, P and K were calculated at the end of the experimental period through independent assessment of the major inputs and outputs.

Table 5: Sources of nutrient flows into and out of the farm

IN flows	OUT flows	Internal flows
IN1 Inorganic fertilizers	OUT1 Harvested products	FL1 Feeds
IN2a Organic inputs: purchased manure and feeds	OUT2 Crop residues and manure	FL2 Household waste
IN2b Organic inputs: manure from grazing outside the farm	OUT3 Leaching	FL3 Crop residues
IN3 Atmospheric deposition	OUT4 Gaseous losses	FL4 Grazing of vegetation
IN4 N-fixation	OUT5 Erosion	FL5 Animal manure
IN5 Sedimentation	OUT6 Human excreta	FL6 Farm products to household

Source: De Jager *et al*. (1998)

4.2.3.2 Types of formula for calculating nutrient balances

To distinguish between primary data and estimates, two different balances were calculated in NUTMON: the partial balance at farm level (IN1 + IN2) - (OUT1 + OUT2) made up solely of primary data and the full balance (ALL IN - ALL OUT) made up of a combination of the partial balance and the emissions (atmospheric deposition and nitrogen fixation) and emissions (leaching, gaseous losses, erosion losses) from and to the environment (Vlaming *et al.,* 2001). In this study, particular interest was on how the cropping systems affect the full balances of major nutrients, N, P and K in soil after harvest. Calculation of nutrient balances therefore involves a number of methods: Product flows for N, P and K sampling and analysis (IN 1 and IN2 and OUT1 and OUT 2) and use of transfer functions (IN3, IN4 and IN 5, and OUT 3, OUT4, OUT5 and OUT6) (van den Bosch *et al.,* 1998).

4.2.3.3 Use of Transfer Functions and Assumptions

Transfer functions are used in estimating those flows which cannot be obtained by simple measurements namely IN-3, IN-4, OUT-3, OUT-4 and OUT-5. Transfer functions explain variables which are difficult to obtain as a function of parameters which are easy to obtain (Smaling 1996 and Stoorvogel 1990). NUTMON-toolbox calculated nutrient balances by subtracting sum of nutrient outputs from sum of nutrient inputs and presents then in Kg ha^{-1}.

$$Nutrient\ balance_{(N,P,K)} = \left[\sum Inputs(2,3,4)\right] - \left[\sum Outputs(1,2,3,4,5)\right]$$

Where:

Inputs 2-4 are nutrient contained in: In 2- Organic inputs, IN 3-Atmospheric deposition, IN 4 Biological nitrogen fixation. Outputs 1-5 are nutrients contained in: OUT 1-Harvested products, OUT 2- Removed crop residues, OUT 3-Leaching, OUT 4-Volatization, OUT 5-Runoff/erosion.

Positive balances indicated that nutrients were accumulating in the soil and negative balances indicate that the soil is being mined off nutrients (Nandwa et al., 2001).

4.2.4 Statistical Analysis

The N, P, and K balances for the various PPUs were generated by NUTMON-toolbox and then exported to GenStat 15th Edition, 2012 for further analysis.

The effects of cropping system and fertilizers on soil nutrient balances were compared by analysis of variance (ANOVA) at plot level and separated using the Fisher's Protected Least Significant Differences ($P \leq 0.05$).

4.2.5 Results and Discussion

4.2.5.1 Nitrogen Balances

Averaged across the two seasons, significantly ($P \leq 0.05$) less negative N balances were obtained in maize/dolichos intercrop with FYM application. However, there was no significant difference in dolichos-maize rotation and sole maize with FYM application (Table 6).

Table 6: Effect of cropping systems and fertilizers on N (Kg ha^{-1} yr^{-1}) balances

Cropping System	Fertilizers	N balance (Kg ha^{-1} yr^{-1})
Maize (M)	CTRL	-6.8^{c}
	FYM	-14.53^{ab}
	FYM+TSP+UREA	-14.73^{ab}
	TSP+UREA	-11.4^{bc}
Dolichos -Maize	CTRL	-9.4^{bc}
	FYM	-11.07^{bc}
	FYM+TSP+UREA	-15.13^{ab}
	TSP+UREA	-14^{ab}
Maize/dolichos	CTRL	-10.73^{bc}
	FYM	-9.14^{bc}
	FYM+TSP+UREA	-15.67^{ab}
	TSP+UREA	-20.13^{a}
LSD 0.05	Cropping System (CS)	2.961

Key: CTRL = no input; TSP = Triple superphosphate; FYM =Farmyard Manure. Means in a column followed by the same letter(s) are not significantly different at *P* = 0.05 according to Fisher's Protected Least significant Difference Test.

More negative N balances were noted in intercropping and dolichos-maize rotation with application of TSP+Urea and TSP+FYM+Urea. Control treatment showed less negative N across all cropping systems. Negative N balances across all treatments could be attributed to nutrient removal in harvested products. Fatima *et al*. (2008) noted that nutrient removal of above ground plant parts through harvesting has implications on residual effect of legumes on N balance in soil. Ndufa (2001) also noted low levels of soil N in continuously cropped maize even after residue incorporation in soil.

Less negative N balances obtained in intercrop with application of FYM and Control could be attributed to supply of N through biological nitrogen-fixation (BNF) by dolichos and decomposition of its incorporated residues. However, these amounts may have been insufficient to reduce higher crop N uptake hence the negative N balance. Highest losses of N in intercrop with TSP+Urea and in crop rotation with TSP+FYM+Urea application could have been as a result of higher N accumulation by maize which was removed through harvested products. Additionally, this could be due to high input of TSP+Urea leading to high N levels being lost through leaching and gaseous loss. Kroeze *et al.* (2003) attributed negative nitrogen balance to the high outflow of nitrogen through harvested products and leaching.

4.2.5.2 Phosphorus Balances

Significant ($P \leq 0.05$) less negative P balances were obtained in crop rotation system with the application of FYM compared to intercrop and monocrop. The intercrop system with TSP+Urea application obtained higher negative P balances compared to FYM+TSP+Urea and FYM. The maize-dolichos rotation had significantly more negative P balances with control treatment compared to monocrop and intercrop (Table 7).

Table 7: Effect of cropping systems and fertilizers on P (Kg ha^{-1} yr^{-1}) balances

Cropping System	Fertilizers	P balance (Kg ha^{-1} yr^{-1})
Maize (M)	CTRL	-1.333^{cd}
	FYM	-1.933^{abc}
	FYM+TSP+UREA	-1.966^{abc}
	TSP+UREA	-1.433^{cd}
Dolichos-Maize	CTRL	-2.3^{ab}
	FYM	-0.367^{e}
	FYM+TSP+UREA	-0.467^{de}
	TSP+UREA	-0.491^{e}
Maize/dolichos	CTRL	-1.966^{abc}
	FYM	-1.533^{bcd}
	FYM+TSP+UREA	-2.166^{abc}
	TSP+UREA	-2.4^{a}
LSD 0.05	**Cropping System (CS)**	**0.3753**

Key: CTRL = no input; TSP = Triple superphosphate; FYM =Farmyard Manure. Means in a column followed by the same letter(s) are not significantly different at P = 0.05 according to Fisher's Protected Least significant Difference Test.

Higher negative P balances were realized even with addition of P through TSP+FYM+Urea and TSP+Urea in intercrop. The additional supply of P from TSP could have contributed to increased root development hence better P uptake and plant growth eventually resulting to more negative P balances due to its subsequent removal in harvested products. Grant *et al*. (2001) noted that plants require adequate P from the very early stages of growth for optimum crop production. Nuruzzaman *et al*. (2005) also documented that the presence of a legume in a cropping system often increases P uptake for the subsequent crop in rotation or companion crop in an intercropping system. Onwonga *et al*. (2015) also noted that legumes had significantly higher yields and attributed the same to their efficiency in P acquisition from soils. Integration of lablab into the cropping systems resulted in higher P balances as compared to sole maize cropping system. Veneklaas 2007 and Pearse 2006) revealed that more P was lost through crop uptake under dolichos based cropping system and this could be attributed to acquisition P efficiency by the legume. Dolichos-maize rotation with TSP+FYM+Urea application resulted in significantly ($p \leq 0.05$) more negative P balances (Table 7). This was due to higher P input through FYM as well as higher biomass production, which could have led to more P release upon decomposition.

Mpairwe *et al.* (2002) had also noted an increased biomass production due to application of manure and that the main contributing factor was the uptake of P through biomass which was removed at harvest. Bauer and Black, (1994) similarly observed that plant productivity was closely linked to organic matter available for decomposition hence affecting the quantity of P released.

4.2.5.3 Potassium Balances

Averaged across the two seasons, less K negative balances were realized in FYM across monocrop, dolichos/maize and rotation as compared to TSP+FYM+Urea and TSP+Urea. Higher negative balances were obtained in intercrop with control treatment having no significant difference in crop rotation and monocrop. There was a significant ($P \leq 0.05$) more K negative balance in intercrop with application of TSP+Urea compared to monocrop and crop rotation (Table 8).

Table 8: Effect of cropping systems and fertilizers on K (Kg ha^{-1} yr^{-1}) balances

Cropping System	Fertilizers	K balance (Kg ha^{-1} yr^{-1})
Maize (M)	CTRL	-1.933^{de}
	FYM	-0.4^{ef}
	FYM+TSP+UREA	-2.867^{bcd}
	TSP+UREA	-4.533^{bc}
Dolichos-Maize	CTRL	-2.667^{cd}
	FYM	-0.201^{ef}
	FYM+TSP+UREA	-2.133^{de}
	TSP+UREA	-4.933^{ab}
Maize/dolichos	CTRL	-3^{bcd}
	FYM	-1.133^{f}
	FYM+TSP+UREA	-3.067^{bcd}
	TSP+UREA	-6.666^{a}
LSD 0.05	**Cropping System (CS)**	**0.944**

Key: CTRL = no input; TSP = Triple superphosphate; FYM =Farmyard Manure. Means in a column followed by the same letter(s) are not significantly different at *P* = 0.05 according to Fisher's Protected Least significant Difference Test.

Negative K balances with addition of TSP+FYM+Urea across all cropping systems shows that nutrient inputs were more than outputs through harvested products and other nutrient loss pathways. This also confirms observation by Murugappan *et al.* (1999) that mining of soil K always occurred regardless of whether K is added or not due to luxury consumption of K by most crops. Higher negative K balances in intercrop with TSP+Urea application were due to soil nutrient uptake and removal in harvested products. Onwonga *et al.* (2008) noted that in legume rotations, increase in yield corresponded to K acquisition hence its decline in soil. This is also in agreement with Fermont *et al.* 2007 who found that intercropping systems increased nutrient losses due to harvest of combined products at the same time. Potassium losses from soil commonly occur via leaching to greater depths, which is influenced by the production system.

4.3 Conclusion

Averaged across the two seasons, less negative N balances were obtained in maize/dolichos intercrop with FYM application. Pronounced higher N losses were realized in maize/dolichos intercrop with TSP/Urea application. P losses were higher in maize/dolichos intercrop with TSP+FYM+Urea and TSP+Urea application. Less negative P balances were obtained in dolichos-maize rotation with application of FYM and TSP+Urea.

Significantly ($P \leq 0.05$) higher K losses were observed across cropping systems; dolichos/maize intercrop, dolichos-maize rotation and monocrop with TSP+Urea application. Dolichos-maize rotation with FYM application resulted in reduced K losses as compared to Monocrop and intercrop. Negative N and P balances were pronounced in maize/dolichos intercrop and dolichos-maize rotation with application of FYM and TSP+FYM+Urea. Stronger nutrient losses across cropping systems were mainly due to removal of harvested products from the soil as well as losses due to leaching. Inclusion of legumes in the cropping system led to more P and K losses as compared to sole maize though N losses were minimized when dolichos was used. The study showed that rotation could be preferred to intercropping so as to reduce NPK losses. Increased crop residues incorporation would also minimize the soil nutrient losses.

4.3 EFFECTS OF DOLICHOS OF INTEGRATION (*Lablab purpureus*) WITH FERTILIZER APPLICATION ON SOIL NUTRIENTS STATUS AND MAIZE YIELDS IN MAIZE (*Zea mays* L.) CROPPING SYSTEMS OF NAIROBI COUNTY, KENYA

Abstract

Inherent low soil fertility combined with unsustainable agricultural practices is the main contribution to low maize productivity in Central Kenya. Against this backdrop, this study investigated the effects of integration of dolichos and fertilizer application on soil nutrients status and maize yields in maize cropping systems of Kabete Sub-county, Nairobi County. The field experiment was conducted between mid-March to May 2015 long rain season (LRS) and October to December 2015/16 short rain season (SRS). The experimental setup was laid out in a Randomized Complete Block Design with a split-plot arrangement replicated three times. The main plots were the cropping systems; (i) mono-cropping (sole maize), (ii) intercropping (dolichos (*Lablab purpureus* (L.)/maize) and (iii) rotation (dolichos - maize). The sub-plots were fertilizer types: (i) farmyard manure; (FYM), (ii) (triple superphosphate (TSP) and urea), (iii) combined fertilizer (FYM +TSP + Urea) and (iv) no fertilizer input (control). Soil samples were taken at 0-20 cm depth for determination of soil nutrient status; nitrogen (N), phosphorus (P) and potassium (K) at the end of each cropping season.

Significantly ($P \leq 0.05$) high soil N and P levels were obtained in maize/dolichos intercrop with application of FYM (0.3% and 22.6 ppm; 0.29% and 19.6 ppm) and TSP+FYM+Urea (0.28% and 22.5 ppm; 0.3% and 16.5 ppm) during the LRS and SRS respectively. The soil K levels were significantly ($P \leq 0.05$) higher in maize/dolichos intercrop with FYM (1.32 cmol/Kg and 1.83 cmol/Kg) application during the SRS and LRS respectively. Maize grain yields in the SRS were significantly ($P \leq 0.05$) higher in dolichos/maize intercrop with application of TSP+FYM+Urea (7.1 t ha^{-1}) and FYM (7.0 t ha^{-1}). Likewise, significantly ($P \leq 0.05$) higher maize grain yields were obtained in dolichos/maize intercrop with TSP+FYM+Urea (5.2 t ha^{-1}) and TSP+Urea (5.2 t ha^{-1}) during the LRS. Dolichos-maize rotation with TSP+FYM+Urea application resulted in significantly higher dry matter yields (17.9 t ha^{-1}) compared to intercrop with TSP+Urea (19.6 t ha^{-1}) application in the SRS. When compared across the two seasons, soil N, P and K were significantly high in maize/dolichos intercrop with application of FYM and TSP+FYM+Urea in SRS. Significant ($P \leq 0.05$) higher dry matter yields were obtained in dolichos-maize rotation with FYM application and higher grain yields were realized in intercrop with application of FYM and TSP+FYM+Urea in SRS as compared to the LRS. It is evident that improved nutrient status in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea translated into increased maize yields. With the increase in yields, significant nutrient losses were realized. To optimize NPK concentration in the soils, to ensure enhanced soil fertility with increased maize productivity, intercropping maize with dolichos with FYM and TSP+FYM+Urea is a viable and sustainable option for the smallholder farmers of Nairobi County.

Key words: Cropping systems, Fertilizers; Soil nutrients; Maize yields; Soil fertility

4.3.1 Introduction

Maize (Z*ea mays L)* is one of the most important cereals widely adapted worldwide (Christian, 2012). In Kenya, maize is a major staple food and food security crop grown by every smallholder farmer (KARI, 2002). Its production is however on a downward trend with declining soil fertility as the most widespread, dominant limitation on yields of Maize (Mugwe *et al.,* 2009).

Soil fertility degradation is recognized as a major factor underlying the low crop productivity in sub-Sahara Africa (SSA) and affects the livelihoods of the majority of the population that depends directly on agriculture for food and income (Sanchez, 2002). Several reasons for the declining soil fertility have been advanced and these among others include continuous unsustainable cropping system leading to soil nutrient depletion and likely soil degradation thus posing serious threats to maize productivity (Henao and Baanante, 2006). Since smallholder farmer's crop productivity remains the main system of intensive farming in Central Kenya, there is a need for developing technologies that will enhance the productivity of this basic system. Following widespread popularity of inorganic fertilizer sources used in agriculture since the 1940's, the use of inorganic fertilizer became the natural complementary option that received the attention of agriculturists in an effort to boost soil productivity (Omotayo and Chukwuka, 2009). However, application of inorganic fertilizers has also faced important limitations due to high costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007). Preferential application of fertilizers on the other hand has also led to development of fertility gradients on smallholder farms (Tittonell, 2003) and farmers continue to apply blanket fertilizer recommendations leading to variations in crop yields (Tittonell *et al*., 2007). Consequently, there is growing need to develop techniques for improving soil fertility without causing damage to the environment and that are within the farmer's socio-economic circumstances (Topliantz *et al.*, 2005). The addition of organic sources could increase maize yield through improving soil fertility and higher fertilizer use efficiency (Gangwar *et al.*, 2006). However, as much as most farmers use organic fertilizer which is mostly available to maintain soil fertility, different organic resources have differing chemical compositions that determine residue decomposition rates, consequently affecting nutrient release rates and patterns, which are in part controlled by the resource quality of the materials (Giller and Cadisch, 1997). Higher and sustained yield could be obtained with judicious and balanced fertilization combined with organic manures and integration of legumes for ecological balance, low cost cultivation, clean environment and nutritious food without affecting human health (Bhatti *et al.*, 2008). Proper application of organic and inorganic fertilizers can increase the activities of soil micro-organisms and soil available nutrient contents (Saha *et al.*, 2008). The inclusion of legumes in cereal systems allows cereals to benefit from the N that is fixed by legumes.

Intercropped legumes fix most of their nitrogen from the atmosphere and not compete with maize for nitrogen resources (Adu-Gyamfi *et al.*, 2007; Vesterager *et al.*, 2008). However, there is limited information available on the quantities of combined fertilizers that should be applied to the cropping systems in central Kenya. Hence, this study undertakes to bring more insights on existing different soil fertility management strategies in different cropping systems of Central Kenya. Therefore, the present study was carried out to evaluate the effects of the integration of dolichos with inorganic and organic fertilizers on maize yields and soil nutrients in Nairobi County, Kenya.

4.3.2 Materials and Methods

The study was conducted at the University of Nairobi field station during the LRS of mid-March to May 2015 and SRS of October to December 2016. The experimental design was laid out in a randomized complete block design (RCBD) with split plot arrangement, replicated three times. Detailed descriptions of the site, experimental design, treatment and agronomic practices are as described in chapter 3 of this thesis.

4.3.3 Soil, plant sampling and analysis

Composite soil samples for determination of initial physical and chemical properties were collected within the 20 cm depth by zigzag random sampling method, before application of treatments (Table 1). Samples for nutrient status N, P and K analysis were thereafter collected at harvest from each plot. The samples were air-dried and sieved through 2 mm mesh before laboratory analysis. Soil P was determined using the Mehlich III Double Acid method (Mehlich *et al.*, 1962). Total N was determined by Kjeldahl digestion method (Black**,** 1965; Anderson and Ingram, 1993). Exchangeable K was measured by Flame Emission Spectrophotometry, whereas (Mc Lean, 1982). Grain and dry matter (DM) yields were determined at harvest, within a quadrat area of 1m^2 from three center rows of each sub plot. For dry matter measurement, plant stems were cut immediately above ground and weighed to determine fresh weight.

4.3.4 Grain and DM yield determination

Crop (adjusted to 13% moisture content) grain and dry matter yield (70 ^{0}C) was determined at physiological maturity from three center rows of each plot. The average numbers of seeds per plant/plot were obtained. The final grain yield was determined by weighing all the seeds from the sampled plants per plot and converting the yield to kg ha^{-1}. The grain and DM yields were expressed on hectare basis: Grain yield (kg/ha) = Grain yield/m^2 (kg) x 10000 (t/ha)…….. (i)

4.3.5 Statistical Analysis

The data recorded on soil nutrients status and maize yields were subjected to statistical analysis of variance using GenStat statistical software (Payne *et al.*, 2006). The significant treatment means were compared and separated using the Fisher's Protected Least Significant Differences P ≤ 0.05 at a probability level of 5%.

4.3.5 Results and Discussion

4.3.5.1 Soil Nutrient Concentrations

4.3.5.2 Available Phosphorus

Higher soil P was obtained in intercrop with FYM and TSP+FYM+Urea application. However it was not significantly different in dolichos-maize rotation and monocrop with FYM and TSP+FYM+Urea application. Control treatment had low amount of P with significant difference across monocrop, intercrop and crop rotation in the LRS (Table 9). Significant ($P \leq 0.05$) differences in P level were observed in monocrop with TSP+FYM+Urea and FYM application with no significant difference in intercrop and crop rotation during SRS. Control treatment had higher amount of P as compared to the LRS with no significant difference across all cropping systems (Table 9).

Table 9: Effect of cropping systems and fertilizer application on available P (ppm)

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize
LRS	CONTROL	11.4^{a}	11.0^{a}	11.0^{a}
	FYM	17.1^{abcde}	19.6^{abcdef}	17.2^{abcde}
	TSP/FYM/UREA	13.3^{ab}	16.5^{abcde}	14.6^{abc}
	TSP/UREA	15.4^{abc}	16.1^{abcd}	16.0^{abcd}
	Mean	14.31a	15.79^{a}	14.73^{a}
SRS	CONTROL	15.5^{abc}	16.8^{abcde}	15.1^{abc}
	FYM	26.9^{bcdef}	28.5^{cdef}	26.1^{bcdef}
	TSP/FYM/UREA	29.6^{def}	26.1^{bcdef}	31.1^{f}
	TSP/UREA	28.6^{cdef}	27.18^{b}	29.4^{ef}
	Mean	24.29^{b}	24.66^{b}	25.43^{b}

L.S.D Cropping system * Treatment = 8.157
Season*Cropping System* Treatment =11.54

Note. Within rows means followed by the same letters are not significantly different at $P < 0.05$.

FYM and TSP+FYM+Urea were more effective in increasing P as compared to other treatments across cropping systems during SRS. This could be attributed to FYM decomposition and subsequent release of nutrients as well as decomposition of higher amounts of crop residue that were produced with FYM application. Monocropping maize with FYM and TSP+FYM+Urea led to significantly higher soil P as compared to rotation and intercrop in SRS. This could be due to export of P to the legume crop. Kouyate *et al.,* (2012) observed higher soil P under monocropped sorghum compared to ration with legumes attributing to export of P to grains. They further noted that P losses from soil increase with increasing grain yields due to most of the P being transported to the grain, involvement of legumes could also have resulted in less soil P due to higher uptake of P by legumes which is essential in BNF and root development (Cassman *et al.,* 1981). Furthermore, it has been demonstrated that legumes can increase uptake of P for the companion crop when intercropped or rotated (Li *et al.,* 2004). Maize/dolichos however resulted in significantly ($P \leq 0.05$) higher soil P with FYM application compared to monocrop and rotation in both seasons. This was probably due to the ability of legumes to solubilize insoluble P. Higher P under legumes has also been reported by Bagayoko *et al.,* 2000 and Li *et al.,* 2008 attributing this to mobilization of soluble P by legumes exudates. Another reason for increase in P levels could be due to addition of soil P through decomposition of residues due to higher biomass production through inclusion of dolichos.

Better litter quality of dolichos may also have been contributing factor to increased P levels, this also observed by Ayoub (1986) who attributed this to better mineralization. Significant P level was obtained in SRS as compared to the LRS. The higher amounts of soil available P in SRS may have been due to the residual effects of FYM. According to Rowell *et al.*, (1994), the rapid adsorption of P onto soil particle surfaces is followed by a slower conversion into less available forms including mineral phosphates, thus P in the FYM is available in the LRS after application but remains over long periods of time hence their residual effects. Negassa *et al.* 2005, studying the integrated use of farmyard manure and NP fertilizers for maize in Oroma, Ethiopia reported that FYM had significant residual effect on grain yield.

4.3.5.3 Total Nitrogen

Higher nitrogen levels were obtained in Maize/dolichos intercrop with application of FYM and TSP+FYM+Urea during SRS. There were no significant differences in nitrogen levels across cropping systems with application of FYM, TSP+FYM+Urea and TSP+Urea (Table 10) in both seasons.

Table 10: Effect of cropping systems and fertilizer application on available N (%)

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize
LRS	CONTROL	0.2011^{a}	0.1849^{a}	0.1974^{a}
	FYM	0.2922^{bc}	0.2999^{bcd}	0.2798^{bc}
	TSP/FYM/UREA	0.2703^{bc}	0.3043^{bc}	0.2886^{bc}
	TSP/UREA	0.2908^{bc}	0.2724^{bc}	0.2782^{bc}
	Mean	0.2685^{ab}	0.2654^{ab}	0.2659^{ab}
SRS	CONTROL	0.1966^{a}	0.1949^{a}	0.193^{a}
	FYM	0.292^{bcd}	0.3356^{c}	0.2948^{bc}
	TSP/FYM/UREA	0.2589^{b}	0.280^{bc}	0.2764^{bc}
	TSP/UREA	0.2788^{bc}	0.3018^{bc}	0.2787^{bc}
	Mean	0.2585^{a}	0.2859^{b}	0.2574^{a}

L.S.D Cropping System*Treatment = 0.029

Note. Within rows means followed by the same letters are not significantly different at $P < 0.05$.

The control treatment had significantly lower ($P<0.05$) levels of N across cropping systems. This could be due to no input addition to soil for N uptake of by maize for its growth and development.

Besides there was no legume crop in this treatment that could supply N through biological nitrogen fixation. Significantly ($P \leq 0.05$) higher soil N was obtained in with FYM and TSP+FYM+Urea application across all the cropping system. This could be attributed to direct addition of N to the soil as FYM and TSP+FYM+Urea mineralized as well as crop residue addition. Higher soil organic matter due to addition of FYM has shown to closely correlate with the amount of N in the soil (Kapkiyai *et al.,* 1999). Adekayode and Ogunkoya (2011) observed higher N content in plots treated with FYM attributing this to direct input of N and ability of manure to make N available for a long time due to slower release of N from the high residual pool. Higher N levels were obtained in intercrop with FYM application as compared to monocrop and rotation. Higher N with dolichos inclusion compared to monocrop could be attributed to higher fixation of nitrogen in addition to litter quality. Ayoub (1986) also observed higher rates of nitrogen release though biological fixing and decomposition under dolichos based. It has also been reported that intercropping may result in increased amount of nitrogen fixed by legumes as the companion non-fixing if they accumulate (Li *et al.,* 2003). A significant amount of N can be added to soil through BNF which is then made available to the same crop or subsequent crops (Wortmann *et al.,* 2000).

4.3.5.3 Available Potassium

Significantly ($P \leq 0.05$) higher amount of K was observed in intercrop with FYM application as compared to monocrop. However, there was no significant difference in K levels in crop rotation with FYM application. The control treatment had low K levels across monocrop, crop rotation and intercrop in the LRS (Table 11). The same trend was observed across all cropping systems with fertilizer application in the SRS.

Table 11: Effect of cropping systems and fertilizer application on available K (Cmol/Kg)

Season	Treatment	Dolichos-Maize	Maize/dolichos	Maize	Mean
LRS	CONTROL	1.144^{abcde}	1.169^{abcde}	1.067^{ab}	1.127^{a}
	FYM	1.714^{fg}	1.832^{f}	1.622^{f}	1.723^{d}
	TSP/FYM/UREA	1.635^{f}	1.574^{f}	1.638^{f}	1.616^{c}
	TSP/UREA	1.600^{f}	1.684^{fg}	1.546^{f}	1.610^{c}
	Mean	1.523^{bc}	1.565^{c}	1.468^{b}	
SRS	CONTROL	1.082^{ab}	1.102^{abc}	1.009^{a}	1.064^{a}
	FYM	1.270^{cde}	1.316^{e}	1.281^{b}	1.281^{b}
	TSP/FYM/UREA	1.273^{cde}	1.294^{de}	1.282^{b}	1.282^{b}
	TSP/UREA	1.318^{e}	1.225^{bcde}	1.251^{b}	1.251^{b}
	Mean	1.236^{a}	1.234^{a}	1.188a	

L.S.D Cropping System* Treatment =9
Season* Cropping System* Treatment = 0.1199

Note: Within rows means followed by the same letters are not significantly different at $P < 0.05$.

Soil K increased as compared to the initial values across the cropping systems and seasons. Increase of K in maize/dolichos with FYM application is as a result of input of K through residue decomposition as well as fertilizers. This could be attributed to the slow buildup of organic matter due to incorporation of residues and FYM which lead to an increase in soil K (Gikonyo and Smithson 2003). Kapkiyai *et al.,* (1999) also showed a closer link between amount of soil organic matter and the quantity of available K. Maize/dolichos had significantly higher K compared to sole maize in both seasons. This could be attributed to higher biomass production which ensured more K release upon decomposition. Dolichos-maize and sole maize did not increase soil K in season 2. Bagayoko *et al.,* (2000) showed that sole cropping, intercropping and rotation of millet and cowpea led to a decline in K levels. Murugappan *et al.,* (1999) similarly reported that crops tend to have luxury consumption of K, which could lead to decline in soil K. Soil K significantly reduced in the SRS compared with the LRS. These losses are more pronounced especially when the biomass is removed as most losses of K occur through removal of above-ground biomass (Smaling, 1993). Additionally, removal of above ground biomass could have led to less marked increase in soil organic matter hence K decline.

4.3.5.5 Maize Grain Yields

Significantly ($P \leq 0.05$) higher maize grain yields were obtained in dolichos/maize intercrop system with application of TSP+FYM+Urea and TSP+Urea as compared to monocrop in the LRS. However the yields were not significantly different with FYM application in intercrop and monocrop (Table 12)**.**

Table 12: Effect of cropping systems and fertilizer application on Maize grain and dry matter yields (t/ha)

Seasons	**Cropping System**	**Treatment**	**Grain Yields (t/ha)**	**Dry matter Yields (t/ha)**
LRS	Crop rotation	CONTROL	2.540^{abc}	6.14^{ab}
		FYM	3.502^{cde}	11.18^{cdefg}
		TSP/FYM/UREA	4.811^{ef}	12.09^{defgh}
		TSP/UREA	4.775^{ef}	7.59^{abcd}
	Intercrop	CONTROL	1.972^{ab}	4.03^{a}
		FYM	4.707^{ef}	6.01^{ab}
		TSP/FYM/UREA	5.198^{f}	9.03^{bcd}
		TSP/UREA	5.164^{f}	8.80^{bcd}
	Monocrop	CONTROL	1.653^{a}	3.91^{a}
		FYM	4.279^{def}	10.39^{bcdef}
		TSP/FYM/UREA	4.763^{ef}	8.13^{abcd}
		TSP/UREA	4.733^{ef}	10.84^{cdefg}
SRS	Crop rotation	CONTROL	3.497^{cde}	9.48^{bcde}
		FYM	5.301^{f}	16.39^{hij}
		TSP/FYM/UREA	6.756^{gh}	17.90^{ij}
		TSP/UREA	6.669^{gh}	14.96^{fghi}
	Intercrop	CONTROL	3.052^{bcd}	8.09^{abcd}
		FYM	7.062^{h}	11.53^{defg}
		TSP/FYM/UREA	7.100^{h}	13.7^{efghi}
		TSP/UREA	6.678^{gh}	19.56^{j}
	Monocrop	CONTROL	2.519^{abc}	6.61^{abc}
		FYM	5.543^{fg}	15.28^{ghij}
		TSP/FYM/UREA	6.753^{gh}	15.04^{fghi}
		TSP/UREA	7.011^{h}	14.88^{fghi}
	L.S.D	Cropping system	1.2427	4.010

Key: Means in a column followed by the same letter(s) are not significantly different at *P* = 0.05 according to Fisher's Protected Least significant Difference Test.

During the SRS, the effects of fertilizer and cropping system were significant ($P \leq 0.05$) with higher maize grain yields being obtained in intercrop with the application of FYM and TSP+FYM+Urea. The grain yields were however not significantly different in crop rotation and monocrop with FYM, TSP+FYM+Urea and TSP+Urea in the SRS (Table 12)**.** The combined application of fertilizers TSP+FYM+Urea led to increased yield as compared to the control treatment. This is in agreement with many authors (Bhandari *et al.,* 2002; Ladha *et al.,* 2003; Regmi *et al.,* 2002) who have also observed that continued use of mineral fertilizers alone results in lower grain yields, while the use of organic fertilizer combined with appropriate mineral fertilization helps to maintain high yields. Significantly ($P \leq 0.05$) higher maize yields were obtained in maize/dolichos intercrop with application of TSP+FYM+Urea and TSP+Urea as compared to sole maize LRS. This could be due to inclusion of dolichos into the maize system thus fixing N increasing nutrient uptake leading to enhanced grain yield. Cheruiyot *et al.* (2003) in a study on the effect of legume managed fallows (common beans and lablab) on soil N found accordingly that among the legume species, lablab showed outstanding positive effect on succeeding maize yield. Li Yang et al., (1999) reported that if a legume is integrated with another crop commonly a cereal, the N nutrition of the associated crop may be improved by the direct N transfer from the legume to the cereal. The legume uses fixed atmospheric N which can be exploited by the companion crop (Stern 1993). Higher yields obtained in intercrop with TSP+FYM+Urea and TSP+Urea application can be attributed to the nutrients released by the fertilizers which are also readily available and thus translates to higher maize grain yields. Studies by Murwira and Kirchmann (1993) showed that synchrony between N release and crop uptake was best achieved by applying combinations of manure and mineral N. This is evident in Zimbabwe where Supplementation of 5 t ha^{-1} with 40 kg N ha^{-1} (inorganic fertilizer) resulted in a statistically higher yield than sole manure treatment (Murwira *et al.* 2002). Ibewiro *et al.* (1997) assessed nitrogen contribution by legume roots to succeeding maize crops in Ibadan, Nigeria and showed that the root biomass of velvet bean and *Lablab purpureus* (L.) sweet variety increased maize yields. This also applies to FYM application in which the results were not significantly different. Tejada *et al.* (2006) reported that manure is a good fertilizer on soil that supplies P and N to produce high yields. This is attributed to manure’s slow release of plant nutrients especially of N and P.

High grain yields were obtained in the SRS compared to the LRS across cropping systems. This could be explained in terms of the elevated available nutrients in soil due to residual effect of FYM application and its subsequent uptake by maize (Buresh *et al.,* 1997).

4.3.5.6 Maize Dry matter yields

Higher dry matter yields were obtained in monocrop with application of FYM and TSP+Urea compared to intercrop. There were no significant ($P \leq 0.05$) differences in monocrop and intercrop with application TSP+FYM+Urea in the LRS. Similarly, there were no significant differences under intercrop across all fertilizer treatments (Table 12) in the LRS. Higher dry matter yields were obtained in crop rotation with application of TSP+FYM+Urea and FYM compared to intercrop and monocrop during SRS. However the dry matter yield was not significantly different in monocrop and intercrop with FYM, TSP+FYM+Urea and TSP+Urea application. Maize dry matter yield responded significantly ($P \leq 0.05$) to TSP+FYM+Urea and FYM application in intercrop in the SRS compared with LRS. Higher biomass production in the SRS could be due to improvement in soil productivity as a result of maintenance of soil organic matter levels through continuous input and residual effects of TSP+FYM+Urea and FYM treatments. Higher dry matter yield under intercropping could be attributed to N fixation by the legumes which improve available N, as well as in the below ground biomass zone exploration hence reduced competition as well as the ability of the legume to bring minerals deep down the soil profiles skerman *et al.,* (1988). There was a general reduction in dry matter yields in control plots as compared to TSP+FYM+Urea and FYM application where it showed consistent increment of dry matter yields. The most probable explanation for this event is that FYM application improves structure and water holding capacity of soils which in turn promotes the vegetative growth of a plant together with nutrient uptake translating to increased dry matter. Similar results was reported by Cassman *et al*. (2003) and Gupta (2004) in which the average dry matter maize yield for combined mineral and organic fertilizers application had a yield increment of 25 to 75% and 6 to 68% over the control treatments, respectively. The integration of legumes into intercrop and rotation potentially enhanced the yields of the following maize crop, an effect which can largely be attributed to the increase in plant available nitrogen in the soil for uptake by the same crop and the following crops (Herridge and Ladha, 1995).

4.3.6 Conclusion

Significant ($P \leq 0.05$) high soil NPK levels were obtained in maize/dolichos intercrop with application of FYM and TSP+FYM+Urea during the SRS and LRS. Similarly, significant ($P \leq 0.05$) high maize grain yields were obtained in dolichos/maize intercrop with TSP+FYM+Urea and TSP+Urea during the LRS. Dolichos-maize rotation with TSP+FYM+Urea application resulted in significantly higher dry matter yields compared to intercrop with TSP+Urea application in the SRS. The combinations of FYM and TSP+FYM+Urea resulted in higher maize yields, compared to singular application of either manure (FYM) or mineral fertilizer TSP+Urea. However, with increased maize yields due to addition of combined FYM and TSP+FYM+Urea to the soil, significant nutrient losses were realized. Soil N declined even with integration of dolichos with fertilizer application. Adoption of the best performing technology: maize/dolichos intercrop combined with application of 5 t/ha FYM and 60 kg/ha TSP+Urea ought therefore to be recommended in the short run with prudent nutrient management strategies for system sustainability.

4.4 SIMULATION OF EFFECT OF DOLICHOS AND FERTILIZER PPLICATION ON SOIL CARBON STOCKS IN MAIZE (*Zea mays* L.) CROPPING SYSTEMS OF NAIROBI COUNTY, KENYA

Abstract

The level of soil organic carbon (SOC) that is attained under cropping system largely depends upon rates of carbon input and its decomposition. In this study, Roth C model was used to to simulate the long term effect of dolichos integration with fertilizer application on soil organic carbon stocks in maize cropping systems. The main plots were the cropping systems: (i) intercropping (dolichos (*Lablab purpureus* (L.)/maize), (ii) Rotation (dolichos-maize) and (iii) Sole-maize (Monocrop). The experimental setup in Kabete Sub-county was laid out in a Randomized Complete Block Design with a split plot arrangement in between mid-March to May 2015 long rain season (LRS) and October to December 2015/16 short rain season (SRS).

The sub-plots were fertilizer types: (i) farmyard manure; FYM), (ii) triple superphosphate (TSP) and urea), (iii) combined fertilizer (FYM+TSP+Urea) and (iv) no fertilizer input (control). Soil samples were taken at 0-20 cm depth for determination the changes in soil organic carbon levels (%). The Rothamsted Carbon Model estimated the amount of soil organic carbon stocks under projected future scenarios of climate change for over 20-year period. Soil carbon (C) inputs were obtained from crop residue and FYM inputs and converted into t C/ha. The C inputs were calculated from grain yield data using a harvest index (HI). Significantly ($P \leq 0.05$) higher SOC stocks were obtained in maize/dolichos intercrop with TSP+FYM+Urea application as compared to dolichos-maize rotation and sole maize. Significant ($P \leq 0.05$) high SOC (t C ha^{-1}) density and stocks were respectively, obtained in maize/dolichos intercrop with FYM (60.7 and 56.2) and TSP+FYM+Urea (59.6 and 55.2) application compared to sole maize and dolichos-maize rotation during SRS. . Higher SOC stocks (t C/ha) (140) were obtained in maize/dolichos intercrop with FYM application as compared to dolichos-maize rotation (120) and sole maize (110). Over a 20 year period, SOC stocks maintained a significant increase with application of TSP+FYM+Urea and FYM in the order maize/dolichos intercrop, rotation and sole maize system. Projected carbon stocks increased in maize/dolichos with continuous application of TSP+Urea and FYM hence replenishing nutrient losses in the long run. Therefore, with consistence of carbon input sources from fertilizers under different cropping systems particularly involving intercrop and rotation will increase SOC stocks over time thus increasing carbon sequestration rates as climate mitigation strategy.

Keywords: Cropping systems, Fertilizers, Projections; Soil carbon stocks; Soil carbon density; Roth-C

4.4.1 Introduction

Soil organic matter (SOM) is the largest terrestrial pool of carbon (Schmidt *et al.,* 2011) and stores more than three times the amount of C in the atmosphere (Lal, 2004). Soil organic carbon dynamics affect soil quality, agricultural productivity and atmospheric CO_2 concentration (Smith, 2008).

Such changes in SOC are associated with an altered CO_2 exchange between terrestrial ecosystems and the atmosphere, and they impact significantly on regional carbon budgets (Janssen *et al.,* 2003). A net carbon loss from soils adds to the increase in the atmospheric CO_2 concentration, probably leading to higher global temperatures (IPCC, 2001), hence could accelerate decomposition of SOM (Jones *et al.,* 2005); whereas net soil CO_2 sequestration could help to mitigate the greenhouse effect and to improve soil quality. Carbon sequestration in agricultural soils can be achieved through adaption of improved management practices (Lal *et al.,* 1998) as carbon emissions from agricultural activities contribute to the enrichment of atmospheric CO_2 (Kimble *et al.,* 2002) thus mitigating this trend. Agricultural activities have profound influence on soil organic carbon dynamics both in the short and the long terms and therefore a strong need to increase SOC stock to improve the natural resources quality and for sustainable crop productivity. One way of improving soil carbon stock is by increasing carbon (C) input through retention of crop residues and animal manure and intensification of agriculture. Higher crop productivity under intensive agriculture increases crop residue input into the soils and hence increasing SOC levels (Franzluebbers, 2005). SOC improvement in depth distribution can be achieved by planting deep-rooted crop varieties with large belowground biomass production. The use of crop residues and animal manures returns the much needed C back to the soil and thus results in increased SOC density and soil quality hence improving on soil health (Benbi *et al.,* 1998). Soil carbon sequestration is essentially limited by the quantity of carbon input into the soil system. The fertilizer input into the soil, which determines the C from crop productivity input, will tend to increase the attainable level to near the potential level. Apart from fertilizer carbon input, cropping systems particularly involving crop rotations and intercrops could enhance soil organic carbon accumulation by influencing the amount of C input and rate of decomposition (Nieder *et al.,* 2003). Therefore, there is a possibility of increasing soil carbon sequestration through improved soil nutrient management.

To realize SOC sequestration potential, it requires adoption of sustainable practices such as integrated soil fertility management involving land use and fertilizer management practices. While a considerable amount of research related to C sequestration and global climate change has been conducted in developed nations (Kukal 2008), comparatively fewer studies have been conducted on impact of fertilizer management practices on soil carbon sequestration in different cropping systems. The models that attempt to explain SOC changes have been developed to predict loss rates or sequestering of soil carbon stocks and develop SOC management schemes (Lal 2009). The Rothamsted organic carbon turnover model (RothC model) has been used particularly to predict SOC changes in agricultural, forest and grassland systems in large parts of the world (Guo *et al*. 2007; Liu et al. 2009). Smith *et al.*, 1997) evaluated nine SOC models with data from seven long-term experiments in different parts of the world and found that the RothC-26.3 model was one of the best since it simulated all land uses, had few errors and achieved modeling with fewer available data, as well as being simple in its structure. Modelling allows us to estimate and predict the short and long-term trends of SOC changes and SOC sequestration under projected future scenarios of climate change which is vital so as to take measures for an adequate management in various ecosystems (Wan *et al.*, 2011). The present investigation was conducted to estimate and predict the effect of fertilizer application on soil organic stocks and their projections under a dolichos-maize based cropping system using Roth-C model.

4.4.2 Materials and Methods

The study was conducted at the University of Nairobi field station during the LRS of mid-March to May 2015 and SRS of October to December 2016. The experimental design was laid out in a randomized complete block design (RCBD) with split plot arrangement, replicated three times. Detailed descriptions of the site, experimental design, treatment and agronomic practices are as described in chapter 3 of this thesis.

4.4.3 Soil, sampling and analysis

Soil organic carbon: Soil samples for organic carbon determination were collected within the 0.2m depth between the plants in a row in every plot, using a 5 cm diameter soil auger at harvest time of each cropping season. The samples were air-dried for one week and sieved through a 2 mm mesh and analyzed for soil organic carbon using the Walkley-Black wet oxidation method (Nelson and Sommers, 1982).

Soil organic carbon stocks; samples for determination of soil organic carbon stocks (calculated per unit area) were collected near plant roots to a depth of 20 cm using a soil auger.

In addition, a ring sampler was used to collect soils for the measurement of bulk soil density. Bulk density was estimated using the core method after oven-drying a specific volume of soil at 105 C for 48 h (Blake 1965).

4.4.4 Calculation and projection of carbon density and stocks

Soil organic carbon density (SOCD) i.e. the carbon storage of soil per unit area at a certain depth was calculated using the formula; SOCD (kg m^{-2}) = SOC × BD × A × H.

Wherein, SOC is soil organic carbon content (g kg^{-1}); BD is soil bulk density (g cm^{-3}); A is the plot area (m^2); H is the thickness of the topsoil (20 cm) and converted to t C/ha.

Soil organic carbon stocks were calculated by multiplying the carbon content by soil bulk density and the thickness of the sampled soil layer (Bernoux *et al.*, 1998), using the formula: SOC (t C/ha): $E = \rho_s x A x C$. Wherein, E is the carbon stock ($Mg.ha^{-1}$); p_s, the soil bulk density (g cm^{-3}); A, the thickness of the sampled soil layer (cm) and C, carbon content in the soil (%).

4.4.5 Model Description and Data requirements

The RothC-26.3 model is a SOM decomposition model that divides incoming plant residues into decomposable plant material (DPM) and resistant plant material (RPM); these both decompose to form microbial biomass (BIO), humified organic matter (HUM) and evolved CO_2 (Coleman & Jenkinson, 1996). The model also includes an inert pool of organic matter (IOM). Roth-C is one of the most widely used SOC models (Jenkinson *et al.,* 1991; McGill, 1996) and has been evaluated in a wide variety of ecosystems including croplands, grasslands and forests (Falloon & Smith, 2002). The schematic structure of the Roth-C model (Figure 2) depicts plant residues entering the soil environment, undergoing decomposition by the soil microbial biomass to form several pools with the evolution of CO_2.

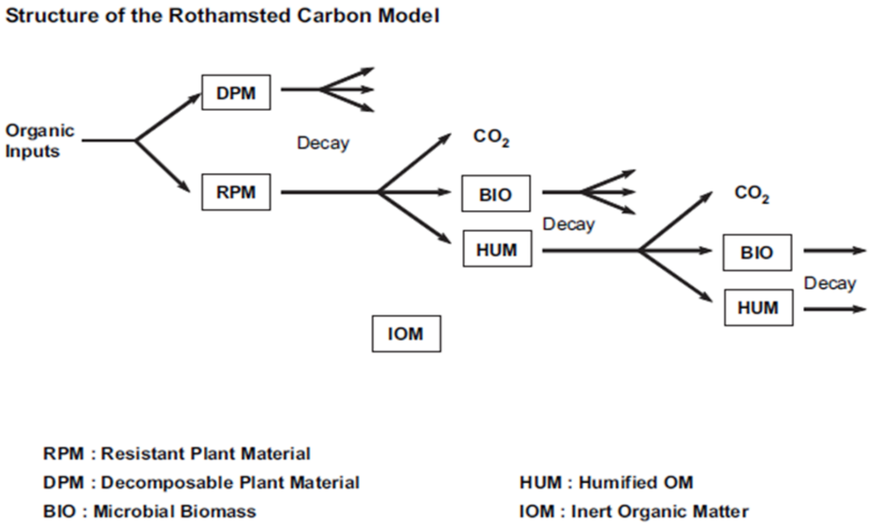

Figure 2: Roth-C model structure. Source: Jenkinson and Coleman, (1994).

The Roth-C model requires three types of data:(a) Climatic data; monthly rainfall (mm), monthly evapotranspiration (mm), average monthly mean air temperature (° C); (b) Soil data; clay content (%), inert organic carbon (IOM), initial soil organic carbon (SOC) stock (t C ha^{-1}), depth of the soil layer considered (cm); (c) Land use and land management data; soil cover, monthly input of plant residues (t C ha^{-1}), monthly input of farmyard manure (FYM) (t C ha^{-1}), residue quality factor (DPM/RPM ratio).

4.4.5.1 Calibration procedure

For calibration, RothC model was run through an equilibrium period (7000–10,000 years) standard procedure to represent soil and vegetation conditions prior to human disturbance (Parton *et al.*, 1987). The equilibrium files for all the land management units; treatments (i.e. control, FYM, TSP+FYM+Urea and TSP+Urea) were prepared. The model was set up to simulate the characteristics of the trial site, including the land management represented by monthly C inputs (t C ha^{-1}), monthly FYM inputs (t C ha^{-1}) and soil cover (Jenkinson and Coleman 1990) (whether soil is covered by a crop or is fallow) which was assumed from March until September, because it is in the range of the soil cover for the maize crop. All soil pool data were converted from g C/kg soil to t C/ha for use in the model. This was accomplished for 0-20 cm bulked samples using the formula: t C/ha = g C/kg × BD × D (section 2.5).

Soil carbon inputs obtained from crop residue were calculated from grain yield data using a harvest index (HI). Climate data from Kabete on-site weather station were converted to average monthly temperature (°C) and monthly rainfall and pan evaporation (mm). Land management data with a DPM/RPM (decomposable plant material/resistant plant material) ratio of 0.67 and an inert organic matter (IOM) content of 0.204 t C ha^{-1} approximated using equation (1) proposed by Falloon *et al*, 1998 (because the radiocarbon content was not known) were used to simulate equilibrium land use at the study site.

$IOM = 0.049TOC^{1.139}$ (1)

Where: TOC is Total organic carbon, t C ha^{-1}

IOM is Inert organic matter, t C ha^{-1}

Model input files were created using the input data collected from the site, and model runs executed to accurately simulate management regimes at the site studied. Model outputs were then studied, model fit to measured data assessed and plant C inputs to soil recorded.

4.4.5.2 Model validation

During the validation phase, the model adjustments made described as “model calibration” were kept and only modified the simulation schedules to set the year that forest-to-agriculture conversion occurred, according to the history of Kabete site. Assessment of model performance for validation was conducted using the output variables corresponding to soil organic carbon inputs.

4.4.5.3 Model run

The initial carbon content of the soil organic matter pools and the annual plant addition to the soil were obtained by running the Roth-C model to equilibrium under constant environmental conditions (Coleman & Jenkinson, 1996). The constant climatic conditions were taken to be the average of climate data from 1900 to 1930. By initializing the model in, and running the model from 1900, potential initialization effects are minimized (Smith *et al.*, 2005).

Roth-C is known to be relatively insensitive to the distribution of C inputs through the year; the proportions of plant material added to the soil in each month were set to describe the pattern of inputs for a typical arable crop as given in Table 13.

Table 13: The proportion of carbon assumed to be added in plant material each month for croplands

Month	1	2	3	4	5	6	7	8	9	10	11	12
Cropland	0.0	0.0	0.16	0.16	0.16	0.16	0.5	0.0	0.0	0.0	0.0	0.0

Plant cover was assumed to occur all year round in 12 months for croplands. After the first equilibrium run, the annual plant addition, P, was adjusted to give the measured soil carbon content given in the soils database, using equation (2);

$$P = P_i \times \frac{Cmeas - IOM}{C_{sim} - IOM} \qquad (2)$$

where P_i is the initial total plant addition (the sum of the proportions given in Table 13), C_{meas} is the measured soil carbon given in the soils database, C_{sim} is the simulated soil carbon after the 10 000 year run and IOM is the carbon content of the inert organic matter fraction in the soil (all in t C ha^{-1}).

The inert organic matter (IOM) content of 0.204 t C ha^{-1} approximated using equation (1) proposed by Falloon *et al*, 1998 (because the radiocarbon content was not known) were used to simulate equilibrium land use at the study site. The adjusted annual plant addition was then redistributed through the months as in Table 4, and the equilibrium run repeated. This iteration was continued until the measured and the simulated carbon contents of the soil were within 0.00001 t Cha^{-1}. Having determined the plant additions and carbon contents of the soil organic matter pools, the simulations were continued from 1990 (baseline year) to 2015 using the measured climate and simulated net primary productivity (NPP) data described above. Predicted climate, NPP and land-use data were used to run the simulations between 2000 and 2020. To account for the impact of the treatments in the field trial on SOC, experimental treatments were then simulated using annual weather data and land management parameters; treatments (control, FYM, TSP+FYM+Urea and TSP+Urea) were prepared given in experimental documentation. Table 14 shows the plant C inputs used in the RothC model for the study site.

Table 14: Plant C inputs used in the RothC model for Kabete experiment

	C inputs (t C ha^{-1} year^{-1})			
Cropping System	Control + Residue	10 t FYM ha^{-1} year^{-1} + Residue	5 t FYM ha^{-1} year^{-1} + N1P1+ Residue	N1P1 + Residue
Crop rotation	2.1	2.43+2.23	1.215+1.12	2.4
Monocrop	2.05	2.25+2.23	1.215+1.12	2.2
Intercrop	2.15	2.55+2.23	1.215+1.12	2.55

Note: Residue was calculated from grain yield data using a harvest index (HI) and converted into t C/ha.

Soil organic carbon projections were then estimated and predicted over a 20-year period using the values obtained by the calibration and calculating the C inputs obtained under two different management scenarios: carbon input of plant residues and farmyard manure.

4.4.6 Results and Discussions

4.4.6.1 Soil carbon stocks and soil carbon density

Significant ($P \leq 0.05$) high SOC density and stocks were obtained in maize/dolichos intercrop with FYM and TSP+FYM+Urea application compared to sole maize and dolichos-maize rotation during LRS (Table 15). The same trend was observed during the SRS in intercrop with FYM and TSP+FYM+Urea.

Table 15: SOC density (t C/ha) and stocks (t C ha^{-1}) (0-20 cm) as influenced by fertilizer application under maize-based systems

Seasons	**Cropping System**	**Treatment**	**SOC Density (t C/ha)**	**SOC Stocks (t C/ha)**
LRS	CR	CONTROL	46.59^{a}	43.13^{a}
		FYM	57.14^{efg}	52.91^{efg}
		TSP/FYM/UREA	55.61^{def}	51.49^{defg}
		TSP/UREA	51.28^{bc}	47.48^{abcd}
	IC	CONTROL	46.64^{a}	43.19^{a}
		FYM	59.08^{gh}	54.71^{fg}
		TSP/FYM/UREA	57.36^{efgh}	53.11^{efg}
		TSP/UREA	52.76^{cd}	48.85^{bcde}
	MC	CONTROL	45.73^{a}	42.34^{a}
		FYM	55.07^{def}	50.99^{def}
		TSP/FYM/UREA	54.27^{cde}	50.25^{def}
		TSP/UREA	51.06^{bc}	47.28^{abcd}
SRS	CR	CONTROL	48.28^{ab}	44.70^{abc}
		FYM	59.23^{gh}	54.84^{fg}
		TSP/FYM/UREA	58.19^{fgh}	53.88^{efg}
		TSP/UREA	53.25^{cd}	49.30^{cde}
	IC	CONTROL	47.67^{a}	44.14^{ab}
		FYM	60.70^{h}	56.20^{g}
		TSP/FYM/UREA	59.61^{gh}	55.19^{fg}
		TSP/UREA	54.28^{cde}	50.26^{def}
	MC	CONTROL	47.60^{a}	44.08^{ab}
		FYM	58.18^{fgh}	53.87^{efg}
		TSP/FYM/UREA	57.49^{efgh}	53.23^{efg}
		TSP/UREA	52.76^{cd}	48.85^{bcde}
L.S.D	Season*Cropping System*Treatment = 2.9973			2.7568

Key: Means in a column followed by the same letter(s) are not significantly different at $P = 0.05$ according to Fisher's Protected Least significant Difference Test.

Application of FYM and TSP+FYM+Urea increased SOC density and stocks across all cropping systems in both seasons. Manure application led to direct C input into the soil thus enhancing soil physical conditions such as improved soil structure for better uptake of water and nutrients in the soil. This could also be attributed to combined fertilizer application (TSP+FYM+Urea) that led to SOC stocks increase due to greater C input associated with enhanced primary production and crop residues retention into the soil. Rudrappa *et al.* (2006) reported that balanced fertilization improved total SOC concentration over 50% NPK or NP alone in 0-15 cm soil layer.

4.4.6.2 Estimated amount of soil organic carbon stocks and projections under monocropping with fertilizer application (t C ha^{-1})

The projected SOC stocks increased in sole maize with application of FYM. Application of TSP+FYM+Urea maintained relatively high carbon stocks over a 20-year period. Sole maize had the lowest carbon stocks in control compared to plots with FYM and TSP+FYM+Urea application (Figure 3).

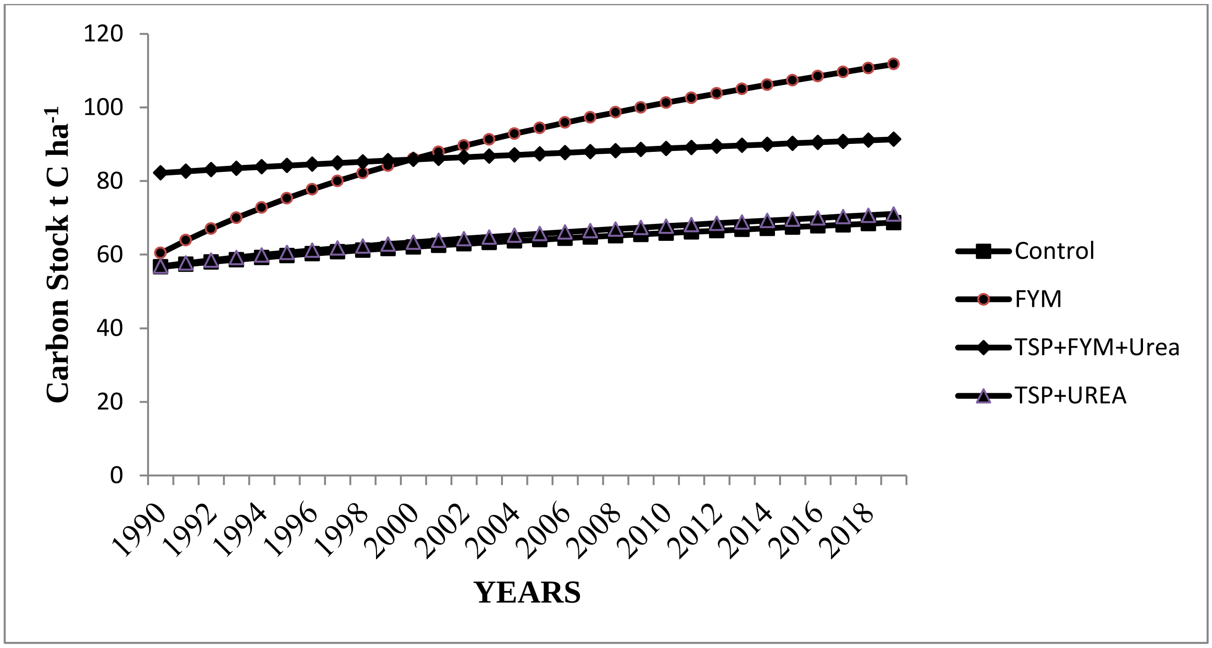

Figure 3: Predicted soil organic carbon stocks over a 20-year period under monocrop with fertilizer application

Sole maize with application of FYM and TSP+FYM+Urea showed increased SOC stock over the 20-year period. This could be due to accumulation of the organic residues with more carbon accumulation obtained in the incorporated maize stover at the top soil layer, with little or no organic residue movement or accumulation beneath the top soil layer. Cereals, particularly maize will return nearly twice as much residue to the soil compared with legumes consequently resulting to higher levels of SOM increase (Reicosky, 1997). The advantage that cereals have over legumes for achieving maximum carbon sequestration has also been demonstrated by Curtin et al. (2000). They have shown that while black lentil fallow in semi-arid Canada added between 1.4 and 1.8t C/ha, a wheat crop would add 2-3 times this amount of C annually.

Similarly, in Argentina, soybean, which produced 1.2 t C/ha of residue, resulted in a net loss of soil C while maize with 3 t C/ha of residue, significantly reduced soil carbon loss from the system (Studdert and Echeverria, 2000). TSP+FYM+Urea application however did not increase the SOC levels as compared to sole FYM application. Depending on the system, the application of even relatively high amounts of FYM (10 t/ha) does not guarantee an increase in soil carbon levels. This was also noted in a long-term study in Kenya by Kapkiyai (1999) where SOM declined even when manure was applied and maize residue retained. It has been estimated that in order to maintain organic carbon stock in the soil, 35 t/ha of manure or 17 t/ha manure with 16 t/ha of stover would be required annually (Woomer *et al.*, 1997).

4.4.6.3 Estimated amount of soil organic carbon stocks and projections under dolichos-maize rotation with fertilizer application (t C ha^{-1})

The projected carbon stock levels were significantly high in dolichos-maize rotation with application of FYM over a 20-year period. There was a slight increase in soil organic carbon stocks projections with application of TSP+FYM+Urea compared with TSP+Urea. Control treatment had the lowest level of carbon stock estimated over time (Figure 4).

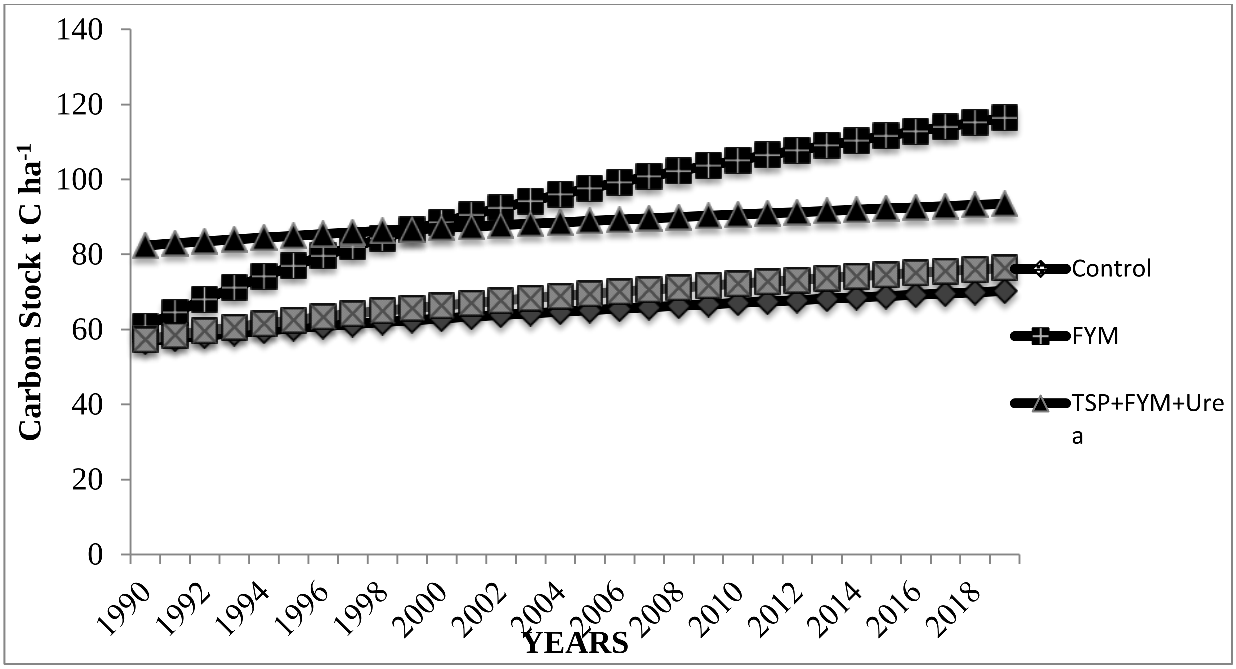

Figure 4: Predicted soil organic carbon stocks over a 20-year period under rotation with fertilizer application

Rotating dolichos with maize with FYM application projected high carbon stock levels compared with TSP+Urea and control treatment. This was because FYM application had a major impact on mineralization rates by increasing soil C directly, whereas the effect of mineral fertilizer N was less pronounced since it increased C inputs only indirectly by improving plant growth. This agrees with Eghball (2002), who observed an increase in soil organic carbon after 4 years of manure application where about 25% C was retained in the soil carbon pool. Increase in SOC stocks in crop rotation with FYM application could also be attributed to dolichos ground cover increasing nutrient availability for the plants and hence high biomass production and crop growth enhancement. With increased biomass, plants were able to bind more C in the soil. Legume residues such as dolichos are generally of high quality (low C:N ratio) and so decompose rapidly (Woomer *et al*., 1994). The application of FYM had little change in total SOC during the 20-year projection period while control treatment and TSP+Urea showed a slight decline in total SOC. Additions of manure was more effective than crop residue retention or the addition of fertilizers as a means of offsetting SOM decline, however, the best SOM maintenance can be achieved by combinations of inputs (Kapkiyai *et al.*, 1999).

4.4.6.4 Estimated amount of soil organic carbon stocks and projections under maize/dolichos intercrop with fertilizer application (t C ha^{-1})

The projected soil organic carbon stocks in maize/dolichos intercrop were significantly higher with application of FYM as compared to control treatment and TSP+Urea. Significant increase in soil organic carbon stocks was obtained with application of TSP+FYM+Urea over a 20-year period (Figure 5).

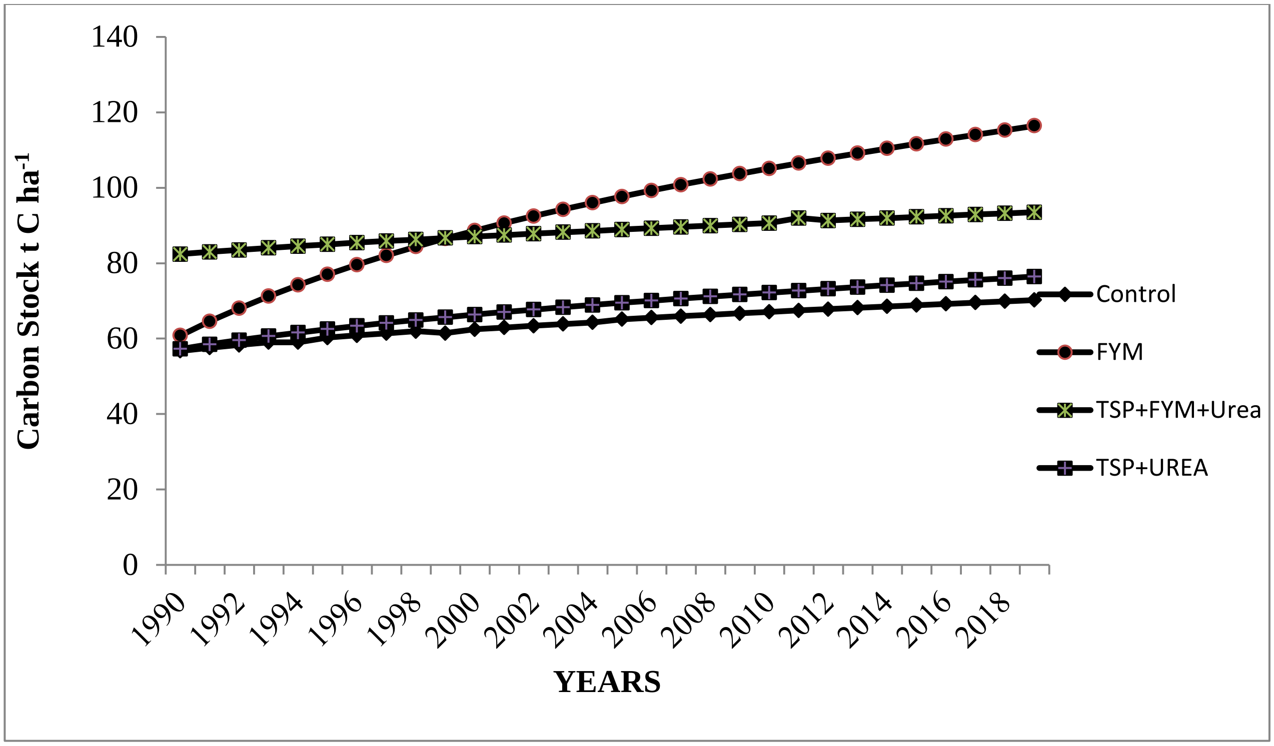

Figure 5: Predicted soil organic carbon stocks over a 20-year period under intercrop with fertilizer application

Application of combined TSP+FYM+Urea in intercrop realized a higher amount of SOC stocks. This may be because the addition of N fertilizer into soils increased crop growth and thus increasing the accumulation of soil organic matter through increased litter production at surface layer as showed by (Fornara & Tilman, 2012). Previous studies based on long-term experiments reported similar findings (Ding *et al.*, 2012; Yang *et al.*, 2012). Similarly, addition of FYM in intercrop increased SOC projected stock. This could mainly be due to improved soil physical characteristics that promote the formation and stabilization of soil macro aggregates and particulate. This could be explained by higher organic matter decomposition rates achieved by combinations of inputs (Kapkiyai *et al.*, 1999). Manure is more resistant to microbial decomposition than crop residues; consequently, for the same carbon input, carbon storage is higher with manure application than with plant residues (Feng and Li, 2001). Gregorich *et al.* (1998) also found that manured soils had large quantities of soluble C with a slower turnover rate than in control or chemically fertilized plots. Many field trials have found that manure is the best means for incorporating organic matter into soils and promoting carbon storage.

The control treatment had less SOC stock across sole maize, rotation and maize dolichos intercrop. However, no significant difference of SOC was observed between TSP+Urea and control treatments although TSP+Urea had a higher value. This meant that FYM was the primary contributor to the treated SOC pool compared with chemical fertilizers. Manure contains most elements required for plant growth including N, P, K and micronutrients. And most importantly, the organic matter from the manure contributes greatly to SOC. Therefore, application of FYM at the surface layer was a result of greater C inputs from organic matter and root biomass, thus better crop growth (Ding *et al.,* 2012).

4.4.7 Conclusion

Significantly ($P<0.05$) higher SOC stocks were obtained in maize/dolichos intercrop with FYM and TSP+FYM+Urea application as compared to dolichos-maize rotation and sole maize. Over a 20-year period, SOC stocks maintained a significant increase with application of TSP+FYM+Urea and FYM in the order maize/dolichos intercrop, rotation and sole maize system. Projected carbon stocks increased in maize/dolichos with continuous application of FYM hence replenishing nutrient losses in the long run. The use of organic fertilizer (FYM) directly increased SOC contributing to carbon sequestration. The modelling approach represents one of the most promising methods for the estimation of SOC stock changes and allowed us to evaluate the changes in SOC over a 20-year period. To enhance soil fertility dolichos/maize intercrop alongside application of FYM and combined FYM+TSP+Urea is the best bet technological package for increased productivity and sustainability of the smallholder farming systems of Kabete, Nairobi County.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 DISCUSSION

Maize/dolichos intercrop with application of FYM and FYM+TSP+Urea obtained high levels of soil moisture and soil organic carbon as compared to crop rotation and monocrop during the SRS. The same trend in soil moisture and organic C levels in the above treatments was observed in LRS albeit with no significant differences compared with the SRS. Similarly, significantly ($P \leq 0.05$) high soil N, P and K levels were obtained in maize/dolichos intercrop in the SRS as compared to LRS with application of FYM and TSP+FYM+Urea. Averaged across the two seasons, FYM application in maize/dolichos intercrop and dolichos-maize rotation produced less negative NPK balances and higher balances in monocrop with TSP+Urea application. Significantly higher SOC stocks were obtained in maize/dolichos intercrop with FYM and TSP+FYM+Urea application as compared to dolichos-maize rotation and sole maize. Over a 20 year period, SOC stocks maintained a significant increase with application of TSP+FYM+Urea and FYM in the order maize/dolichos intercrop, rotation and sole maize system. Maize grain and dry matter yields in the SRS were significantly ($P \leq 0.05$) high in dolichos/maize intercrop with application of TSP+FYM+Urea and FYM. Likewise, significantly ($P \leq 0.05$) high maize grain yields were obtained in dolichos/maize intercrop with TSP+FYM+Urea and TSP+Urea during the LRS. When compared across the two seasons, soil moisture content, organic carbon, N, P and K were consistently high in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea in SRS. Generally, maize/dolichos intercrop with application of FYM and TSP+FYM+Urea consistently showed that improved soil moisture, organic carbon, nutrient status and carbon stocks translated into increased maize yields. With the increase in yields, significant nutrient losses were realized. Application of FYM improves soil fertility by influencing its physical, chemical and biological properties. It improves water circulation and soil aeration, and increases the soil moisture holding capacity. This is in agreement with (Su *et al.,* 2006; Adeyemo and Agele, 2010 who showed that organic manure has the ability to improve soil physical structure by enhancing aggregate stability hence reducing runoff and increasing water holding capacity.

Increase in maize yields in maize dolichos intercrop with FYM application combined together with TSP+Urea could be attributed to manure gradual soil mineralization and release of nutrients become available hence increasing crop production. Research has shown that combinations of organic and chemical fertilizers result in greater crop yields compared with sole organic or sole inorganic fertilizers (Chivenge *et al*., 2009). Vanlauwe *et al.* (2002) reported that grain yield increases of up to 400% over the control in cases where the control yields are low. This increase in grain yield has been attributed to improved N synchrony with combined inputs through direct interactions of the organic and inorganic fertilizers. Soil NPK balances varied depending on the fertilizer used under different cropping systems. Inclusion of dolichos in rotation and intercrop with TSP+Urea and TSP+FYM+Urea increased negative NPK balances as compared to sole maize. This could be attributed to export of nutrients through harvest of the component crops in the intercrop as observed by Fermont *et al.*, (2007) as well as increased yields which increase NPK losses through harvested products Onwonga *et al.,* (2008). Projected carbon stocks increased in maize/dolichos with continuous application of FYM and TSP+FYM+Urea hence replenishing nutrient losses in the long run. Additions of manure were generally more effective than crop residue retention or the addition of mineral fertilizers as a means of offsetting SOM decline. It is therefore evident that for increased maize production in Kiambu County, maize/dolichos intercrop with FYM and TSP+FYM+Urea application should be adopted. This should however be noted is at the expenses of soil nutrient levels and hence for ecological sustainability of this system, there is need for tradeoffs when selecting the treatments to apply to the soil.

5.2 CONCLUSIONS

Soil moisture content, Soil organic carbon and N, P and K were consistently high in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea in SRS. Negative N and P balances were pronounced in maize/dolichos intercrop and dolichos-maize rotation with application of FYM and TSP+FYM+Urea. Significant ($P \leq 0.05$ higher dry matter yields were obtained in dolichos-maize rotation with FYM application and higher grain maize yields were realized in intercrop with application of FYM and TSP+FYM+Urea in SRS as compared to the LRS.

It is evident that improved soil moisture, organic carbon, nutrient status and carbon stocks in maize/dolichos intercrop with the application of FYM and TSP+FYM+Urea translated into increased maize yields. With the increase in yields, significant nutrient losses were realized. Projected carbon stocks increased in maize/dolichos with continuous application of FYM and combined TSP+Urea and will hence replenish nutrient losses in the long run. Adoption of the best performing technology: maize/dolichos intercrop with combined application of 5 t ha^{-1} FYM and 60 kg ha^{-1} TSP+Urea ought therefore to be tapered (in the short run) with prudent nutrient management strategies for system sustainability.

5.3 RECOMMENADATIONS

1. To increase soil moisture content and organic carbon in the maize based cropping system, farmers can benefit from crop rotation with dolichos and intercropping with TSP+FYM+Urea and sole FYM application would provide an effective way of improving good water holding capacity.
2. To minimize soil nutrient losses, intercropping with TSP+FYM+Urea and FYM application should be adopted together with crop residue retention. To enhance long term sustainability of the farm, rotation and intercropping with legumes like dolichos should be practiced in N limited environments. In case of P deficiencies, rotation with dolichos with P mineral fertilizers source combined with organic manure TSP+FYM+Urea is advisable while for K limited environments crop rotation with FYM added would be appropriate.
3. To increase maize dry matter and grain yields, maize/dolichos intercrop and dolichos-maize rotation with FYM and TSP+FYM+Urea application is recommended in the short run, with prudent nutrient management strategies for system sustainability.
4. More studies should be conducted to determine the carbon sequestration, crop residue linkage, soil carbon stocks and projections towards climate change mitigation measure. To increase soil carbon stocks maize/dolichos with continuous application of FYM should be adopted to replenish nutrient losses in the long run hence increasing soil carbon sequestration.

CHAPTER 6: REFERENCES

The references are indicated (X) in the respective thesis chapters in which they appear.

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CHAPTER 7: APPENDICES

Analysis of Variance for Soil Nutrient Balances

a. Nitrogen Balances Kg ha^{-1} yr^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		59.60	29.80	1.22	
Rep.*Units* stratum						
Season	0	(1)				
Treatment	3		493.02	164.34	6.72	0.002
CS	2		54.17	27.08	1.11	0.348
Season.Treatment	0	(3)				
Season.CS	0	(2)	0.00			
Treatment.CS	6		327.48	54.58	2.23	0.078
Season.Treatment.CS	0	(6)	0.00			
Residual	22	(24)	538.34	24.47		
Total	35	(36)	1005.61			

b. Phosphorus Balances Kg ha^{-1} yr^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		1.6275	0.8137	2.07	
Rep.*Units* stratum						
Season	0	(1)				
Treatment	3		3.9877	1.3292	3.38	0.036
CS	2		15.4077	7.7038	19.61	<.001
Season.Treatment	0	(3)	0.0000			
Season.CS	0	(2)				
Treatment.CS	6		16.9077	2.8179	7.17	<.001
Season.Treatment.CS	0	(6)	0.0000			
Residual	22	(24)	8.6444	0.3929		
Total	35	(36)	27.6164			

c. Potassium Balances Kg ha^{-1} yr^{-1}

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		4.421	2.211	0.89	
Rep.*Units* stratum						
CS	2		3.144	1.572	0.63	0.541
Season	0	(1)				
Treatment	3		277.996	92.665	37.24	<.001
CS.Season	0	(2)	0.000			
CS.Treatment	6		27.089	4.515	1.81	0.143
Season.Treatment	0	(3)				
CS.Season.Treatment	0	(6)	0.000			
Residual	22	(24)	54.744	2.488		
Total	35	(36)	211.079			

Season 1

Analysis of Variance for Soil Nutrients
Soil Organic Carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.02263	0.01131	0.56	
Rep.*Units* stratum					
CS	2	0.18878	0.09439	4.71	0.011
Treatment	3	3.36474	1.12158	55.93	<.001
CS.Treatment	6	0.05221	0.00870	0.43	0.855
Residual	94	1.88496	0.02005		
Total	107	5.51332			

Soil Moisture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	18.91	9.45	0.74	
Rep.*Units* stratum					
CS	2	19.71	9.86	0.77	0.464
Treatment	3	504.29	168.10	13.21	<.001
CS.Treatment	6	11.12	1.85	0.15	0.989
Residual	94	1196.16	12.73		
Total	107	1750.19			

pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.27387	0.13693	1.78	
Rep.*Units* stratum					
CS	2	0.24154	0.12077	1.57	0.214
Treatment	3	17.39700	5.79900	75.37	<.001
CS.Treatment	6	0.95643	0.15941	2.07	0.064
Residual	94	7.23227	0.07694		
Total	107	26.10110			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	60.66	30.33	0.59	
Rep.*Units* stratum					
CS	2	41.68	20.84	0.40	0.670
Treatment	3	662.34	220.78	4.26	0.007
CS.Treatment	6	43.21	7.20	0.14	0.991
Residual	94	4866.21	51.77		
Total	107	5674.10			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.002499	0.001250	0.55	
Rep.*Units* stratum					
CS	2	0.000193	0.000096	0.04	0.958
Treatment	3	0.190546	0.063515	28.15	<.001
CS.Treatment	6	0.009236	0.001539	0.68	0.664
Residual	94	0.212070	0.002256		
Total	107	0.414544			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.09976	0.04988	1.74	
Rep.*Units* stratum					
CS	2	0.16843	0.08422	2.94	0.058
Treatment	3	5.74888	1.91629	67.00	<.001
CS.Treatment	6	0.19186	0.03198	1.12	0.358
Residual	94	2.68850	0.02860		
Total	107	8.89745			

Analysis of Variance for Maize yields
Grains yields

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		1.4572	0.7286	1.80	
Rep.*Units* stratum						
CS	1	(1)	0.9749	0.9749	2.40	0.143
Treatment	3		62.6566	20.8855	51.48	<.001
CS.Treatment	3	(3)	0.0192	0.0064	0.02	0.997
Residual	14	(8)	5.6798	0.4057		
Total	23	(12)	48.8881			

Biomass yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	6.759	3.379	1.11	
Rep.*Units* stratum					
CS	2	158.313	79.157	26.08	<.001
Treatment	3	119.290	39.763	13.10	<.001
CS.Treatment	6	37.169	6.195	2.04	0.103
Residual	22	66.762	3.035		
Total	35	388.292			

Season 2

Analysis of Variance for Soil Nutrients

Soil Organic Carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.00451	0.00225	0.14	
Rep.*Units* stratum					
CS	2	0.07700	0.03850	2.32	0.104
Treatment	3	4.02759	1.34253	80.84	<.001
CS.Treatment	6	0.03431	0.00572	0.34	0.912
Residual	94	1.56109	0.01661		
Total	107	5.70449			

Soil Moisture

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.70	2.35	0.12	
Rep.*Units* stratum					
CS	2	13.30	6.65	0.34	0.711
Treatment	3	1301.69	433.90	22.33	<.001
CS.Treatment	6	11.21	1.87	0.10	0.997
Residual	94	1826.66	19.43		
Total	107	3157.56			

pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	1.5835	0.7917	3.82	
Rep.*Units* stratum					
CS	2	0.0591	0.0295	0.14	0.867
Season.Treatment	3	8.6990	2.8997	14.00	<.001
CS.Season.Treatment	6	0.1120	0.0187	0.09	0.997
Residual	94	19.4702	0.2071		
Total	107	29.9237			

Soil P

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	2871.6	1435.8	5.98	
Rep.*Units* stratum					
CS	2	8.2	4.1	0.02	0.983
Treatment	3	3528.0	1176.0	4.90	0.003
CS.Treatment	6	67.7	11.3	0.05	1.000
Residual	94	22553.6	239.9		
Total	107	29029.1			

Soil N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.014044	0.007022	4.29	
Rep.*Units* stratum					
CS	2	0.018688	0.009344	5.71	0.005
Treatment	3	0.167152	0.055717	34.04	<.001
CS.Treatment	6	0.014573	0.002429	1.48	0.192
Residual	94	0.153857	0.001637		
Total	107	0.368315			

Soil K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	0.15719	0.07860	2.04	
Rep.*Units* stratum					
CS	2	0.05335	0.02667	0.69	0.503
Treatment	3	0.88295	0.29432	7.64	<.001
CS.Treatment	6	0.07340	0.01223	0.32	0.926
Residual	94	3.62251	0.03854		
Total	107	4.78941			

Analysis of Variance for Maize yields

Grains yields

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	4.0727	2.0363	3.01	
Rep.*Units* stratum					
Treatment	3	88.0806	29.3602	43.37	<.001
CS	2	1.8028	0.9014	1.33	0.285
Treatment.CS	6	5.7026	0.9504	1.40	0.257
Residual	22	14.8917	0.6769		
Total	35	114.5503			

Biomass yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	35.734	17.867	2.59	
Rep.*Units* stratum					
CS	2	20.765	10.383	1.51	0.244
Treatment	3	390.267	130.089	18.87	<.001
CS.Treatment	6	101.159	16.860	2.45	0.058
Residual	22	151.691	6.895		
Total	35	699.617			