ASSESSMENT OF THE AGRO-BIOLOGICAL EFFICIENCY OF MAIZE INTERCROPPED WITH BEANS UNDER INTEGRATED NUTRIENT APPLICATION

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DECLARATION AND RECOMMENDATION

DECLARATION

This Thesis is my original work and has not been submitted before in any institution for any other award.

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DEDICATION

To my lovely children Angela, Innocent and Bernice.

Passion is a virtual

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ABSTRACT

Intercropping is regarded as the practical application of basic ecological principles such as diversity, competition and facilitation. Competition among plants growing in proximity plays an important role in determining their growth and yield. Agro-biological relations that can lead to high productivity under maize/ bean intercrop in intensively cultivated agricultural lands were investigated from March to December 2014 in Nyeri, Kenya. The study aimed at identifying sustainable nutrient management option that can lead to high yield and income in green maize and beans intercropping system. Three components of field trials comprising of maize, beans and maize-bean intercrop were conducted in a randomized complete block design (RCBD) with three replications. Each component was subjected to treatments that included: Control-without fertilizer (WF), with 150 kg/ha 17:17:17 mineral fertilizer (MF), 8 tons/ha Tithonia biomass (TDB) and integrated application (MFTDB) comprising 4 tons/ha tithonia and 100 kg/ha mineral fertilizer. Growth and yield parameters were taken on ten randomly selected plants. Yield, agro-biological and economic advantage indices were used to calculate the intercropping advantage. Data was subjected to analysis of variance (ANOVA) using SAS version 9.1. Significantly different treatment means were separated by Duncan Multiple Range Test at P = 0.05 level. Integrated nutrient application (MFTDB) gave the highest maize and bean height, diameter, number of leaves, number of pods and number of beans per pod. MFTDB produced 21.7% higher green maize yields than control, while MF and TDB produced 8.96% and 7.52% higher yields respectively than the control. The land equivalent ratios were higher than one in all intercropping plots indicating an optimum exploitation of the environmental resources. Control plots showed the highest yield advantage in terms of Land Equivalent Ratio (LER) of 1.70. The intercropping obtained maize and beans yield was low compared to the expected yield, showing a mutual inhibition and underperformance of both maize and beans in the association, but when maize yield was converted to Bean Equivalent Yield (BEY), the intercropping BEY was higher than the BEY in the sole for all fertilizer types, thereby revealing an agronomic advantage. The crowding coefficient (K) values for maize was much higher than 1, indicating an absolute yield advantage of maize over beans. The highest Competitive Ratio (CR) for maize was obtained from MFTDB indicating that maize was 4.38 and 5.61 more competitive than beans in the intercrop of trial one and two; likewise the aggressivity index showed that maize dominated beans in the intercrop. The Actual Yield Loss (AYL) values for maize indicated a yield gain of 11.2% when MF was used in trial one and 15.05% when MFTDB was used in trial two compared to sole crops. Beans recorded yield loss in all fertilizer types except in TDB which had a yield gain of 20.45%. The study recommends use of tithonia manure for bean production. The economic performance of the intercropping systems, affirmed that the most advantageous fertilizer type for maize was MFTDB with an Intercropping Advantage (IA) of 6.566 and the monetary advantage index (MAI) indicated a definite yield and economic advantages in maize-bean intercrop over their sole cropping with integrated nutrient being the most economical and advantageous fertilizer regime.

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LIST OF ABREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
A	Aggressivity
ANOVA	Analysis of Variance
AYL	Actual Yield Loss
CEC	Cation Exchange Capacity
CN ratio	Carbon Nitrogen ratio
CR	Competitive Ratio
IA	Intercropping Advantage
K	Relative crowding coefficient
LAI	Leaf Area Index
LER	Land Equivalence Ratio
LSD	Least Significant Difference
MF	Mineral Fertilizer
MAI	Monetary Advantage Index
NPK	Nitrogen (N), Phosphorus (P), Potassium (K)
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
TDB	*Tithonia diversifolia* Biomass
WF	Without Fertilizer

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Self-sufficiency in maize (*zea mays* L) production is a major strategy for achieving food security in Kenya. The strategy is adopted to avoid undue reliance on unstable and unpredictable world food markets and to generate incomes to farmers and landless labourers (Mousavi and Eskandari, 2011). However, pursuit of the self-sufficiency strategy can be costly and economically inefficient in resource allocation where land is scarce. Thus, conflicts among policy makers in the government can exist in using the self-sufficiency strategy to achieve food security. Apart from being grown for grain, maize can be produced 'green', or when it is grown to be consumed at an early stage when the cob is still green. It requires intense production when produced as a horticultural crop (Eskandari, 2012). There is however paucity of information on the best way to maximize the production of green maize. Research on ways of increasing the yield and quality of green maize will go a long way in alleviating poverty and improving the nutritional status of the growers and consumers. Production can be increased either by increasing output per unit area of land or by putting more land under production. However, land in the high rainfall areas of Kenya is limiting due to high population concentration in these areas. This situation has necessitated adoption of intercropping as a way of increasing the land food output (Itulya and Aguyoh, 1998).

Intercropping is a common practice in most small scale farming systems of Africa. Intercropping systems have been reported to be more productive than sole crops grown on the same land (Francis *et al*., 1982). Intercropping a non-legume with legume crop has been a traditional practice of peasant farmers in sub-tropical and tropical countries, where it has been observed that the yields of both crops are reduced when intercropped, compared to yields when they are grown alone, although the combined yields may be higher than individual yields (Eskandari, 2012). Intercropping is associated with greater yield stability, greater land-use efficiency, increased competitive ability toward weeds, improvement of soil fertility due to the addition of N by fixation, and some favorable exudates from legume species (Mousavi and Eskandari, 2011). Among the crops that have been intensely grown in a mixture with others is maize. Cereal-legume intercropping plays an important role in subsistence food production in both developed and developing countries, especially in areas with limited farm holdings and where farmers cannot afford inorganic fertilizers (Dahmardeh *et al*., 2010).

Legumes fix atmospheric nitrogen, which may be utilized by the host plant or may be released from the nodules into the soil and be used by other plants growing nearby (Partey *et al.*, 2011).

Eskandari, (2012) demonstrated that yield production under intercropping is higher than in sole cropping systems. This is because resources such as water, light and nutrients can be utilized more efficiently than in the respective sole cropping systems. Gosh *et al.* (2006) indicated that almost all reported intercropping combinations with a significant yield advantage involved non legume/legume combinations. Many legumes are preferred due to their inherent properties like short duration and ability to fix nitrogen. Muyayabantu *et al.* (2012) attributed the higher yields often observed in the intercrops to the more efficient utilization of the environmental resources. However, while most reports on intercrops have indicated increase in maize yields, Musambasi *et al.* (2012) reported a low maize yield when maize and cowpea (*Vigna unguiculata*) were intercropped and a high yield when maize and field beans *(Phaseolus vulgaris* L.) were intercropped.

Continuous and intensive use of highly priced synthetic fertilizer materials for boosting crop productivity in the past decades has obviously been linked to rapid decline in tropical soil fertility and crop productivity (Babajide *et al.*, 2012). In integrated nutrient management, nutrients from the organic manures are supplemented with inorganic nutrients that are readily available to plants (Gosh *et al.*, 2006). *Tithonia diversifolia* green biomass is an effective source of nutrients and has been used successfully to improve soil fertility and crop yields in Kenya (Jama *et al.*, 2000). Tithonia manure applied at rates above 3.6 t/ha resulted in enhanced growth, yield and sweetness of watermelon plants (Aguyoh *et al.*, 2010). The integration of tithonia biomass with mineral fertilizers is consequently essential to supply sufficient nutrients and would have added advantages, as compared to sole use of mineral fertilizers (Jama *et al.*, 2000).

Interactions among species play an important role in determining the structure and the dynamics of plant communities in agriculture (Aerts, 1999). When two crops are planted together, intra and/or inter specific competition or facilitation between plants may occur. Studies have shown that mixtures of cereals and legumes produce higher grain yields than either crop grown alone (Olufemi *et al.* 2001). The yield increase is not only due to improved nitrogen nutrition of the cereal component, but also to other unknown causes (Connolly *et al.*, 2001).

Several biological and agro-economic indices, such as land equivalent ratio, relative crowding coefficient, aggressivity, competitive ratio, actual yield loss, monetary advantage, and intercropping advantage, have been developed to describe the competitive and economic advantage of intercropping systems (Adetiloye *et al*., 2010); Banik *et al*., 2000; Ghosh, 2004; Banik *et al*., 2006; Dhima *et al*., 2007,). These indices are important for the evaluation and characterisation of intercropping systems, because they reflect the influence of the competition among the system's component crops. Their values can thus help to plan the association between crops and their cropping management. These indices, however, have not been used for evaluating competition between maize and beans in an intercropped system using integrated nutrient application. Substantial agronomic advantages from intercropping do not always ensure an economic advantage (Tamado and Eshetu, 2000). There is therefore need to assess the extent of such advantages, and a more satisfactory method would probably be to calculate the absolute value of the genuine yield advantage (Willey, 1979).

1.2 Statement of the Problem

As pressure on the agricultural lands increases due to increase in population, soil fertility declines due to continuous use of the same piece of land. To maintain soil fertility, farmers spend substantial amounts of their income on inputs such as inorganic fertilizers. Most farmers practice intercropping because of the perceived advantages such as expected greater yield stability, greater land-use efficiency and improvement of soil fertility due to the addition of N by fixation, however, there is paucity of knowledge on the extent of advantages of the intercrop and the use of local shrubs such as tithonia to enhance soil fertility. Although field studies by Gosh *et al*., (2006), Partey *et al*., (2011) and Muyayabantu *et al*., (2012) have been carried out to compare economically the sole crop yield when taken along with other crops in the system, agro-biological relationships amongst the maize-beans intercrops has not been well elucidated.

1.3 Objectives

1.3.1 General Objective

To contribute to the knowledge of the intercropping relationships and competition indices of maize intercropped with beans under integrated nutrient management system.

1.3.2 Specific Objectives

(a) To determine the effects of Tithonia green manure on growth and yield of maize and beans either planted as monocrop or intercrop

(b) To determine the effects of mineral fertilizer on growth and yield of maize and beans either planted as monocrop or intercrop

(c) To determine the biological efficiency of intercropping maize and beans

(d) To establish economic advantage of maize-beans intercrop

1.4 Hypothesis

(a) Application of Tithonia green manure has no effect on the growth and yield of maize and beans either planted as monocrop or intercrop

(b) Mineral fertilizer has no effect on the growth and yield of maize and beans either planted as monocrop or intercrop

(c) Intercropping has no effect on the biological efficiency of maize-beans intercrops

(d) There is no economic advantage in maize-beans intercrop

1.5 Justification

Maize is a heavy feeder of plant nutrients, and growing of this crop alone over the years will barren the land and cause decline in productivity. Inclusion of legumes in the cropping system has been advocated for by various researchers to sustain the soil health. Furthermore, maize harvested when green is in high demand, especially in populated areas and urban centers. In high productive areas where average farmland is less than 0.5 ha/household, maize harvested green should give fast return and allow for the planting of another crop. Grain legumes fix approximately 15 to 210 kg Nha^{-1} seasonally in Africa (Dakora and Keya, 1997). However, increased exploitation of this biological N is constrained by various environmental and nutritional factors, including the cropping patterns. Soil fertility determines the output per unit area of land. Intercropping non-legumes with leguminous crops is one of the methods of improving soil fertility. The study sort to assess the agro-biological efficiency of intercropping and establish the economic advantages of intercropping maize and beans, a realization that should encourage small holder farmers to commercially produce both green maize and beans, increase their consumption and improve on their health and living standards.

CHAPTER TWO

LITERATURE REVIEW

2.1 Cropping Systems

Cropping Systems is the sequence in which the crops are cultivated on piece of land over a fixed period and their interaction with farm resources and other farm enterprises (Tsubo *et al.*, 2005). There are several cropping systems; among them is mono cropping which in industrial crop production is used to facilitate planting and harvesting across large pieces of land as well as application of pesticides and fertilizers often using specialized equipment. Monocropping, however have reduced yields over time probably due to autotoxicity, a chemical substance released when one crop follows another of the same family (Reicosky *et al.*, 1997). Mixed cropping which is growing of two or more crops simultaneously on the same piece of land, Lehmann *et al.* (1998) strip cropping where soil conserving and soil depleting crops are grown in alternate strips running perpendicular to the slope of the land or to the direction of prevailing winds for the purpose of reducing erosion, and crop rotation where crops are changed from year to year according to a planned sequence (Ijoyah *et al.*, 2013). There are some basic principles considered when adopting a cropping system; crops should complement each other and share resources Reicosky *et al.* (1997) while utilizing the available resources efficiently. Strategies would include choosing plants with different nutrient uptake rates, different heights for even distribution of sunlight or different rooting patterns (Ofori and Stern, 1987). Other important considerations are a diversity of growth cycles and plants that keep the soil covered. Whatever the cropping system, it should maintain and enhance soil fertility, minimize spread of weeds, pests and diseases, conserve soil and water and use resources more efficiently while improving food and financial security by reducing risks of crop failure (Hauggaard-Nielsen *et al.*, 2007) Among the major cropping systems in the highly populated areas is intercropping.

Farmers practice intercropping systems to increase productivity and sustainability. The individual crops that constitute an intercrop can differ in their use of resources spatially, temporally, or in form, resulting in overall more complementary and efficient use of resources than when they are grown in sole cropping; thus decreasing the amount of available weeds (Hauggaard-Nieson *et al.*, 2001). Characteristics of any given cropping system can fundamentally alter the abiotic and biotic features of an agro-ecosystem and could modify the microenvironment of the crop. For example, a cropping system that reduces weed population may provide a weed suppressive foundation upon which cultural weed control could be laid (Tsubo *et al*., 2005).

2.2 Monocropping vs Intercropping systems in Maize and Bean

Most sustainable crop productivity researchers have associated intercropping to increased total productivity per unit area through maximum utilization of land, labour and growth resources (Craufard, 2000). Yields of intercropping are often higher than in sole cropping systems Lithourgidis *et al*. (2006), mainly due to resources such as water, light and nutrients that can be utilized more effectively than in sole cropping systems (Li *et al*., 2006). Maize, being the most important food crop in Kenya is in most cases intercropped with minor/companion crops. Maize based cropping systems are very popular in the tropics. In general, small scale farmers in sub-Sahara region practice maize/legumes association (especially maize-bean/cowpea intercropping) without using any fertilizer (Muyayabantu *et al*., 2012). In intercropping system, the cereal species are usually taller; they grow faster than the legume species. They also have extensive root system with large mass of fine roots (Lehmann *et al*., 1998). Intercropping kale and beans has shown increased productivity in terms of land equivalent ratios (LER) (Itulya and Aguyoh., 1998). Hazra *et al*. (1993) found that legume yields compensate for the loss of millet in the intercropped systems, increasing total green foliage yield by 11 to 29% and dry foliage yield by 5 to 23% over pearl millet grown alone. A study by Doss *et al*. (1981) reported greater marketable yields on no-rye plots than rye plots when tomato was grown with rye as a cover crop. Maize-cowpea sequential and pigeon pea/maize-intercropped systems produced, respectively, 17 and 24% higher maize yields than continuous sole maize (Rao and Mathuva, 2000). The annual grain legume based cropping systems were 32-49% more profitable than continuous sole maize. Total intercrop yield was greater than the sole crop yields. Intercropping soybean and maize gave land equivalent ratio (LER) values of 1.40 and 1.29 respectively indicating that higher productivity per unit area was achieved by growing the two crops together than by growing them separately (Ijoyah *et al*., 2013). A study by Obiero *et al*. (2013) reported that castor/beans intercrop was a better intercrop combination with resultant yields levels in the range of 2.15 - 2.43 and 0.3 - 0.83 tons seeds per hectare per year for an intercrop of castor (1.5 m × 1.0 m) with beans (0.5 m × 0.2 m) respectively.

In contrast, castor with maize intercrop gave low maize grain yield of between 0.01 – 0.25 tons ha^{-1} yr^{-1}. It was concluded that castor could be grown successfully with beans without straining food crop production. In addition an intercrop of castor with maize and beans would not have significant effect on the yield performance of castor. Pilbeam *et al.* (1994) warned that beans may fail to nodulate and fix nitrogen due to differences in the amount and distribution of rain in relation to crop growth. Branch number, pod number, and seeds/pod were major contributors to grain yield in beans (Obiero *et al*., 2013). Intercropping increases the sustainability of the crops in the cropping system, especially for small resource-poor farmers (Itulya *et al*., 1997).

Common bean (*Phaseolus vulgaris* L.) is an important herbaceous annual grain legume in the world, and is a cheap source of protein among majority of Sub-Saharan African people (Dzudie et al., 2002). In Kenya, field bean is the most important legume crop with its production spread over the counties (Anyango *et al*., 1998). Field bean grain contains about 25% protein and 64% carbohydrate. Field beans contributes to the sustainability of cropping systems and soil fertility improvement by providing ground cover and plant residues, fixing nitrogen, and suppressing weeds. A larger percentage of the nitrogen fixed goes towards meeting the crop's nitrogen requirement with some of the remainder, possibly, contributing towards meeting the nitrogen requirement for a crop that may be grown in association or following bean in a cropping schedule. In most cases beans are mainly grown by small-scale farmers in various types of intercropping systems with maize, millet, sorghum and other cereals (Singh *et al*., 2003). Under such cropping systems, beans not only offer diversification in available food stuffs, but also serve as a security crop in case of failure of the main crop.

Many authors including Egbe, (2010), Mucheru-Muna *et al.* (2010), Ndung'u *et al.* (2005), Obadoni *et al.* (2010), Okoth and Siameto, (2011) and Osman *et al.* (2011) have reported that maize grown where leguminous crops have been incorporated into the soil often gave better yield and yield components than maize plants grown in bare soils. This better performance has been attributed to increased total soil N resulting from biological fixed N and mineralized N from decomposed incorporated legume materials. It has also been reported that field bean green manure has the ability to increase soil nitrogen, Pushpavalli *et al.* (1994), release Singh *et al.* (1992); Palm *et al.* (1996) and maintain and renew the soil organic matter and improve the soil physical and chemical characteristics Tiwari *et al.* (1980). The low C: N ratio that is associated with most of the incorporated bean green manure often results into increased decomposition and mineralization of nutrients. This facilitates better uptake and accumulation of these nutrients for better maize growth and consequently, increased yield. Lelei *et al.* (2009) reported higher number of cobs and dry matter yields following leguminous fallow than natural fallow and attributed these to the supply of N through mineralization of the high quality residues. The breakdown of plant residues by soil microorganisms produces compounds that are resistant to decomposition like gums and resins. These compounds help soil particles stick together and form granules. Granulated soil has greater soil permeability and aeration, and better water holding capacity, so that seeds germinate quicker and root growth is easier (Clark, 2007). Mongi *et al.* (1976) found that legumes planted 3 weeks after maize had significantly reduced yields and therefore recommends planting legumes simultaneously with maize.

Intercropping of maize and beans is more economical than maize mono-cropping when phosphorous fertilizer is not applied as compared to applications of 30 or 60 kg P/ha (Mongi et al., 1976). The author also reported that alternate row intercropping gave 34% more monetary return than mono-cropped maize, while maize and beans planted in the same hills had an increase of 29% in monetary return. The addition of beans to the maize field provides an important protein supply for human and livestock consumption, improves soil fertility and structure, suppresses weeds, and insures against total crop failure when one crop fails (Mongi *et al.*, 1976).

2.3 Use of legumes in Intercropping

Intercropping legumes with non-legume can be a principal means of intensifying crop production both spatially and temporally, improving crop yields for smallholder farmers. Legume intercrops are a potential source of plant nutrients that compliment/supplement inorganic fertilizers (Jeranyama *et al.*, 2000). Legume intercrops have several socioeconomic biological and ecological advantages compared to sole cropping for small-holder farmers (Chemeda, 1997). In addition, certain legume crops provide food to humans and livestock (Jeranyama *et al.*, 2000). Utilizing soil and atmospheric nitrogen (N) is an important benefit of leguminous crops. In a study by Dabney *et al.* (2001), it was noted that release of N from legumes when used as green manure crops depend on species and growth stage of the crop and climatic condition, among other factors. Rapid mineralization of nitrogen by the green manure crops is advantageous in certain situations where crop nitrogen demand is high for early growth. On the other hand, slow release of N could be beneficial for crops that have a relatively longer growing season and peak nitrogen demand occurs after mid-bloom. To observe the amount of nitrogen provided by different leguminous crops in soil, Ebelhar *et al.*

(1984) conducted field experiments from 1977 through 1981 in Kentucky where they found that hairy vetch provided a significant amount of N regardless of applied N fertilizer rates.

Legumes fix atmospheric nitrogen, which may be utilized by the host plant or may be released from the nodules into the soil and be used by other plants growing nearby (Andrews, 1979). Legumes can also transfer fixed N to intercropped cereals during their joint growing period and this N is an important resource for the cereals (Shen and Chu, 2004). Legumes fix approximately 15 to 210 kg Nha^{-1} seasonally in Africa according to Dakora and Keya, (1997), and therefore, feature prominently in the cropping systems of traditional farmers. Field beans have great potential as green manure due to its rapid nitrogen accumulation and efficient nitrogen fixation (Franzluebbers *et al.*, 1994). However, increased exploitation of this biological N is constrained by various environmental and nutritional factors, including the cropping patterns used. In Africa where soil moisture often limits yields, research on neglected nitrogen fixing legumes would constitute a sound basis for increased sustainable production (Dakora and Keya, 1997). Karpenstein and Stuelpnagel, (2000) reported that at maturity, the amount of fixed nitrogen ranged between 178kg N for crimson clover and 242 kg N ha^{-1} for winter pea, respectively, and at the end of anthesis 75% and 85% of the total fixed nitrogen was achieved for clover and pea, respectively. Field beans can fix 73-354 kg Nha^{-1}year^{-1} (FAO, 1984). In a biological soil management project, nitrogen fixation was sufficient for a moderately yielding food-crop, but more intensive farming required additional input of N (Whitmore, 2000). There is growing interest worldwide in the use of organic fertilizer to replenish depletion in soil fertility and reduce pollution of the environment which frequently occurs as a result of the continuous use of chemical fertilizers. It is therefore, a worthwhile technology for adoption of an organo-mineral nutrient management approach which combines two major nutrient sources at reasonable proportions that are expected to improve crop production efficiency.

2.4 Integrated Nutrient Management

Addition of organic materials as soil amendments has been identified as an alternative approach to application of chemical fertilizers for improved soil fertility and crop productivity in the tropics, where most soils are relatively low in fertility. Continuous and intensive use of highly priced synthetic fertilizer materials for boosting crop productivity in the past decades has obviously been linked to rapid decline in tropical soil fertility and crop productivity (Babajide *et al.*, 2012). In integrated nutrient management, nutrients from the organic manures are supplemented with inorganic nutrients that are readily available to plants (Gosh *et al*., 2006). *Tithonia diversifolia* green biomass is an effective source of nutrients and has been used successfully to improve soil fertility and crop yields in Kenya (Jama *et al*., 2000). It has the ability to decompose and release its nutrients rapidly (Gachengo, 1999). Its abundance and adaptability to various environments coupled with rapid growth rate and very high vegetative matter makes it an important source of nutrients and organic matter for soil rejuvenation (Jama *et al*., 2000). *Tithonia diversifolia* commonly known as Mexican sunflower is a non nitrogen-fixing shrub of the Asteraceae family (Buresh and Niang, 1997; Jama *et al*., 2000). The shrub is common in some parts of Kenya. Green leaf biomass of tithonia is high in nutrients, and an on- farm research has demonstrated that soil fertility benefits are greater for green biomass than for dried biomass of tithonia (Jama *et al*., 2000).

Green biomass of tithonia has been recognized as an effective source of nutrients for lowland rice in Asia (Buresh and Niang, 1997; Jama *et al*., 2000), for maize in eastern and southern Africa (Jama *et al*., 2000). Tithonia manure applied at rates above 3.6 t/ha resulted in enhanced growth, yield and sweetness of watermelon plants (Aguyoh *et al*., 2010). The integration of tithonia biomass with mineral fertilizers is consequently essential to supply sufficient nutrients. The integration of tithonia and mineral fertilizers would have added advantages, as compared to sole use of mineral fertilizers (Jama *et al*., 2000). Assuming mean concentrations of 3.5 % N, 0.37 % P and 4.1 % K, green biomass of tithonia equivalent to 2 to 4 t dry matter ha $^{-1}$ will likely supply sufficient N (70 to 140 kg N ha^{-1}) and K (80 to 165 kg K ha^{-1}) to crops (Jama *et al*., 2000). Application of about 5 t dry matter ha $^{-1}$, which supplies about 18 kg P ha $^{-1}$, can overcome moderate P deficiencies, but does not overcome severe P deficiency, and therefore P must be supplied through commercial P sources (Jama *et al*., 2000). Positive effects of the application of inorganic fertilizers on crop yields and yield improvements had been documented (Carsky and Iwuafor, 1999). A study by Senaratne *et al*. (1993) reported improvement in the competitive ability of leguminous plants in legumes/grass mixture with K application. Nutrients are released more slowly from organic manure and they are stored for a longer time in the soil, thereby ensuring a long residual effect (Sharma and Mittra, 1991).

Nitrogen is one of the essential plant nutrients and a key determinant of crop productivity, but it is rapidly depleted from soil through leaching, plant uptake, denitrification, volatilization and erosion. Various means of providing nitrogen have various shortfalls. The supply of organic fertilizers in the form of farmyard manure, guano manure, tithonia and other manures acquired from livestock wastes is limited. Commercial fertilizers are expensive for most Kenyan farmers, while green manuring is unpopular, because no crop is produced. Grain legumes fix approximately 15 to 210 kg N ha^{-1} seasonally (Dakora and Keya, 1997). Nitrogen fixation accords pulse crops the potential to sustain or enhance total soil nitrogen fertility. Regional field experiments have shown that this potential is often not realized, because nitrogen fixation is inhibited by the supply of nitrate in the root zone, coupled with a low demand for N during plant growth (Shwenke *et al.*, 1998). Although the majority of farmers in this region do not use organic or inorganic fertilizers, fertilizers may be beneficial depending on soil fertility. On the low-fertility site, the addition of 45 kg/ha of nitrogen fertilizer resulted in a 2.5 to 3.5 fold increase in maize and sesame sole cropped yields respectively (Mkamilo, 2004). However, the medium-high fertility site showed no benefit from fertilization. Phosphorous fertilizer at an application rate of 40 kg P_2O_5/ha had no significant effect on either soil type, as it was not a limiting factor in the soil. When nitrogen fertilizer was added to the intercrop, it increased the maize yield, but significantly reduced the sesame yield due to increased inter-crop competition, making the benefits of fertilizer negligible (Mkamilo, 2004). Soil nutrient mining may become a problem if other practices such as crop rotation or fallowing are not employed. Moderate levels of inorganic fertilizer may be beneficial in the long run. According to Gosh *et al.* (2006), imbalanced nutrient application coupled with low N and P content represent major constraints that limit crop productivity in intercropping systems in many soils.

The continuous use of inorganic fertilizers has been associated with an increase of soil acidity, nutrient imbalances and soil degradations. This shortcoming of inorganic (mineral) fertilizer use has motivated many researchers to explore an ecological approach for efficient nutrient management (Ayoola and Makinde, 2008). Application of organic manure alone to sustain cropping has been reported to be inadequate due to their relatively low nutrient contents and their inability to provide a sufficient amount of nutrients (Palm *et al.*, 1997). Integrated nutrient management approaches, in which both organic manure and inorganic fertilizers are used, have been suggested as an efficient approach for crop production (Palm *et al.*, 1997).

2.5 Agro-biological Efficiency

Interactions among species play an important role in determining the structure and the dynamics of plant communities in agriculture (Aerts, 1999). Increased diversity of the physical structure of plants in an intercropping system produces many benefits. Increased leaf tithonia and other manures acquired from livestock wastes is limited. Commercial fertilizers are expensive for most Kenyan farmers, while green manuring is unpopular, because no crop is produced. Grain legumes fix approximately 15 to 210 kg N ha^{-1} seasonally (Dakora and Keya, 1997). Nitrogen fixation accords pulse crops the potential to sustain or enhance total soil nitrogen fertility. Regional field experiments have shown that this potential is often not realized, because nitrogen fixation is inhibited by the supply of nitrate in the root zone, coupled with a low demand for N during plant growth (Shwenke *et al*., 1998). Although the majority of farmers in this region do not use organic or inorganic fertilizers, fertilizers may be beneficial depending on soil fertility. On the low-fertility site, the addition of 45 kg/ha of nitrogen fertilizer resulted in a 2.5 to 3.5 fold increase in maize and sesame sole cropped yields respectively (Mkamilo, 2004). However, the medium-high fertility site showed no benefit from fertilization. Phosphorous fertilizer at an application rate of 40 kg P_2O_5/ha had no significant effect on either soil type, as it was not a limiting factor in the soil. When nitrogen fertilizer was added to the intercrop, it increased the maize yield, but significantly reduced the sesame yield due to increased inter-crop competition, making the benefits of fertilizer negligible (Mkamilo, 2004). Soil nutrient mining may become a problem if other practices such as crop rotation or fallowing are not employed. Moderate levels of inorganic fertilizer may be beneficial in the long run. According to Gosh *et al*. (2006), imbalanced nutrient application coupled with low N and P content represent major constraints that limit crop productivity in intercropping systems in many soils.

The continuous use of inorganic fertilizers has been associated with an increase of soil acidity, nutrient imbalances and soil degradations. This shortcoming of inorganic (mineral) fertilizer use has motivated many researchers to explore an ecological approach for efficient nutrient management (Ayoola and Makinde, 2008). Application of organic manure alone to sustain cropping has been reported to be inadequate due to their relatively low nutrient contents and their inability to provide a sufficient amount of nutrients (Palm *et al*., 1997). Integrated nutrient management approaches, in which both organic manure and inorganic fertilizers are used, have been suggested as an efficient approach for crop production (Palm *et al*., 1997).

2.5 Agro-biological Efficiency

Interactions among species play an important role in determining the structure and the dynamics of plant communities in agriculture (Aerts, 1999). Increased diversity of the physical structure of plants in an intercropping system produces many benefits. Increased leaf cover in intercropping systems helps to reduce weed populations once the crops are established (Beets, 1990). Having a variety of root systems in the soil reduces water loss, increases water uptake and increases transpiration. The increased transpiration may make the microclimate cooler, which, along with increased leaf cover, helps to cool the soil and reduce evaporation. Cecílio Filho *et al.* (2010) evaluated the economics of intercropping tomato and lettuce in greenhouses. They observed that this cropping system provided an increase in net income of up to 14.8% over the individual cropping of tomato and up to 85% over the individual cropping of lettuce. According to these authors, optimizing greenhouse conditions, labour and inputs contributed to the reduced cost of production and thus to the increased profitability of the intercropping system. This is important during times of water stress, as intercropped plants use a larger percentage of available water from the field than mono-cropped plants. Rows of maize in a field with a shorter crop will reduce the wind speed above the shorter crops and thus reduce desiccation (Beets, 1990). Increased plant diversity in intercropped fields may reduce the impact of pest and disease outbreaks by providing more habitats for predatory insects and increasing the distance between plants of the same crop. Hauggaard-Nieson *et al.* (2001) found that there was an increased efficiency in utilizing environmental resources for plant growth and a better competitive ability towards weeds as compared to sole crops. Baumann *et al.* (2002) reported that intercropping increase light interception by the weakly competitive component and can, therefore, shorten the critical period for weed control and reduce growth and fecundity of late-emerging weeds. The apparent increased competitiveness of intercropping systems makes them potentially useful for adoption into low in-put farming systems in which options for chemical weed control are reduced or non-existent (Hauggaard-Nielsen *et al*., 2007).

When two crops are planted together, intra and/or inter specific competition or facilitation between plants may occur. The system of intercropping is an important factor which affects the quantity on N fixed by legumes (Carr *et al*., 2004). The differences in the depth of rooting lateral root spread and root densities are some of the factors that affect competition between the component crops in an intercropping system for nutrients. The cereal component, maize, usually is taller, has a faster growing or more extensive root system, particularly a larger mass of fine roots and is competitive for soil nitrogen (Carr *et al*., 2004). This forces the legumes component, beans, to fix N from the atmosphere (Hauggaard-Nieson *et al*., 2001). This is expressed as a facilitative effect of intercrop components, meaning that maize and beans have complementary effect in consuming nitrogen. Maize receives its required nitrogen from soil and beans from biological fixation of atmospheric N. in intercrops, it gives maize more nitrogen, leading to more N uptake, and therefore, more crude protein of maize in intercropping compared with its sole crop. Studies have shown that mixtures of cereals and legumes produce higher grain yields than either crop grown alone (Olufemi *et al.*, 2001). The yield increase is not only due to improved nitrogen nutrition of the cereal component, but also to other unknown causes (Connolly *et al.*, 2001). Competition among mixture is thought to be a major aspect affecting yield as compared with sole cropping of cereals (Ndakidemi, 2006) and a number of indices that are important for the evaluation and characterisation of intercropping systems, as they reflect the influence of the competition among the system's component crops.

Indices such as land equivalent ratio (LER) indicate the efficiency of intercropping for using the resources of the environment compared with mono cropping. When LER is greater than 1, the intercropping favors the growth and yield of the species. In contrast, when LER is lower than 1, the intercropping negatively affects the growth and yield of plants grown in mixtures (Caballero *et al.,* 1995; Dhima *et al.*, 2007; Ofori and Stern, 1987). The competitive ratio (CR) assesses the competition between different species, and represents simply the ratio of individual LERs of the two component crops. Competitive Ratio takes into account the proportion of the crops in which they are initially sown in the intercrop. Other coefficients used include the relative crowding coefficient (K) and Aggressivity (A) which measures the relative dominance of one species over the other in a mixture and indicates how much the relative yield increase in crop 'a' is greater than that of crop 'b' in an intercropping system (Bantie *et al.*, 2014) and the actual yield loss (AYL) index; which according to Banik *et al.* (2000) gives more precise information about the competition than the other indices between and within the component crops and the behaviour of each species in the intercropping system, as it is based on yield per plant. The AYL is the proportionate yield loss or gain of intercrops in comparison to the respective sole crop.

2.6 Economics of Intercropping

The principal reasons for smallholder farmers to intercrop are flexibility, profit maximization, risk minimization against total crop failure, soil conservation and improvement of soil fertility, weed control and balanced nutrition (Shetty *et al.,* 1995). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field (Thobatsi, 2009). According to Seran and Brintha (2010) the intercropping system provides higher cash return to smallholder farmers than growing the mono crops. Gunasena *et al.* (1978) studying maize-soybean intercropping system, found that the gross economic returns were increased by the intercropping. On the other hand, using monetary advantage index (MAI), Osman *at al.* (2011) reported that intercropping with two rows of cowpea and one row of millet gave significantly higher economic benefit than mixture with one row of each of the crops. Using the same MAI, Oseni (2010) found that intercropping with two rows of sorghum and one row of cowpea gave higher economic return compared to the other planting arrangements and the sole crops. These observations suggest that intercropping could improve the system's productivity, increase the income for smallholder farmers, and compensate losses (Osman *et al.*, 2011).

The monetary equivalent ratio (MER) measures the economic advantage of intercropping over the sole crop that has the largest economic return. When the yield advantage of an association of cassava-cowpea-maize was assessed, Ghosh (2004) found that the economic advantage of intercropping was only 6-14 percent (MER = 1.06-1.14) even though the agronomic advantage ranged from 12-63 percent when assessed with the land equivalent ratio (LER = 1.12-1.63). However, in a cassava-okra-maize- cowpea association, the agronomic advantage ranged from 2-25 percent (LER = 1.02-1.25). The MER indicated no economic advantage and the efficiency of the system was only 50-62 percent of the most economic sole crop, which was cassava.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

The study was conducted at a private farm next to Kimathi University in Nyeri, Kenya. The field lies at latitude of 0°26'38"N and longitudes 36°58'53" East at an altitude of approximately 1815m above sea level, in the eastern slopes of Aberdare ranges, in Nyeri County. The minimum and maximum mean temperatures are 12.2°C and 23.2°C, with an average annual rainfall of 928 mm. The soils are well drained, extremely deep dark reddish brown, friable clay with an acidic humic top soil (Jaetzold and Schmidt, 2006). The area is predominated by coffee and horticultural crops such as beans, Irish potatoes, and cabbages among others.

The highest and lowest rainfall received during the study period were 159.8 mm (May) and 16.8 mm (July) in trial one and 123.0 mm (Nov) and 17.0 mm (Sept) in trial two (Figure 1). The mean maximum and minimum temperatures for trial one were 28°C (Mar) and 23.1°C (Jul) while for trial two was 26.2°C (Sept) and 22.8°C (Nov) respectively, with mean temperature of 24.8°C and 23.8°C in trial one and two, respectively.

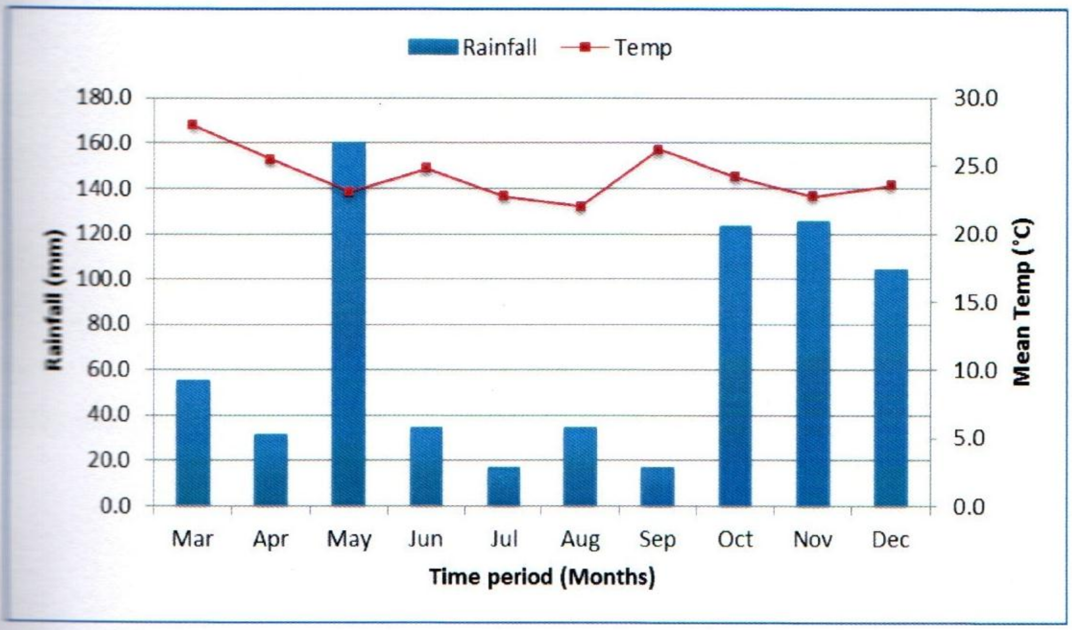

Figure 1: Monthly rainfall and temperature during the study period (Source- Muringato Forest Meteorological Department, 2014)

3.2 Experimental Design and Treatment Application

The study was conducted in three components. The first component consisted of maize alone, the second was an association of maize and beans and the third was of beans alone. The experimental design was randomized complete block (RCBD) with four treatments and three replications. Four fertilizer methods were studied, traditional method or Without Fertilizer (WF) was the control; Conventional method or Mineral (inorganic) Fertilizer (MF) 17-17-17 at 150 kg/ha; Biological method consisting of the application of Tithonia biomass (TDB) alone at 8 t ha^{-1} and integrated nutrient management method consisting of the application of MF 17-17-17 at 100kg/ha combined with Tithonia at 4 t ha^{-1} ½ (MF+TDB). The treatment combinations are shown in table 1 below.

Table 1: Treatment combinations

Treatment	Rate of organic and inorganic fertilizer
WF	Zero (Control)
MF	17.17.17 at 150 kg/ha
TDB	TDB at 8 t/ha
MFTDB	17.17.17 at 100 kg/ha and TDB at 4 t/ha

WF- Without Fertilizer – Control, **MF-** Mineral fertilizer, **TDB-** *Tithonia diversifolia* biomass

The experiment covered an area of 33 m by 18 m with each component covering 18×10m which was separated by a 1 m buffer. Individual plot measured 3 m by 4 m (12 m^2) with an inter-plot spacing of 0.5 m. (Figure 2).

TDB	MF	TDB+MF	WF
MF	TDB	WF	TDB+MF
WF	MF	TDB+MF	TDB

Component 1 – Maize alone

WF	TDB+MF	TDB	MF
MF	WF	TDB+MF	TDB
TDB	TDB+MF	MF	WF

Component 2-Maize/Bean intercrop

TDB	TDB+MF	MF	WF
WF	MF	TDB	TDB+MF
MF	WF	TDB+MF	TDB

Component 3 -Beans only

Figure 2: Experimental layout showing the cropping components in Randomized Complete Block Design (RCBD)

Key:
WF- Without Fertilizer – Control, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

3.3 Tithonia Manure Preparations

Tithonia biomass from green leaves and young tender branches was obtained from nearby shrubs, cut and shredded (into smaller fragments of less than 5 cm in length with stem girths ranging from 2.8 cm to 4.2 cm) as described by Jama *et al.* (2000). Fresh Tithonia biomass was incorporated into the soil at 15 cm depth, three days before planting to initiate decomposition Jama *et al.*, (2000).

3.4 Soil and Manure Analysis

Soil and manure analysis was conducted at the Soil Cares laboratory in Karen (Nairobi). For the initial soil and tithonia biomass characterization, the top 0-15 cm of the soil profile was sampled following a zigzag sampling design at various points across the entire experimental field using a soil auger after which a composite sample was delivered for chemical analysis. Tithonia biomass was cut, chopped into small parts and delivered fresh for chemical analysis. At the end of each trial, other soil samples were taken from each plot from within the top 0-15 cm.

Prior to near-infrared analyses, they were oven dried, hand cleaned to remove foreign particles and ground to pass through a 2 mm sieve. The diffuse reflectance spectra of the samples were recorded with a FTS-3000 near-infrared spectrometer set in the near-infrared region (1000-2500 nm). The resolution of the instrument was 32 cm^{-1} and 64 scans were recorded. The light source was a Tungsten-Halogen lamp with a Calcium Fluoride (CaF_2) beam splitter and a lead selenite (PbSe) detector was used. The sample cup had a 10 mm diameter and a 2.3 mm depth. The spectrum for each sample was produced from 30 data points and the spectral data were recorded as log 1/R (R: Reflectance) with a background taken by the pure soil sample. The near infrared reflectance data was processed with genetic inverse least squares method to predict the nutrient amounts in the samples. A calibration set was used in the development of calibration model and a validation set to verify the prediction ability of the developed model were prepared in the form of text files (Chang and Laird, 2002).

Initial soil analysis and chemical composition of tithonia manure results are shown in Table 2 and 3, respectively.

Table 2: Initial soil analysis from the experimental site

Parameter	Units	Value
pH	pH Value	5.2
Organic carbon content	g/kg	39.7
Total nitrogen content	g/kg	3.09
Phosphor stock	mmol P/kg	9.5
K (exch. Potassium)	mmol+/kg	5.6
Mg (exch. Magnesium)	mmol+/kg	35.8
Ca (exch. Calcium)	mmol+/kg	108
Cation Exchange Capacity	mmol+/kg	178
Clay content	g/kg	720
Sand content	g/kg	70

Table 3: Chemical composition of tithonia biomass manure

Parameter	Units	Value
pH	pH Value	6.53
Organic carbon content	g/kg	29.57
Total nitrogen content	g/kg	2.5
Phosphor stock	mmol P/kg	0.34
K (exch. Potassium)	mmol+/kg	3.2
Mg (exch. Magnesium)	mmol+/kg	44
Ca (exch. Calcium)	mmol+/kg	60
Cation Exchange Capacity	mmol+/kg	168

3.5 Planting Material

Maize (Duma 43) and bean (Mwitemania) seeds from Kenya Seeds Company were sourced from a local agro-supplier in Nyeri. Both crop varieties are high yielding and early maturing besides being ecologically suitable for the area.

3.6 Land Preparation and Planting

Clinic^R 480 SL a post emergence non selective herbicide was initially sprayed to control annual and perennial weeds, especially grasses, before the land was manually ploughed and harrowed to a depth of 30 cm. Plot demarcation was done and shredded tithonia biomass applied and incorporated thoroughly into the soil at rates of 4 and 8 tonnes/ha (4.8 and 9.6 kg/plot) days before planting. Supplementary irrigation was done before planting. Mineral fertilizer (17:17:17) was applied and mixed with the soil at rates of 100 and 150 kg/ha based on treatment during planting. Three Maize seeds per hole were sown at a spacing of 0.75 m × 0.5 m and 1 m × 0.5 m in mono crop and intercrop respectively. Maize in association plots were intercropped with beans at a spacing of 0.20m in row. In monoculture, three beans seeds were sown at 0.5 m × 0.20 m. Two weeks after sowing (WAS), maize and bean seedlings were thinned to two plants per stand to achieve recommended population of 64 plants per plot in sole maize, 240 plants per plot in sole bean and 48 maize and 160 bean plant in the maize-bean intercropped plots.

3.7 Routine Plant Maintenance Practices

Standard good agricultural practices were observed in the entire experimental area. Watering was continuously done to field capacity as need arose. Thinning was carried out on the second week of planting while first and second weeding were done on fourth and tenth week respectively after planting. Aphids in beans were controlled by application of 1.2 kg ha^{-1} Karate (R) (10 % EC cypermethrin) while maize stalk borer pest was controlled using Deraphon granules (0.5% W/W Cypermethrin) Pesticides.

3.8 Data Collection

Data was collection in the following areas, growth and yield parameters, yield components and agro-biological efficiency indices.

3.8.1 Growth Parameters

Maize and bean plant heights was measured on five randomly selected and tagged plants using a meter tape from the ground to the top of the shoot fortnightly and recorded in centimeters. Stem diameter (mm) of the five tagged plants of the two crops (maize and beans) was measured using a vanier caliper at a height of 10 cm from the ground. The number of leaves for both crops was recorded at harvesting.

3.8.2 Yield Parameters

Maize was harvested green after attaining physiological maturity. Days to 50% tasselling was recorded. Total number of cobs and weight from ten plants was taken. Number of rows, diameter and length of the cobs was also recorded. For beans, total number of pods per plant was counted from ten randomly selected plants; the number of grains per pod, diameter and length of pods and weight of beans was taken using a weighing balance.

3.8.3 Yield component indices

Data on the following yield component indices were taken;

a. Intercrop Expected Yield (IEY)

Maize and bean intercropping expected yield was estimated based on the following

Formula: $IEY = MOY \times DIS/DIM$……………………………………………………Equation (1)

Where, IEY is the intercropping expected yield; MOY is the mono crop obtained yield for each crop; DIS and DIM are the crop's density in intercropping and mono cropping systems. The information was useful in:

(a) Determination of mutual inhibition and under-performance yield when the intercropping obtained yields for each crop in the association is lower than its corresponding intercropping expected yield

(b) Determination of the level of cooperation when the intercropping obtained yields for each crop in the association is higher than its corresponding intercropping expected yield (Willey, 1979).

b. Bean Equivalent Yield

As it is difficult to compare the performance of two different crops in intercropping system (maize and bean), maize yields was converted into bean equivalent yield (BEY) as described by (Prasad and Srivastava, 1991)

$$BEY\ (t/ha) = \frac{\text{Yield of maize x unit price of maize}}{\text{Unit price of bean}}$$ …………………………… Equation (2)

The current market price of these two crops was used in calculating BEY in intercrop or in sole. The BEY in intercropping is yield of intercrop beans plus BEY of intercrop maize.

The difference between BEY in the intercrop and BEY in the sole represent the agronomic intercropping advantage (AIA) over respective sole crops

3.9 Assessing Agro-biological Efficiency using competition indices

The following parameters were determined:

3.9.1 Land Equivalent Ratio (LER)

LER verifies the effectiveness of intercropping for using the resources of the environment compared to sole cropping. The Intercrop advantage was calculated through the determination of land equivalent ratio. The LER were calculated as follows:

$LER = (Yab/Yaa) + (Yba/Ybb)$...Equation (3)

Where Yaa and Ybb were yields of sole crops for Maize (a) and beans (b) and Yab and Yba are crop yields in intercrops for maize and beans. Values of LER greater than 1 were considered advantageous (Ofori and Stern, 1987).

3.9.2 Relative Crowding Coefficient (K)

Relative Crowding Coefficient (K) measures the dominance of one species over the other in a mixture. The relative dominance of maize over beans was calculated as follows:

$K = (Ka \times Kb)$ ....Equation (4),

Where, $Ka = Yab \times Zba / (Yaa-Yab) \times Zab$ and $Kb = Yba \times Zab / (Ybb-Yba) \times Zba$, Where, Zab and Zba were the respective sown proportions (based on seed numbers) of maize and beans in the intercropping systems (Dhima *et al.*, 2007). There is an intercrop advantage when the value of K is greater than 1, no intercrop advantage when K is equal to 1 and an intercrop disadvantage when K is less than 1.

3.9.3 Competitive Ratio (CR)

Competitive ratio (CR) indicates the number of times by which one crop or species is more competitive than the other. The CR represents the ratio of individual LERs of the two component crops and takes into account the proportion of the crops on which they are initially sown. Relative species competition is often evaluated using competitive ratios (Adetiloye *et al.*, 2010) . The CR index was calculated as follows:

$CRa = La/Lb \times Zba/Zab$ and $CRb = Lb/La \times Zab/Zba$..................................Equation (5),

Where CRa is the competitive ratio of maize and La and Lb are the partial LERs of maize and beans respectively, Zba is the proportion of maize in the maize/bean intercrop and Zab is the proportion of beans in the maize/bean intercrop. If $CRa > 1$, there is a positive benefit and the rop can be grown in association; if $CRa < 1$, there a negative benefit. The reverse is true for Rb.

3.9.4 Aggressivity (A)

Aggressivity is an index that represents a simple measure of how much the relative yield increase in maize is greater than that of beans and vice versa in an intercropping system. It was calculated based on the following equation:

$Aa = (Yab/Yaa \times Zab) - (Yba/Ybb \times Zba)$ and

$Ab = (Yba/Ybb \times Zba) - (Yab/Yaa \times Zab)$..Equation (6),

Where Yaa and Ybb are yields of sole crops of maize and beans respectively and Yab and Yba are yields of intercrops of maize and beans. Zab and Zba are the sown proportions of maize and beans in intercrop maize/beans, respectively. If Aa = 0, both crops are equally competitive; if Aa is positive, maize is dominant and if Aa is negative, maize is the dominated crop and likewise for beans. (Gosh *et al.*, 2006).

3.9.5 Actual Yield loss (AYL)

Actual Yield loss (AYLa or AYLb) represents the proportionate yield loss or gain of each species when grown as intercrops, relative to their yield in pure stand. The AYL was calculated according to the formula by Banik *et al.* (2000),

$AYLab = AYLa + AYLb$... Equation (7),

$AYLa = (Yab/Zab/Yaa/Zab) - 1$ and $AYLb = (Yba/Zba/Ybb/Zba) - 1$. Where Yaa and Ybb are the yields of maize and beans, respectively, as sole crops and Yab and Yba are the yields of maize and beans in the maize/beans intercrops. Zab and Zba are proportion of maize and beans, respectively. Positive AYL indicate an advantage while negative value indicate disadvantage of the intercrop when the main objective is to compare yield on individual plant basis.

3.10 Determination of Economic Advantage

The following economic advantage parameters were determined:

3.10.1 Monetary advantage index (MAI)

The economic performance of intercropping was evaluated to determine if the combined yields of maize and beans are high enough for the farmers to adopt the system. The monetary advantage index (MAI) was calculated as:

MAI = (value of combined intercrops) (LER-1) / LER; ....Equation (8),

The higher the MAI value, the more profitable the cropping system is (Ghosh, 2004).

3.10.2 Intercropping advantage (IA)

Intercropping advantage (IA) which estimates the economic advantage of the intercrop was calculated using the following formula given by Banik *et al*. (2000),

$IAma = AYLma \times Pma$ and $IAb = AYLb \times Pb$ .... Equation (9),

Where Pma is the commercial value of maize yield (the current price per 110 kg bag of green maize is Ksh 4800), and Pb is the commercial value of beans, the current price per 90 kg bag of beans is Ksh 5400 (Kenya Agricultural Commodity Exchange, 2013).

3.11 Data Analysis

Data was subjected to analysis of variance (ANOVA) using SAS version 9.1. Treatment means were separated by Duncan Multiple Range Test at $P \leq 0.05$ levels. The RCBD model to be fitted for the experiment was: $\mathbf{Y_{ij} = \mu + T_i + \beta_j + \varepsilon_{ij}}$

$i = 1, 2, 3, 4; \quad j = 1, 2, 3$

Where; Y_{ij} -Crop response

μ -grand mean,

T_i -i^{th} Treatment effect,

β_j -j^{th} blocking effect,

ε_{ij} -random error component which are normally and independently distributed about zero means with a common variance σ^2.

CHAPTER FOUR

RESULTS

4.1 Growth Parameters

4.1.1 Effects of tithonia biomass and mineral fertilizer on maize and bean plant height and diameter

Maize and bean plant heights were influenced by tithonia biomass and mineral fertilizer either used alone or in combination both in mono crops and intercrops in both trials. In maize plants, trial two generally recorded higher height than trial one; and intercropped maize exhibited higher height than sole maize in all the treatments. Maize height in sole cropping was not significantly different in the first two weeks after planting for both trials. However, the height, progressively increased in subsequent sampling dates with the highest being MFTDB with 31% and 12% compared to the control at 84 DAP (at tasselling) in trials one and two respectively. Similar trends were observed in both trials in plots planted with maize and beans (Tables 4 and 5).

Table 4: Effect of tithonia manure and mineral fertilizer on maize plant height (cm) in trial one

	Fertilizer	Days After Planting					
	Type	14	28	42	56	70	84
Monocrop Maize	WF	3.56a*	9.93a	22.50b	59.60a	83.05c	146.00c
	MF	3.28a	9.93a	24.03b	58.53a	98.40b	196.00ab
	TDB	3.23a	9.07a	21.87b	65.00a	90.30bc	166.00bc
	MFTDB	3.67a	11.00a	30.27a	65.67a	112.71a	210.33a
Intercrop Maize	WF	3.58ab	10.4ab	28.53a	59.27b	100.40b	154.67c
	MF	3.82a	11.53a	29.47a	64.87ab	107.16ab	199.33ab
	TDB	3.40b	9.20b	25.53b	69.53ab	111.09ab	180.00bc
	MFTDB	3.62ab	10.0b	29.13a	73.60a	117.97a	219.00a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

WF- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 5: Effect of tithonia manure and mineral fertilizer on maize plant height (cm) in trial two

	Fertilizer	Days after planting					
	Type	14	28	42	56	70	84
Monocrop Maize	WF	4.63a*	12.17c	26.47c	56.83ab	112.47b	183.00b
	MF	4.43a	14.00bc	34.13ab	64.50ab	138.23a	200.67a
	TDB	4.19a	14.73ab	31.43b	53.83b	140.67a	198.17ab
	MFTDB	4.63a	16.20a	35.87a	69.33a	143.10a	207.83a
Intercrop Maize	WF	4.97ab	12.73c	27.73b	52.20b	87.13c	158.83b
	MF	4.82a	13.60bc	29.90ab	68.00a	127.03ab	196.50a
	TDB	4.42b	15.03b	26.80b	65.83a	115.87b	191.00a
	MFTDB	4.62ab	17.67a	33.53a	73.67a	133.10a	203.00a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

WF- Without fertilizer, **MF-** Mineral fertilizer, **TDB-** *Tithonia diversifolia* biomass

Application of tithonia manure and mineral fertilizer generally increased the diameter of maize plants. Trial one maize plant had a wider stem diameter than those of trial two; and sole maize plants diameter exceeded that of mixed maize plants in both trials. Maize diameter was higher at 42 DAP in trial one when MFTDB was used (1.99 cm) compared to only 1.40 cm in control, although was not significantly different at 56 DAP. In mono crop maize the diameter was significantly different at 42 DAP for trial two, with mineral fertilizer and tithonia manure producing the widest at 1.76 cm compared to 1.31 cm in the control. In the intercropped maize, diameter at 42 and 56 DAP significantly increased by 62% and 24% respectively, when integrated nutrient was applied (Table 6 and 7).

Table 6: Effect of tithonia manure and mineral fertilizer on diameter (cm) of maize plant in trial one

	Days After Planting					
Fertilizer	Monocrop Maize			Intercrop maize		
Type	28	42	56	28	42	56
WF	0.67a*	1.67a	2.24b	0.71a	1.40b	2.42a
MF	0.70a	1.74a	2.33ab	0.82a	1.90ab	2.43a
TDB	0.70a	1.92a	2.36ab	0.65a	1.61ab	2.33a
MFTDB	0.83a	1.63a	2.63a	0.80a	1.99a	2.33a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

WF- Without fertilizer, **MF-** Mineral fertilizer, **TDB-** *Tithonia diversifolia* biomass

Table 7: Effect of tithonia manure and mineral fertilizer on diameter (cm) of maize plant in trial two

	Days After Planting					
Fertilizer	Monocrop Maize			Intercrop Maize		
Type	28	42	56	28	42	56
WF	0.52a*	1.31b	2.23b	0.58c	0.76c	2.17c
MF	0.62a	1.76a	2.63a	0.82ab	1.80ab	2.50b
TDB	0.52a	1.76a	2.50ab	0.65bc	1.38b	2.41b
MFTDB	0.63a	1.63ab	2.76a	0.89a	2.00a	2.87a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

WF- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Beans recorded almost similar heights in the monocrop and intercrop in both trials. The tallest beans were recorded where integrated nutrient was applied whether grown singly or in a mixture. A significant difference was recorded in trial two for intercropped beans 28 DAP where the height of beans in the integrated nutrient application was 32.8%, tithonia manure was 19% and mineral fertilizer was 11.4% higher than the control. Beans height increased at 42 DAP which coincided with flower initiation (Tables 8 and 9).

Application of tithonia manure and mineral fertilizer had minimal effect on the diameter of bean plants. Some significant difference was however observed at 42 DAP where the mean diameter was 0.63 cm for MFTDB, 0.59 cm and 0.57 cm for MF and TDB respectively compared to 0.53 cm for the control in trial two (Tables 8 and 9).

Table 8: Effect of tithonia manure and mineral fertilizer on height and diameter (cm) of bean plant in trial one

	Fertilizer Type	Days After Planting					
		Height				Diameter	
		14	28	42	56	28	42
Monocrop Bean	WF	5.24a[*]	11.63a	23.07a	75.40b	0.45a	0.45a
	MF	6.08a	12.90a	25.47a	85.20ab	0.48a	0.48a
	TDB	5.89a	12.35a	27.53a	80.73b	0.49a	0.49a
	MFTDB	6.21a	12.54a	29.20a	93.73a	0.51a	0.55a
Intercrop Bean	WF	7.44a	14.33a	41.8a	52.56a	0.53a	0.64a
	MF	4.9a	11.03a	21.87a	83.27a	0.53a	0.64a
	TDB	5.1a	11.3a	23.53a	85.6a	0.49a	0.63a
	MFTDB	4.92a	11.07a	23.8a	85.97a	0.55a	0.65a

[*] Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

WF- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 9: Effect of tithonia manure and mineral fertilizer on height and diameter (cm) of bean plant trial two

	Fertilizer Type	Days After Planting					
		Height				Diameter	
		14	28	42	56	28	42
Monocrop Bean	WF	5.57b[*]	12.07a	27.33b	50.20c	0.45a	0.48a
	MF	6.46ab	14.40a	38.67a	71.80b	0.47a	0.52a
	TDB	5.93ab	12.75a	33.33ab	66.20b	0.45a	0.48a
	MFTDB	6.60a	13.43a	40.03a	92.60a	0.50a	0.56a
Intercrop Bean	WF	5.30a	13.17c	28.93b	67.77b	0.48a	0.53c
	MF	5.53a	14.67bc	35.83a	77.77a	0.55a	0.59ab
	TDB	5.25a	15.67b	33.53ab	83.27a	0.48a	0.57bc
	MFTDB	5.73a	17.50a	35.97a	83.90a	0.54a	0.63a

[*] Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$.

WF- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.1.2 Effect of tithonia manure and mineral fertilizer on selected growth parameters in maize

Application of tithonia manure and mineral fertilizer influenced the number of leaves at flowering in maize and also the number of day's maize took to 50% tasseling. In trial one, the number of leaves recorded were not statistically significant from each other, while in trial two, the number of leaves differed significantly with MFTDB at 10.23, MF and TDB at 9.77 and 9.5 respectively and only 8.5 for control (Tables 10 and 11). Application of tithonia manure and mineral fertilizer delayed flowering in maize whether grown singly or in a mixture for both trial one and two. The WF (control) attained 50% tasselling at 65 days, MF at 67 days, MFTDB at 68 days and TDB at 69 days for sole maize trial one. Generally maize took fewer days to flower in trial one than trial two. Leaf area of maize was significantly influenced by application of tithonia manure and mineral fertilizer whether planted singly or in combination for both growing trials. In sole maize trial one, the leaf area increased with application of tithonia manure and mineral fertilizer; with integrated nutrient treatment having the highest at 3101 cm^2 compared to 1909cm2 in control. In trial two, the leaf areas of maize were not significant from each other except from the control. In the monocrop maize MFTDB (4497cm^2), MF (4271cm^2) and TDB (4135cm^2) performed better in that order compared to the control (3470 cm^2). Generally, monocrop maize in both trials had higher leaf area than maize in the intercropping (Table 10 and 11).

Table 10: Effect of tithonia manure and mineral fertilizer on selected growth parameters in maize in trial one

	Fertilizer Type	No of Leaves	Leaf area (cm^2)	D to 50% T
Monocrop Maize	WF	8.67a[*]	1909.7a	65c
	MF	10.33a	2688.7a	66.67bc
	TDB	10.0a	2294.3a	68.67a
	MFTDB	10.33a	3101.7a	67.67ab
Intercrop Maize	WF	8.67b	3133ab	65b
	MF	11.33a	2357.3b	67.67a
	TDB	10.67a	3099.3ab	68.33a
	MFTDB	10.67a	3458.3a	69.33a

[*]Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **WF-** Without fertilizer, **MF-** Mineral fertilizer, **TDB-** *Tithonia diversifolia* biomass

Table 11: Effect of tithonia manure and mineral fertilizer on selected growth parameters in maize in trial two

	Fertilizer Type	No of Leaves	Leaf area (cm^2)	D to 50% T
Monocrop Maize	WF	8.5c*	3470.3b	65.33b
	MF	9.77b	4271a	66.67b
	TDB	9.5b	4135a	69.67a
	MFTDB	10.23a	4497.7a	69.67a
Intercrop Maize	WF	8.17b	3121.3b	67.33b
	MF	9.5a	4116.7a	67.67b
	TDB	9.03ab	3977.7a	70a
	MFTDB	9.63a	4144.3a	70a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **WF-** without fertilizer, **MF-** Mineral fertilizer, **TDB-** *Tithonia diversifolia* biomass

4.1.3 Effect of tithonia manure and mineral fertilizer on leaf area at flowering of beans

In trial one, application of tithonia manure to sole bean increased the bean leaf area to over 440 cm^2, mineral fertilizer increased it to 475 cm^2 while integrated nutrient increased leaf area to 526cm^2 as compared to the control with 320 cm^2. A similar trend in leaf area was observed in trial two; with integrated nutrient having the highest at 546 cm^2 compared to only 289 cm^2 in the control. Leaf areas from tithonia and mineral fertilizer treatments did not significantly differ from each other but from the control in intercropped beans (Fig 3 and 4).

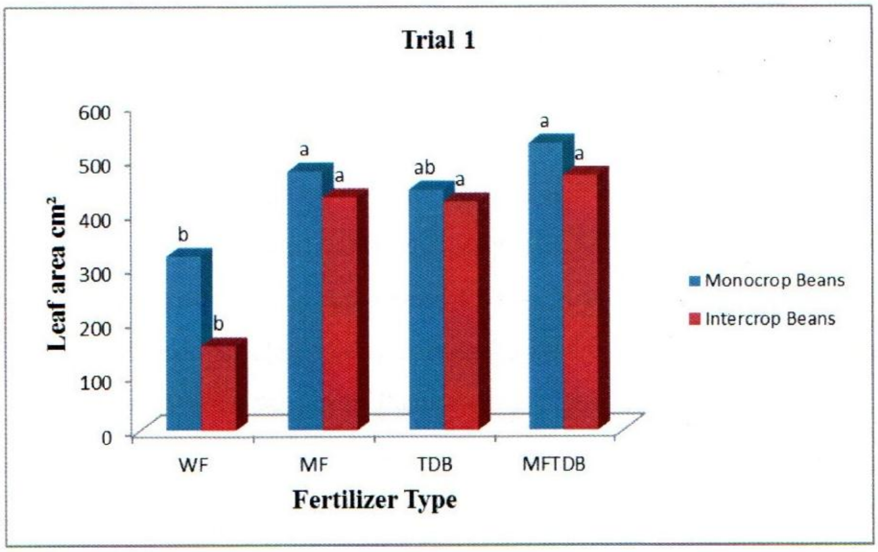

Figure 3: Leaf area (cm^2) of beans at flowering stage as affected by tithonia manure and mineral fertilizer in trial one. **WF-** without fertilizer **MF-** Mineral fertilizer **TDB-** *Tithonia diversifolia* biomass

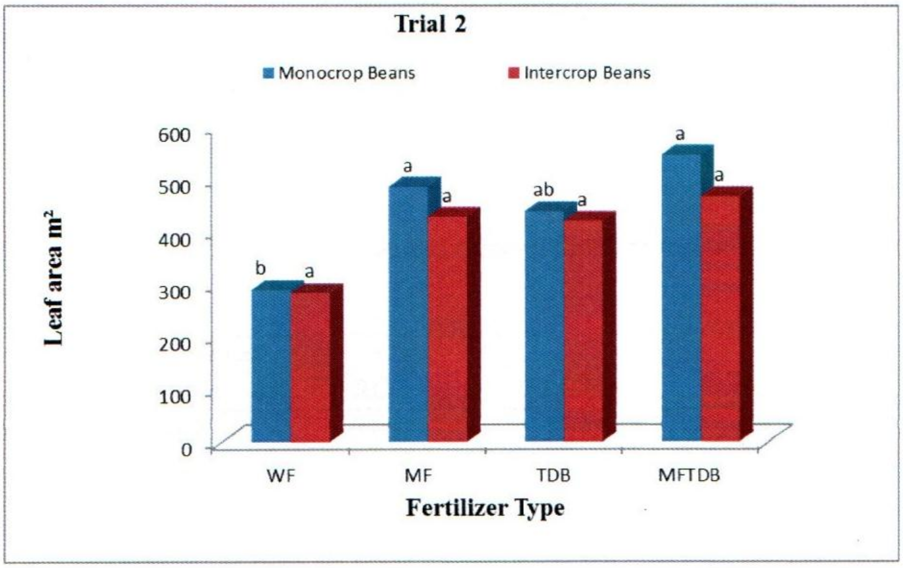

Figure 4: Leaf area (cm^2) of beans at flowering stage as affected by tithonia manure and mineral fertilizer in trial two. **WF**- without fertilizer **MF**- Mineral fertilizer **TDB**- *Tithonia diversifolia* biomass

4.2 Yield parameters

4.2.1 Effect of tithonia manure and mineral fertilizer on selected yield parameters of maize

Application of tithonia manure and mineral fertilizer slightly influenced the number of rows per cob in maize. In trial two, a higher number of rows were observed in intercropped maize with integrated nutrient application at 13.73, while mineral fertilizer and tithonia manure both had 13.47 compared to 12.93 for control. The length of the cobs was not significantly influenced by tithonia manure and mineral fertilizer. The diameter of the maize cobs was however, significantly different with MFTDB, MF and TDB with 4.99 cm, 4.89 cm and 4.71cm respectively, compared to 4.6 cm in control for intercropped maize in trial two. A similar trend was observed in sole and mixed cropping in trial one (Tables 12 and 13).

The average weight of the cobs was significantly influenced by application of tithonia manure and mineral fertilizer for monocrop and intercropped maize in both trials. Generally, trial one cobs were heavier than trial two cobs. Cobs from sole cropped maize were also heavier than from intercropped maize stands, except in the control where the weight of cobs in intercrop was 218 g compared to 206 g in sole crop in trial one, and 206 g for intercropped compared to 189 g in monocrop in trial two. In Trial two mono crops, MFTDB, MF and

TDB were 31.8%, 29.7% and 21.6% respectively heavier than control. The heaviest cobs were from trial one where MFTDB, MF and TDB had 303 g, 269 g and 235g compared to 206 g in Control (Tables 12 and 13).

Table 12: Effect of tithonia manure and mineral fertilizer on selected yield parameters of maize in trial one

	Fertilizer Type	RC	LC (cm)	DC (cm)	WC (gm)
Monocrop Maize	WF	12.93a*	17.93a	4.22b	206.30b
	MF	13.47a	17.94a	4.45a	265.59ab
	TDB	13.07a	17.8a	4.43ab	235.27ab
	MFTDB	13.37a	18.53a	4.56a	303.52a
Intercrop Maize	WF	12.87a	17.67a	4.14a	218.82a
	MF	13.87a	18.97a	4.42a	274.79a
	TDB	13.33a	20.79a	4.37a	251.73a
	MFTDB	13.6a	19.36a	4.47a	288.98a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. Where, **RC** is Rows per cob, **LC** is Length of cob, **DC** is Diameter of cob and **WC** is Weight of cob **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 13: Effect of tithonia manure and mineral fertilizer on selected yield parameters of maize trial two

	Fertilizer Type	RC	LC (cm)	DC (cm)	WC (gm)
Monocrop Maize	WF	12.93a*	18.43b	4.6b	189.95c
	MF	13.33a	20.37a	4.87ab	270.11ab
	TDB	13.07a	20.33a	4.81ab	242.29b
	MFTDB	13.07a	21.23a	4.94a	278.62a
Intercrop Maize	WF	12.93b	18.75a	4.53c	206.76b
	MF	13.47ab	19.47a	4.89a	244.37ab
	TDB	13.47ab	19.95a	4.71b	236.35ab
	MFTDB	13.73a	19.93a	4.99a	282.93a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. Where, **RC** is Rows per cob, **LC** is Length of cob, **DC** is Diameter of cob and **WC** is Weight of cob **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.2.2 Effect of tithonia manure and mineral fertilizer on selected yield parameters of beans

The number of branches was positively influenced by tithonia manure and mineral fertilizer in both growing trials whether grown as monocrop or intercrop. The integrated nutrient application produced highest number of branches in both monocrop and intercropped beans. Trial one generally had higher number of branches per plant than trial two, the number of branches for trial two mono cropped bean was highest when integrated nutrient was used (3.37) followed by MF and TDB at 2.73 and 2.23 respectively compared to 1.97 in control, while in the intercrop beans, the number of branches in TDB (2.23) compared well with MF (2.73) and MFTDB (3.37) (Tables 14 and 15). Application of tithonia manure and mineral fertilizer influenced the number of pods in beans. The highest number of pods per plant was observed in MFTDB and MF in trial one mono crop. Number of pods per bean plant was significantly higher in all treatments in monocrop bean of trial two where MFTDB had 54.39%, MF had 43.66% and TDB had 26.45% more pods per plant than the control. In intercropped beans, all treatments had statistically similar number of pods per plant but higher than the control (Tables 14 and 15).

The number of beans in the pod was slightly influenced by application of tithonia manure and mineral fertilizer in trial two sole crops; with all the fertilizer regimes being statistically similar and different from the control. The number of beans in the pod was generally higher in trial two in both monocrop and intercrop (Average mean 6.24 and 6.57 respectively) compared to trial one monocrop and intercrop (Average mean 3.94 and 2.73 respectively). The length of the pods was not influenced by application of tithonia manure and mineral fertilizer whether planted as monocrop or intercrop for both trials (Tables 14 and 15).

Table 14: Effect of tithonia manure and mineral fertilizer on selected yield parameters of beans in trial one

	Fertilizer Type	BP	NPP	NBP	LP (cm)
Monocrop Beans	WF	4.30b*	11.73b	3.58a	7.72a
	MF	5.70a	19.10a	3.70a	7.56a
	TDB	4.60b	17.17ab	4.07a	8.00a
	MFTDB	5.83a	21.77a	4.40a	7.56a
Intercrop Beans	WF	5.97a	13.40b	2.82a	8.22a
	MF	5.93ab	12.50b	2.60a	7.36a
	TDB	4.07b	15.63ab	2.81a	8.24a
	MFTDB	7.07a	18.90a	2.68a	7.99a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. Where, **BP** is number of branches per plant, **NPP** is number of pods per plant, **NBP** is number of beans per pod and **LP** is length of pod. **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 15: Effect of tithonia manure and mineral fertilizer on selected yield parameters of beans in trial two

	Fertilizer Type	BP	NPP	NBP	LP (cm)
Monocrop Beans	WF	1.97c*	5.20c	5.37b	3.68a
	MF	2.73ab	9.23ab	6.47ab	3.82a
	TDB	2.23bc	7.07bc	6.15ab	3.77a
	MFTDB	3.37a	11.40a	6.97a	4.28a
Intercrop Beans	WF	2.37b	5.3b	5.80a	3.40a
	MF	2.97ab	8.93a	7.39a	4.32a
	TDB	3.37a	8.77a	6.87a	3.59a
	MFTDB	3.37a	9.8a	6.22a	3.53a

*Means followed by the same letters within a column of a cropping system are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. Where, **BP** is number of branches per plant, **NPP** is number of pods per plant, **NBP** is number of beans per pod and **LP** is length of pod. **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.2.3 Effect of tithonia manure and mineral fertilizer on yield of maize and beans

Yield of maize and beans were influenced by application of tithonia manure and mineral fertilizer in both monocrop and intercrop in both trials. Application of combined tithonia manure and mineral fertilizer produced the highest maize yield. A remarkable difference was recorded in the yields of both monocrop and intercrop crops where plots treated with integrated nutrient yielded 24 tons/ha (50% more than the control) and 16 ton/ha (42% more compared to the control) respectively. Mineral fertilizer and tithonia manure produced significantly higher yields (13.256 ton/ha and 10.769 ton/ha respectively) compared to only 9.453 ton/ha of green maize for the control (Figure 5). Trial two generally yielded less green maize whether grown as monocrop or as intercrop compared to trial one, MFTDB gave the highest yield of 15.793 ton/ha, and 13.607 ton/ha in sole and mixed cropped maize respectively, which was not significantly different from yields in MF (Figure 6).

The yields of beans showed a similar trend from application of tithonia manure and mineral fertilizer. Integrated nutrient application in the intercropped beans of trial one produced 21.7% higher yields than control, while MF and TDB produced 8.96% and 7.52% higher yields than the control (Figure 7). In trial two sole crops, MFTDB produced about 3.56 ton/ha, MF and TDB had 2.79 and 1.95 ton/ha respectively compared to only 1.45 ton/ha for the control. Yields of intercropped beans in the treatments were not significantly different from each other except the control (Figures 8)

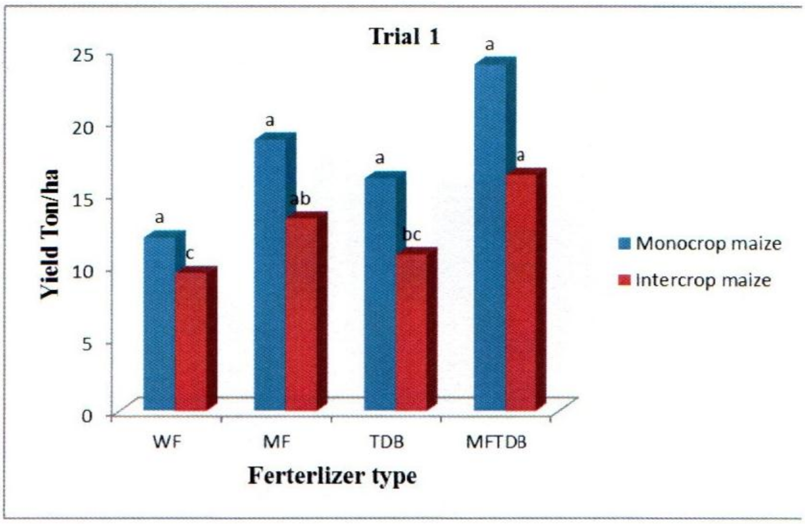

Figure 5: Yield of sole and mixed maize (tons/ha) as affected tithonia manure and mineral fertilizer in trial one. **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

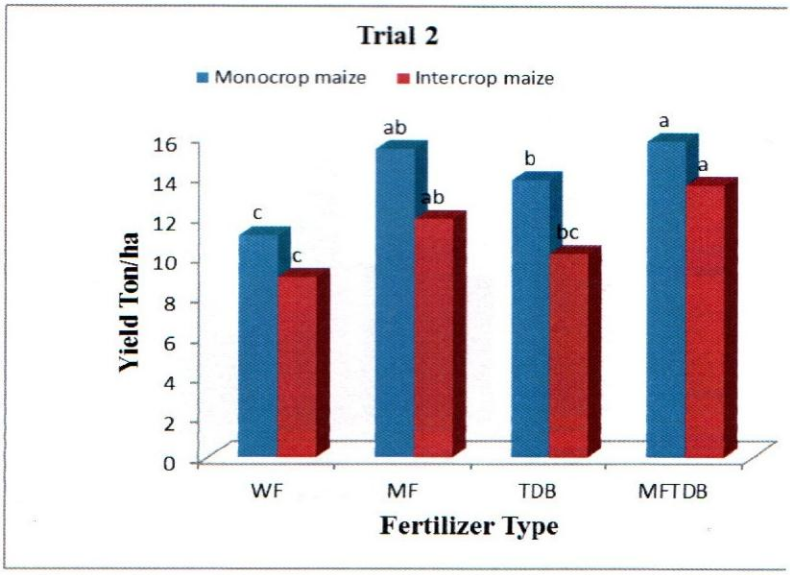

Figure 6: Yield of sole and mixed maize (ton/ha) as affected tithonia manure and mineral fertilizer in trial two WF- Without fertilizer, MF- Mineral fertilizer, TDB- *Tithonia diversifolia* biomass

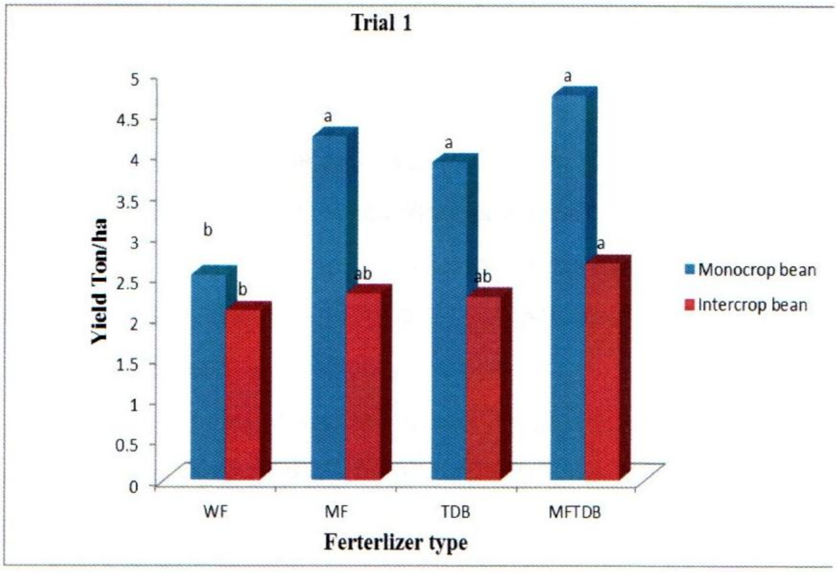

Figure 7: Yield of sole and mixed beans (ton/ha) as affected tithonia manure and mineral fertilizer in trial one WF- Without fertilizer, MF- Mineral fertilizer, TDB- *Tithonia diversifolia* biomass.

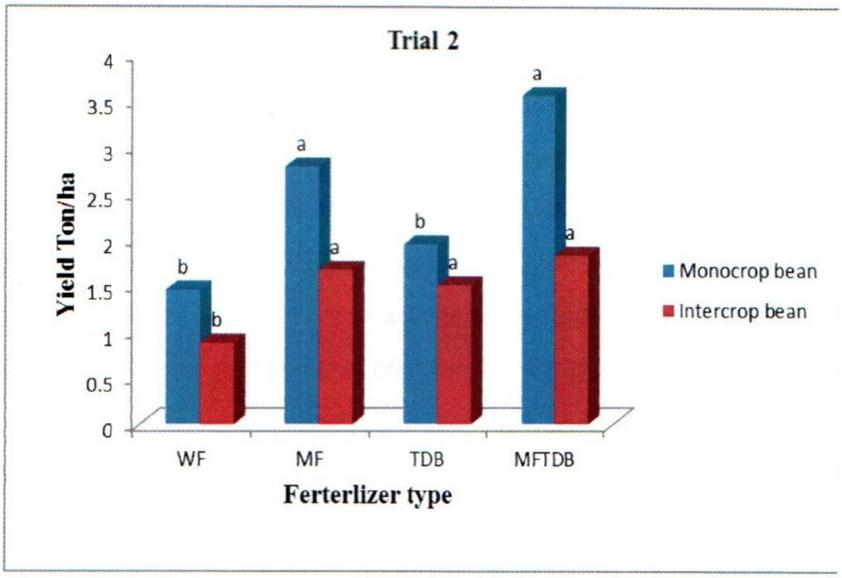

Figure 8: Yield of sole and mixed beans (ton/ha) as affected tithonia manure and mineral fertilizer in trial two WF- Without fertilizer, MF- Mineral fertilizer, TDB- *Tithonia diversifolia* biomass

4.2.4 Effect of tithonia manure and mineral fertilizer on intercropping expected yield

Intercropping Expected Maize Yield (IEMY) was higher than the intercropping obtained maize yield (IOMY) for all fertilizer types in trial one. The shortfall between the expected and obtained maize yield was highest in integrated nutrient application at 2.02 tons and 2.12 tons in trial one and two respectively (Table 16). In trial two, however, IOMY was higher than IEMY except when tithonia manure was applied and had a shortfall of 0.28 tons (Tables 17). IEMY was not significantly different at $P \leq 0.05$ in all fertilizer types in trial one; but was in trial two, with MFTDB, MF and TDB having 11.85 tons, 11.50 tons, and 10.15 tons respectively.

Intercropping Expected Bean Yield (IEBY) was higher than the intercropping obtained bean yield (IOBY) for all fertilizer types in both trials, except when tithonia manure was used and surpassed the expected yield by 0.25 tons in trial two. The shortfall between the expected and obtained bean yield was highest when mineral fertilizer was used in trial one (0.526 tons) and in integrated nutrient application in trial two (0.542 tons) (Tables 16 and 17).

4.2.5 Effect of tithonia manure and mineral fertilizer on Bean Equivalent Yield (BEY)

Bean equivalent yield (BEY) was influenced by application of tithonia manure and mineral fertilizer in both sole and mixed cropping. The highest BEY in mono cropping was obtained from integrated manure at 20.92 tons/ha and 13.78 tons/ha in trial one and two respectively. Although the fertilizer types did not show a significant difference in BEY in trial one, a higher yield was recorded in all fertilizer types compared to control. The BEY in the intercrop was higher in all fertilizer types in both trials, indicating a yield advantage, the highest was recorded in MFTDB and MF at 24.11 tons/ha and 19.08 tons/ha respectively in trial one. A high intercrop yield advantage was obtained from integrated manure at 46.45% and 32.92% in trial one and two respectively compared to control (Tables 16 and 17).

Table 16: Effect of tithonia manure and mineral fertilizer on intercropping expected maize and bean yield (tons/ha) and Bean Equivalent Yield in trial one

Fertilizer Type	IEMY	IOMY	IEBY	IOBY	BEY monocrop	Bean yield	BEY intercrop
WF	10.74a*	11.34c	2.01b	2.50b	10.42a	3.02b	12.91b
MF	16.84a	15.91ab	3.37a	2.74ab	16.33a	5.06a	19.08a
TDB	14.43a	12.92bc	3.11a	2.70ab	13.99a	4.67a	16.69ab
MFTDB	21.57a	19.55a	3.77a	3.19a	20.92a	5.66a	24.11a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. IEMY- Intercropping Expected Maize Yield, IOMY- Intercropping Obtained Maize Yield, IEBY- Intercropping Expected Bean Yield and IOBY- Intercropping Obtained Bean Yield. **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 17: Effect of tithonia manure and mineral fertilizer on intercropping expected maize and bean yield (tons/ha) and Bean Equivalent Yield in trial two

Fertilizer Type	IEMY	IOMY	IEBY	IOBY	BEY monocrop	Bean yield	BEY intercrop
WF	9.95c*	10.76c	1.16b	1.06b	9.66c	1.74b	10.72b
MF	13.81ab	14.26ab	2.23a	2.01a	13.39ab	3.35a	15.40a
TDB	12.47b	12.19bc	1.56b	1.81a	12.09b	2.34b	13.90ab
MFTDB	14.21a	16.33a	2.85a	2.20a	13.78a	4.27a	15.98a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. IEMY- Intercropping Expected Maize Yield, IOMY- Intercropping Obtained Maize Yield, IEBY- Intercropping Expected Bean Yield and IOBY- Intercropping Obtained Bean Yield. **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.3 Agro-biological Efficiency Indices

The following agro-biological indices were evaluated, land equivalent ratio (LER), relative crowding coefficient (K), competitive ratio (CR), aggressivity (A) and actual yield loss (AYL).

4.3.1 Effect of tithonia manure and mineral fertilizer on yield and Land Equivalent Ratio

Maize and bean yield was influenced by application of tithonia manure and mineral fertilizer in both sole and intercropped cultures in both growing trials. The highest maize and beans yield was obtained from mono cropping plots for all the fertilizer types in both trials while both maize and beans yields were generally higher in trial one compared to trial two. Intercropped plots treated with integrated manure gave the highest intercrop total maize yield, 19.5 kg/plot and 16.3 kg/plot in trial one and two respectively and the highest intercrop total bean yield of 3.2 kg/plot and 2.2 kg/plot in trial one and two respectively (Tables 18 and 19).

In general, partial LER for maize and beans was higher than 0.50 in all fertilizer types for both trials. Partial LER for maize of 0.83 was highest when mineral fertilizer was used in trial one and 0.86 when integrated manure was used in trial two. Tithonia manure gave the highest partial LER for beans at 0.8 in trial two although their means were not significantly different at $P \leq 0.05$. All the treatments in both trials gave a LER of more than 1.0, which indicated efficient utilization on environmental resources (Tables 18 and 19).

Table 18: Effect of tithonia manure and mineral fertilizer on maize and bean yield (kg/ plot) and Land Equivalent Ratio (LER) in trial one

Fertilizer Type	Maize Yield monocrop	Maize Yield intercrop	Bean Yield monocrop	Bean Yield intercrop	LER Maize	LER beans	LER
WF	14.323a*	11.343c	3.016b	2.4956b	0.7874a	0.9109a	1.6983a
MF	22.459a	15.907ab	5.056a	2.7412ab	0.834a	0.5586a	1.3926a
TDB	19.24a	12.923bc	4.672a	2.6988ab	0.723a	0.5765a	1.2995a
MFTDB	28.761a	19.551a	5.656a	3.1892a	0.7381a	0.5644a	1.3025a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **LER**- Land Equivalent Ratio, **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 19: Effect of Tithonia manure and Mineral Fertilizer on Maize and Bean Yield (kg/plot) and Land Equivalent Ratio (LER) in trial two

Fertilizer Type	Maize Yield monocrop	Maize Yield intercrop	Bean Yield monocrop	Bean Yield intercrop	LER maize	LER beans	LER
WF	13.2769c	10.764c	1.7448b	1.062b	0.8203a	0.6239a	1.4441a
MF	18.4071ab	14.261ab	3.3472a	2.0084a	0.7804a	0.6169a	1.3973a
TDB	16.6267b	12.185bc	2.3424b	1.81a	0.7373a	0.803a	1.5402a
MFTDB	18.9516a	16.328a	4.2736a	2.1988a	0.8629a	0.5124a	1.3752a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **LER**- Land Equivalent Ratio, **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass.

4.3.2 Effect of tithonia manure and mineral fertilizer on Relative Crowding Coefficient (K) and Competitive Ratio (CR)

Maize had higher Relative Crowding Coefficient (K) values than beans for all treatments in both trials. The K values are a coefficient and therefore negative signs are ignored. K value for maize was highest when integrated manure was used at 71.7 and lowest when mineral fertilizer was used at 2.36 in trial one, suggesting an intercrop advantage. K values for beans were all less than 1.0 for all fertilizer types in both trials except in control (1.49) and TDB (1.34) in trial one and two respectively, indicating an intercrop disadvantage. Relative Crowding Coefficient (K) for the intercrop was highest when integrated manure was used at 29.56 in trial one; Mineral fertilizer recorded an intercrop disadvantage at 0.08. K values in trial two showed an intercrop advantage with the highest being from tithonia manure at 44.76, integrated manure had the lowest K value of 9.48. However, their means were not significantly different at $P \leq 0.05$. (Tables 20 and 21)

Application of tithonia manure and mineral fertilizer influenced the Competitive Ratio of both maize and beans in both trials. CR for maize was greater than 1.0 while CR for beans was less than 1.0 for all the fertilizer types in both trials, meaning that maize was the dominant crop in the intercrop. The highest CR for maize was obtained in plots treated with mineral fertilizer and integrated manure with 5.36 and 5.61 in trial one and two respectively while the lowest CR for maize was from WF (3.66) in trial one and TDB (3.11) in trial two. A high CR for beans was obtained from tithonia manure treated plots (0.32) in trial two. (Tables 20 and 21)

Table 20: Effect of tithonia manure and mineral fertilizer on Relative Crowding Coefficient (K) and on Competitive Ratio (CR) in trial one

Fertilizer Type	K maize	K beans	K	CR maize	CR Beans
WF	14.95a*	-1.4851b	-13.74a	3.664a	0.3611a
MF	2.36a	0.4236a	-0.08a	5.358a	0.2664a
TDB	30.49a	0.4241a	10.95a	4.337a	0.2802a
MFTDB	71.7a	0.4325a	29.56a	4.381a	0.2384a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at P ≤ 0.05. **K**- Relative Crowding Coefficient, **CR**- Competitive Ratio, **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 21: Effect of tithonia manure and mineral fertilizer on Relative Crowding Coefficient (K) and on Competitive Ratio (CR) in trial two

Fertilizer Type	K maize	K beans	K	CR maize	CR Beans
WF	27.76a*	0.604a	22.48a	4.5129ab	0.2321b
MF	26.68a	0.586a	23.53a	4.2928ab	0.23565b
TDB	13.36a	-1.336a	-44.76a	3.1107b	0.32319a
MFTDB	28.3a	0.318a	9.48a	5.6054a	0.17854b

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at P ≤ 0.05. **K**- Relative Crowding Coefficient, **CR**- Competitive Ratio, **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.3.3 Effect of tithonia manure and mineral fertilizer on Aggressivity (A) and Actual Yield Loss (AYL).

In both trials, all the fertilizer types had positive A values for maize. This showed that maize was the dominant crop in the intercrop while beans, which had negative A values was the dominated crop in the intercrop. While the level of dominance in maize was statistically similar in trial one, the level of dominance in maize was significantly different among the fertilizer types in trial two where use of integrated manure increased maize aggressivity by 30% and only 17% when mineral fertilizer was used alone compared to control. Beans were dominated by similar margins in all treatments. (Tables 22 and 23)

Actual yield loss (AYL) for maize had positive values when mineral fertilizer (0.112) was used in trial one and when integrated manure (0.1505) was used in trial two. The AYL for maize in the control for both trials had positive values indicating an advantage of the association. The AYL for beans was however negative for all fertilizer types except the control (0.3663) in trial one, and all negative except for TDB (0.2045) in trial two. The total

AYL for trial one was all negative for the different fertilizer types indicating an intercrop disadvantage. In trial two, however, tithonia manure use resulted to an advantage of intercropping while mineral fertilizer and the combination with tithonia resulted to a disadvantage of intercropping. (Tables 22 and 23)

Table 22: Effect of tithonia manure and mineral fertilizer on Aggressivity (A) and Actual Yield Loss (AYL) in trial one

Fertilizer Type	A maize	A beans	AYL maize	AYL bean	AYL
WF	0.010711a*	-0.010711a	0.0498a	0.3663a	0.4162a
MF	0.013884a	-0.013884a	0.112a	-0.1621a	-0.0501a
TDB	0.01146a	-0.01146a	-0.036a	-0.1353a	-0.1712a
MFTDB	0.01185a	-0.01185a	-0.0159a	-0.1534a	-0.1692a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **A**- Aggressivity, **AYL**- Actual Yield Loss, **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

Table 23: Effect of tithonia manure and mineral fertilizer on Aggressivity (A) and Actual Yield Loss (AYL) in trial two

Fertilizer Type	A maize	A beans	AYL maize	AYL bean	AYL
WF	0.01319ab*	-0.01319ab	0.0937a	-0.0642a	0.0295a
MF	0.012402ab	-0.012402ab	0.0405a	-0.0746a	-0.0341a
TDB	0.010341b	-0.010341b	-0.017a	0.2045a	0.1875a
MFTDB	0.014774a	-0.014774a	0.1505a	-0.2315a	-0.081a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **A**- Aggressivity, **AYL**- Actual Yield Loss, **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.4 Economic Advantage Indices

The economic advantage indices evaluated were; intercropping advantage (IA) and monetary advantage index (MAI)

4.4.1 Effect of tithonia manure and mineral fertilizer on the Intercropping Advantage (IA)

Intercropping Advantage (IA) in maize was 4.89 more profitable where mineral fertilizer was used in trial one, and 6.57 more profitable where integrated manure were used in trial two. The control however showed an intercrop advantage in both trials. There was an intercrop disadvantage when tithonia manure was used alone in both trials, although the intercrop advantage for maize was not significantly different at $P \leq 0.05$. There was an intercrop disadvantage for beans in all fertilizer types of trial one, and only beans treated with tithonia manure benefited from the association in trial two (Table 24).

4.4.2 Effect of tithonia manure and mineral fertilizer on the Monetary Advantage Index (MAI)

The highest MAI was obtained when integrated manure was used with about a MAI of 253 in trial one and 231 in trial two. Although the means were not significantly different at $P \leq 0.05$, integrated manure application produced 35% and 54% more profit than the control in trial one and two respectively (Table 24).

Table 24: Effect of tithonia manure and mineral fertilizer on the Intercropping Advantage (IA) and Monetary Advantage Index (MAI)

	Trial one			**Trial two**		
Fertilizer type	IA maize	IA bean	MAI	IA maize	IA bean	MAI
WF	2.175a*	21.98a	202.4a	4.089a	-3.85a	160.51a
MF	4.889a	-9.73a	227.1a	1.767a	-4.48a	204.57a
TDB	-1.569a	-8.12a	164a	-0.741a	12.27a	217.64a
MFTDB	-0.692a	-9.2a	253.4a	6.566a	-13.89a	230.52a

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **WF**- Without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.5 Residual Soil Properties

Residual soil properties evaluated included, soil pH, Soil Organic Carbon, Cation Exchange Capacity, Nitrogen, Phosphorus, Potassium, Magnesium and Calcium

4.5.1 Effect of tithonia manure and mineral fertilizer soil pH, soil organic carbon and cation exchange capacity (CEC)

Soil pH

Application of Tithonia manure and Mineral Fertilizer did not influence soil pH when maize and beans were grown alone, but significantly differed when the two crops were grown together with plots treated with tithonia being less acidic, although the soil was generally acidic at pH of 5-5.1 (Table 25).

Soil Organic Carbon

The effects of tithonia manure and Mineral Fertilizer on soil organic carbon were significant at $P \leq 0.05$ in both monocropping and intercropping. Integrated nutrient application resulted in highest soil organic carbon in all the cropping methods. Plots treated with tithonia manure or mineral fertilizer alone also had a significantly higher organic carbon than the control, in sole maize TDB and MF had 45.57 g/kg and 44.43 g/kg respectively compared to only 34.7 g/kg in controls. Integrated nutrient application increased soil organic carbon in sole maize and beans by 30.6% and 30.4% respectively compared to 34.2% when the two crops were grown together (Table 25).

Cation Exchange Capacity

The soil Cation Exchange Capacity (CEC) was influenced by the application of tithonia manure and mineral fertilizer in plots planted sole maize and beans and in those intercropped. In sole maize tithonia manure greatly influenced CEC where TDB had the highest at over 196mmol+/kg, MFTDB followed closely at 191mmol+/kg both of which were not significantly different. MF also had some effect on CEC as it had 180mmol+/kg compared to control with only 142mmol+/kg. In sole beans, plots with tithonia manure TDB had significantly higher CEC than all other fertilizer type with 31% more than the control. Integrated and mineral fertilizer had 23% and 21% more CEC than the control respectively, a trend that ensured in the intercropped component (Table 25).

Table 25: Effect of tithonia manure and mineral fertilizer on soil pH (unit), organic carbon (g/kg) and cation exchange capacity (mmol+/kg)

Cropping type	Fertilizer type	pH (unit)	OC (g/kg)	CEC (mmol+/kg)
Maize	WF	5.1a*	34.7c	142b
	MF	5.03a	44.43b	180.33a
	TDB	5.1a	45.57b	196.67a
	MFTDB	5.07a	50.03a	191.67a
Maize/bean	WF	5.07b	33.17c	140d
	MF	5.03b	44.3b	171.67c
	TDB	5.17a	44.17b	200a
	MFTDB	5.1ab	49.07a	182.67b
Beans	WF	5.07a	34c	140c
	MF	5.07a	43.97b	177.67b
	TDB	5.13a	43.7b	202.67a
	MFTDB	5.13a	48.9a	182.67b

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **WF**- without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.5.2 Effect of tithonia manure and mineral fertilizer residual soil macro nutrients

Nitrogen

Residual nitrogen was significantly ($P \leq 0.05$) influenced by tithonia manure and mineral fertilizer in maize sole crop and in the intercrop. In sole maize, integrated nutrient application retained the highest nitrogen 3.38 g/kg, while mineral fertilizer and tithonia manure retained 3.29 g/kg and 3.15 g/kg respectively compared to 2.72 g/kg in control which were all significantly different. In sole beans, the retained nitrogen after tithonia manure and mineral fertilizer treatment was not significantly different from each other except with the control. However, when maize and beans were intercropped, MFTDB retained 21.8% nitrogen while MF and TDB retained 18.96% and 18.7% nitrogen respectively more than the control (Table 26).

Phosphorus

Application of tithonia manure and mineral fertilizer significantly influenced retained phosphorus in both sole crops and in the intercrop. In sole maize, a slight difference which was not significant occurred between soils treated with integrated nutrient (10mmol P/kg), tithonia manure (10.73mmol P/kg) and mineral fertilizer (10.5mmol P/kg) but were all significantly different from the control (7.83mmol P/kg). In sole bean, however, TDB and MF retained more phosphorus (11.3 and 10.46mmol P/kg) than integrated nutrient (9.13mmol P/kg) but all retained more than the control (7.53mmol P/kg). Similar trend was observed in the intercropped plots where TDB, MF and MFTDB retained 35.5%, 31.86% and 13.45% more phosphorus respectively than the control (Table 26).

Potassium

Residual Potassium was significantly influenced by tithonia manure and mineral fertilizer in both monocrop and in the intercrop although potassium levels were too low in all the experimental area. The optimum level of potassium is between 8 and 14 mmol+/kg according to the soil cares laboratory analysis. In sole maize and intercrop, application of either tithonia manure and/or mineral fertilizer significantly influenced retained potassium in the soil compared to control. In sole beans, the highest retained Potassium was from TDB (6.67mmol+/kg) followed by MFTDB (6.3mmol+/kg) and MF (6.1mmol+/kg) compared to 5.1mmol+/kg in control (Table 26).

Table 26: Effect of tithonia manure and mineral fertilizer on residual Nitrogen (g/kg), Phosphorus (mmol P/kg) and Potassium (mmol+/kg)

Cropping type	Fertilizer type	N (g/kg)	P (mmol P/kg)	K (mmol+/kg)
Maize	WF	2.72d*	7.83b	5.23b
	MF	3.29b	10.50a	6.17a
	TDB	3.15c	10.73a	6.17a
	MFTDB	3.38a	10.00a	6.07a
Maize/bean	WF	2.65c	7.27c	5.33b
	MF	3.27b	10.67a	6.30a
	TDB	3.26b	11.27a	6.57a
	MFTDB	3.39a	8.40b	6.23a
Beans	WF	2.73b	7.53c	5.10d
	MF	3.27a	10.46a	6.10c
	TDB	3.25a	11.30a	6.67a
	MFTDB	3.35a	9.13b	6.30b

*Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$ **WF**- without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

4.5.3 Effect of tithonia manure and mineral fertilizer on some residual soil micro nutrients

Magnesium

While application of Tithonia manure and Mineral Fertilizer significantly influenced the residual Magnesium, the highest amount was obtained from the integrated nutrient application from both sole and mixed cropping. In monocrop beans, integrated nutrient application significantly influenced retained Magnesium in the soil compared to other treatments and the control. In the intercrop, however, MFTDB, MF and TDB retained significantly higher magnesium at 27%, 17.8% and 16% respectively from than the control (Table 27).

Calcium

Application of Tithonia manure and Mineral Fertilizer significantly influenced the residual calcium in both sole and mixed cropping. In monocrop maize, TDB had the highest residual calcium of 122mmol+/kg, MF and TDB had 111mmol+/kg and 106mmol+/kg compared to only 77mmol+/kg in the control. In sole beans and intercrop, TDB had the highest residual calcium at 127mmol+/kg which was 40% and 44% respectively more than the control. In the intercrop, MF and MFTDB also had higher residual calcium than control at 39.9% and 31.6% respectively (Table 27).

Table 27: Effect of tithonia manure and mineral fertilizer on residual Magnesium (mmol+/kg) and Calcium (mmol+/kg)

	Maize		Maize/bean		Beans	
Fertilizer tpye	Mg (mmol+/kg)	Ca (mmol+/kg)	Mg (mmol+/kg)	Ca (mmol+/kg)	Mg (mmol+/kg)	Ca (mmol+/kg)
WF	36.3b[*]	77.33c	30.43c	70.67c	36.33ab	76c
MF	30.63c	111.33b	37b	117.67a	30.27b	110.33b
TDB	33.6bc	122.33a	36.33b	127a	34.97b	127a
MFTDB	42.27a	106b	41.83a	103.33b	42.47a	106.67b

[*] Means followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test at $P \leq 0.05$. **WF**- without fertilizer, **MF**- Mineral fertilizer, **TDB**- *Tithonia diversifolia* biomass

CHAPTER FIVE

DISCUSSION

5.1 Effects of Tithonia biomass and Mineral fertilizer on Maize and Beans Growth

Intercropping of cereals and legumes often gives higher resource use efficiency compared to sole cropping (Ofori and Stern, 1987) because intercropping of species that differ in the time of their maximum demands on the environmental resources extends the duration of resource use (Willey, 1979). Findings of the current study support these arguments as height in intercropped maize was generally higher than in mono cropped maize in all the treatments. Similar to the findings of this study Rezaei-Chianeh *et al.* (2011) observed increased maize height at higher plant density when intercropped with faba beans. As much as organic manures have been shown to supply the required plant nutrients, improve soil structure, increase microbial population and at the same time promote plant growth (Dauda *et al*., 2008), the study showed that integrated nutrient (MFTDB) gave the highest maize and bean height, diameter and number of leaves in both trials, this could be due to synergistic effects and improved synchronization of nutrient release and uptake by crop (Palm *et al.,* 1997). Liasu *et al.* (2008) similarly observed increased okra plant height in soils supplemented with fortified tithonia mulch which they attributed to improved soil conditions through replenishment of soil nutrients. Mucheru-Muna *et al.* (2006) also found that on average, tithonia treatments (with half recommended rate of mineral fertilizer) gave the highest plant height and leaf area compared to control while looking at effects of organic and mineral fertilizer inputs on maize yield and soil chemical properties in a maize cropping system in Meru South District, Kenya. In maize plants, trial two generally recorded higher height than trial one which could be attributed to the higher amounts of rainfall which was a total of 404 mm in trial two compared to 296.8 mm in trial one.

It is discernible from the data that a higher number of pods and number of beans per pod was recorded in integrated use of nutrients followed by chemical fertilizer and organic treatments than control respectively. Ogutu, (2013) found that navy beans supplied with 4 t/ha FYM plus 100 kg/ha NPK had significantly the highest number of pods per plant and there was no difference in grain yield between control and application of 8 t/ha FYM. This could be due to the N level in the soil as suggested by Araújo *et al.*, (2008) that higher grain yield, pod number, and total dry matter increased with N level. They found that the grain yield, increased by 16% when 60 kg/ha N was used and 31% when 120 kg/ha nitrogen was used. Mwangi and Mathenge, (2014) warned that it may take approximately two to three weeks before the tithonia green manure is degraded to release the nitrogen, a process that is influenced by temperature, soil moisture, population of soil microbes and efficiency of incorporation. Results from this study confirmed that observation because during the first eight weeks, the growth response of plants treated with tithonia green manure compared lowly to those treated with mineral fertilizer and sometimes even the control.

5.2 Effects of Tithonia biomass and Mineral fertilizer on Maize and bean yield

The results from this study showed that the highest green maize and bean yields were obtained from sole cropping plots in all fertilizer types in both growing trials presumably due to the absence of competition from companion crop. However, the combined yields of green maize and beans in the intercropped system were always better than the sole yield of either crop. Being a heavy feeder of nutrients, maize productivity is largely dependent on nutrient management. Maize and beans separated spatially and they make their major demands on resources at different times, which was the biggest complementary and yield advantage (Ofori and Stern, 1987). Another advantage of the intercrop was the complementarity of the maize bean association as shown by Matusso *et al.* (2012); that the cereal may be more competitive than the legume for soil mineral N, but the legume fixes N symbiotically making nitrogen available for both crops.

The finding of the present study agrees with many scientists who have worked with cereal-legume intercropping systems (Egbe, 2010; Mucheru-Muna *et al.,* 2010; Ndung'u *et al.,* 2005; Obadoni *et al*., 2010; Okoth and Siameto, 2011; Osman *et al*., 2011) and proved its success compared to mono crops especially for smallholder farmers who aim at minimizing risks against total crop failures and also get different products for the family's food and income. Beans in the intercrop of the present study generally yielded lower than their counterparts in sole which could possibly be due to the shading effects of maize that significantly reduced light interception potential of the associated beans and reduced the photosynthetic assimilate. Reduced assimilate resulted in limited food supply for associated *rhizobium* bacteria, and consequently their atmospheric fixation capacity were diminished (Ghosh *et al.,* 2006). Integrated nutrient use produced the highest amount of green maize and beans. These findings are in agreement with those of Aguyoh *et al.* (2010) who reported a significant and positively correlated increase in total yield of watermelon with increasing application rates of *Tithonia diversifolia* manure with yields enhanced by between 8.5% and 31% in plants subjected to the highest level (5.4 t/ha) of tithonia compared to the control.

Jeptoo *et al.* (2013) also found out that application of *Tithonia diversifolia* manure resulted in increased total fresh root weight, dry root and shoots biomass and root volume of carrots compared to the control. Total yield of carrots subjected to 3.0 t/ha increased by 33% and 18% in trial one and two respectively compared to control. Application of farmyard manure at the rate of 5 tons ha^{-1} contributed about 25-30 kg N ha^{-1} to the maize crop. Integration of nutrients increased yield and other yield attributes indicating the enhancement of nutrients availability to the plants which could be due to the fact that application of nitrogen in presence of organic manures helps in the mineralization by minimizing C/N ratio (Rahman *et al.*, 2013). The results relates with Datt *et al.* (2013) who reported that application of farm yard manure incorporated with NPK resulted in increased N fixation and enhanced the microbial activity in french bean. Integrated use of organic manure and chemical fertilizer increased water stable aggregates which could be attributed to the beneficial effects of certain polysaccharides formed during decomposition of organic residues by microbial activity as well as cementing action of bacteria and fungi. Growing a legume in the cropping sequence has special significance in the maintenance of soil fertility and crop productivity because of its unique ability of fixing and utilizing atmospheric nitrogen (Rahman *et al.*, 2013)

Intercropping Expected Yield (IEY) of both maize and beans was higher than the Intercropping Obtained Yield (IOY) for all fertilizer types in both trials except for beans treated with TDB in trial two which surpassed the expected by 0.238 tons per ha. The results showed that the individual plant performance was lower in the intercrop and therefore mutual inhibition and underperformance of both maize and beans in the association due to crowding, nutrient sharing or shading effects of maize to beans. As it is usually difficult to compare the performance of two different crops in an intercropping system, the yields of maize were converted to the yields of beans; Bean Equivalent Yield (BEY). The yield advantage in terms of BEY of the present study was higher in maize/bean intercropping system than in sole cropping of either crop thereby revealing an agronomic advantage that ranged from 13-19%. The yield response due to tithonia manure and mineral fertilizer was consistent over the study period, where the integrated nutrient application recorded the highest BEY while the traditional method (control) showed the lowest in both trials. These findings relates to that of Ghosh *et al.* (2005) who observed a soybean equivalent yield (SEY) of 60% yield advantage from intercropping over sole soybean when sub soiling over conventional tillage was used. Egbe, (2010) however found that Soybean equivalent yield (SOYEQUIV) figures were not significantly different when different densities of sorghum and soybean were used,

5.3 Assessment of Agro-biological Efficiency of maize intercropped with beans using competition indices

The partial LER maize was higher than 0.5 in the all fertilizer types for both trials which indicate that there was an intercropping advantage for both maize and beans. Yield advantage in terms of total LER was greatest in the control plots (1.698) for trial one and TDB (1.540) for trial two. This indicates that about 70% and 54% more area would be required by a sole cropping system to equal the yield in the intercropping system for these treatments. The results of the present study were slightly different from that of Zerihun *et al.* (2013) who reported a higher LER than control, of 1.28 and 1.15 when 16 tons ha^{-1} FYM and 110/46 N/P_2O_5 kg ha^{-1} were used respectively meaning that 28 and 15% greater area would be required under sole maize to produce the same yield as that of combined yield with soya bean under intercropping system. The yield advantage obtained in terms of the use of environmental resources for plant growth due to various combinations of fertilizer rates ranged from 6 to 28% over the yield of sole maize. Similar results were obtained by Muoneke *et al.* (2007) where the control (unfertilized) plots in maize/ soybean intercrop had a higher LER. They indicated that the fixation capacity of the associated soybean under limited nutrient might be enhanced and utilized by the legumes. Similarily, the fixation capacity of beans under limited nutrient might be enhanced making nitrogen available to both maize and beans. The lowest partial LER for maize was from TDB which could be associated with low K levels which were insufficient in tithonia biomass. MF and MFTDB gave the lowest partial LER for beans probably due to shading by maize which was robust, most likely due to its more resource use efficient four-carbon dicarboxylic (C4) pathway than the bean's C3 pathway (Kitonyo *et al.*, 2013). However, there was yield advantage in terms of total LER in all fertilizer types. These findings are in agreement with those of Abd el-Gaid *et al.* (2014) who reported a mixed stand advantage of tomato and common bean with a LER of 1.26 and 1.25 in season one and two; they actually found that tomato plants can tolerate common beans without adversely affecting quality and yield of tomatoes. Takim, (2012), however, found that partial LER for cowpea was lower than 0.50 in all mixtures presumably due to high intra and inter specific competitions in the maize/cowpea intercropping, where maize and cowpea produced 40% and 55% respectively, of their sole yields while LER for maize was above 1.00 which was attributed to better use of environmental resources for plant growth.

The crowding coefficient (K) values for maize was much higher than 1, indicating an absolute yield advantage of maize over beans in the intercropping systems. Such a result was expected since cereals are more competitive than legumes. In addition, integrated fertilizer application gave the highest K values which could be due to increased canopy of maize which drastically overcrowded beans. Tithonia application gave a high K value for beans. Similar results were reported by Banik *et al.* (2000) in chickpea-wheat intercropping and Dhima *et al.* (2007) in cereal-vetch intercropping. K values for beans were all less than 1.0 for all fertilizer types in both trials except when tithonia manure was used trial two, thereby indicating that beans could compete well with maize. The results of the present study contrasted with that of Yilmaz *et al.* (2008) who found out that partial K value of legumes were higher than partial K values of maize in the 50:50 or 67:50 mix-proportion of 1- or 2-row planting pattern. In addition, K values for cowpea were higher compared to common bean, indicating that cowpea was more competitive than common bean in cereal-legume mixtures. This superiority can be attributed to the aggressiveness of maize and to other factors such as morphology and physiology, particularly in the position of its photosynthetic canopy above the bean leaves, allowing it to better use the photosynthetically useful radiation (Cecílio Filho *et al.*, 2013).

The Competitive Ratio which measures the degree with which one crop competes with the other showed that maize had higher competitive indices than beans in all the fertilizer types in both trials. The highest CR for maize was obtained in plots with integrated fertilizer indicating that maize was 4.38 and 5.61 (trial one and two respectively) more competitive than beans in the intercrop. Maize treated with mineral fertilizer also showed a high CR of 5.36 and 4.29 in trial one and two respectively. The findings were in agreement with that of Takim, (2012) who found out that maize was more competitive than cowpea in all mix-proportions and planting patterns. The CR of beans was less than 1 in all fertilizer types showing that they were negatively affected by the association. The present study showed that when nutrients are provided through organic and inorganic fertilizers, maize increases the crowding efficiency over beans which eventually resulted in intercropping disadvantage for beans. Similar to the findings of Oseni *et al.* (2010) who showed that sorghum had higher competitive indices than cowpea in 2S:1C and 1S:1C planting patterns except 1S:2C arrangement.

The competitive ability of the component crops in an intercropping system is determined by its aggressivity value. Aggressivity was positive for maize and negative for beans in all fertilizer types. This showed that maize dominated beans in the intercrop. Although the A values were statistically the same at $P \leq 0.05$, maize was more aggressive when mineral fertilizer (MF) was used in trial one and when integrated nutrients (MFTDB) was used in trial two. This could only mean that maize utilized the nutrient resources better than beans. Similar to the finding of Takim, (2012) who found that A values for maize were always positive while such values for cowpea were all negative in a mix-proportions and planting patterns of maize-cowpea intercrop, showing that maize was the dominant crop. Oseni *et al.* (2010) showed positive aggressivity for sorghum at 2S:1C and 1S:1C planting patterns while it proved less competitive and was dominated by cowpea at 1S:2C planting pattern.

The AYL values for maize were positive when mineral fertilizer was used indicating a higher yield gain of 11.2% in trial one and 15.05% in trial two compared to sole crops. The AYL values for beans were all negative with yield losses ranging from 7.46- 23.15%. Beans responded very well to tithonia manure due to enhanced soil properties and had a yield gain of 20.45%. Similar to other agro-biological parameters evaluated, findings of the present study agrees with that of Takim, (2012) whose AYL values for cowpea were all negative and ranged from -0.257 to -0.813 indicating a yield loss of 25.7% - 81.3%, compared to sole cowpea yield. Yilmaz *et al.* (2008) reported a yield loss of 2 % - 42 % in cowpea while the AYL values for maize were positive in 50M:50C and 60M:40C plots indicating a yield gain of 42 % and 52%, respectively, compared to sole maize yield.

5.4 Effects of Tithonia biomass and Mineral fertilizer on Economic Advantage of intercropping

Substantial agronomic advantages from intercropping do not always ensure an economic advantage and there is a need for some economic evaluations and absolute yield comparisons of intercropping systems (Tamado and Eshetu, 2000). Thus, a more satisfactory use of monitory values would probably be to calculate the absolute value of the genuine yield advantage (Willey, 1979). The intercropping advantage (IA) for maize which is an indicator of the economic feasibility of intercropping systems, affirmed that the most advantageous fertilizer type was mineral fertilizer with the highest IA of 4.889 in trial one and integrated manure with an IA of 6.566 in trial two. There was intercropping disadvantage for beans in all fertilizer type except when tithonia manure was used. Intercrop advantage was depressed when tithonia manure was used in both trials. The present study is in agreement with Yilmaz *et al*., (2008) who showed intercrop disadvantage at different densities of common bean and cowpea in maize-common bean and maize-cowpea intercrops. Takim, (2012) also found out that there was IA for maize and intercrop disadvantage for cowpeas in maize-cowpea intercrop. Beans responded well to tithonia manure application and had a higher IA than all other fertilizer regimes.

Monetary advantage (MA) of intercropping was used to calculate the absolute value of the genuine yield advantage assuming that the appropriate economic assessment of intercropping should be in terms of increased value per unit of area of land (Dhima *et al*., 2007). The result showed that the monetary advantage index (MAI) values were positive in all the fertilizer types and therefore a definite yield and economic advantages in maize-bean intercrop over their sole cropping. The highest MAI of 253 and 230 in trial one and two respectively was obtained in the integrated nutrient MFTDB treated plots, which implied that it was the most economical and advantageous fertilizer regime. This could be attributed to the complementarity of the two crops in the mixture. Dhima *et al*. (2007) obtained the highest MAI values from the common vetch–oat mixture (105.29) at the 65:35 seeding ratio followed by the common vetch–wheat mixture (59.93) at the 55:45 seeding ratio. He reported that if LER and relative crowding coefficient (K) values were high, then there was an economic benefit expressed with MAI values such as obtained in the present study. Krantz *et al*. (1976) also reported higher monetary returns from systems involving intercropping of legumes and non-legumes compared to sole non-legume cropping which was attributed to better utilization of resources. These results, however contradict the findings of Singh and Ajeigbe, (2002) who reported that sole cowpea crop was more profitable than intercropping with cereals.

5.5 Effects of Tithonia biomass and Mineral fertilizer Residual Soil Properties

Application of Tithonia manure and Mineral Fertilizer did not influence soil pH when maize and beans were grown alone, but had slight influence when the two crops were grown together, although the soil was generally acidic at pH of 5-5.1. Plots treated with tithonia manure had a significantly higher pH (5.1) as compared to plots treated with mineral fertilizer and the control. This could be attributed to high pH of tithonia manure (pH 6.5) which slightly raised the soil pH. Although Mugendi *et al*. (1999) found that soil pH decreased significantly in sole tithonia, calliandra with half recommended rate of mineral fertilizer and leucaena with half recommended rate of mineral fertilizer, the soils at their site was at a higher pH (pH 6.8). The pH increase with manure treatment could be attributed to the reduction of exchangeable aluminum in acidic soils. A reduction considered to occur through aluminum precipitation or chelation on organic colloids or by complexation of soluble aluminum by organic molecules (Suge *et al.*, 2012).

Integrated nutrient application (MFTDB) increased soil organic carbon in sole maize and beans by 30.6% and 30.4% of the control respectively. Plots treated with tithonia manure or mineral fertilizer alone also had a significantly higher organic carbon than the control. These findings confirmed a report by Akanbi *et al.* (2007) who reported that the use of composited tithonia manure increases the soil organic matter. Ghuman and Sur, (2006) similarly, reported that application of farmyard manure at 18 t/ha recorded higher organic matter over farmyard manure at 6 t/ha. The increase in organic carbon is ascribed to the addition of organic matter into the soil which was later mineralized by micro-organisms to carbon. Eghball, (2002), observed an increase in soil organic carbon after 4 years of manure application where about 25% C was retained in the soil carbon pool with no significant difference in soil carbon with the mineral fertilizer application only. This was because the organic materials 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 (Eghball, 2002).

The increase in residual N contents was directly related to the organic manure addition to the soil. Tithonia residue incorporation as green manure interacted positively with inorganic fertilizers in building up the soil N. Nitrogen content slightly increased in intercropped plots compared to sole maize although was highest in sole bean plots treated with tithonia. The finding concurs with that of Vesterager- Neilsen and Hogh-Jensen, (2008) who found that maize and cowpea intercropping is beneficial on nitrogen poor soils. Dahmardeh *et al.* (2010) also reported that maize-cowpea intercropping increased the amount of nitrogen, phosphorus and potassium contents compared to monocrops of maize. Mugendi *et al.* (1999) reported that soil-incorporation of calliandra and leucaena green biomass with or without fertilizer increased total soil nitrogen by 1–8% over a period of 4 years. During the same period, total soil nitrogen declined by 2–4% when biomass was not applied. Rahman *et al.* (2013) observed that when a legume is included in an intercrop, a major portion of N comes from biological nitrogen fixation by *Rhizobium* bacterium of the root nodules of mungbean and the rest of N along with other nutrients are recycled in the soil plant system. These nutrients become available after decomposition of the residues. Similarly, Chalka and Nepalia, (2006) found that maize intercropped with soybean produced significantly lower

NPK depletion and higher N uptake. Actually, recent efforts on replenishment of soil fertility in Africa have been through the introduction of legumes as intercrop and/or in rotation to minimize external inputs

CEC was highest in tithonia manure treated plots than all the other fertilizer regimes. Organic fertility amendments enhanced beneficial microorganisms, increased soil organic matter, total carbon, cation exchange capacity and lowered bulk density; thus improved soil quality which ultimately increased the yield of tomato during the second year of study. Organic fertilizers improve soil water holding capacity, CEC, nutrients release to crop plants as well as improving the physical properties of the soil (Bulluck *et al*., 2002). Tithonia treated plots retained more phosphorus and potassium than mineral fertilizer treated plots but they all had higher retention than the control, an increase of available P content in organic matter treated plots might be due to the decomposition of organic matter accompanied with the release of appreciable quantities of organic P which in turn helped increase P availability (Rahman *et al*., 2013). There was higher uptake of K than its addition in control plots, where the initial K was 5.6 mmol+/kg and the highest residual K was 5.3 mmol+/kg mmol indicating K mining from soils. Despite the beneficial effects of intercropping to the cereal crops, Mucheru-Muna *et al*. (2010) observed that it accelerates soil nutrient depletion, particularly phosphorous, due to more efficient use of soil nutrients and higher removal through the harvested crops. The higher K mining from the soil was also observed by Rahman *et al*. (2013). In support to these findings, Olubukola *et al*. (2010) reported that use of tithonia as soil amendment for growth of *Celosia argentea* led to the retention of more N, P, K, Mg and Ca compared to the control. Calcium increased significantly in the tithonia manure, and integrated nutrient treatments than mineral fertilizer treated plots and the control. Calcium was retained more in maize-bean intercropped plots than either sole maize or beans. The increase in the exchangeable calcium and magnesium content of soil might be due to release of those nutrients from added organic sources with inorganic fertilizers to the soil after mineralization (Rahman *et al*., 2013). This indicates that the addition of organic sources release exchangeable calcium and magnesium to the soil.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings lead to the conclusion that;

1. Tithonia biomass manure affected growth and yield of maize and beans whether grown as a monocrop or intercrop
2. Mineral fertilizer (17:17:17) affected growth and yield of maize and beans whether grown as a monocrop or intercrop
3. Intercropping maize and beans, regardless of the fertilizer regime have agro-biological advantages over individual crops
4. There are definite yield and economic advantages in maize-bean intercrop.

6.2 Recommendations

The study recommends;

1. Integration of locally available tithonia biomass and mineral fertilizer for green maize and/or beans production
2. Use of tithonia biomass manure at a rate of 8 tons/ha for beans production
3. Adoption of intercropping green maize and beans by farmers to get higher returns

Recommendations for further research;

1. Further research to be done with varying amounts of tithonia biomass and mineral fertilizer to establish the most economical nutrient regimes.
2. An on farm cost-effective study to be done between the tithonia manures, mineral fertilizers and integrated nutrient.

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APPENDIX

ANOVA TABLES

```
Height at 42 days after planting sole maize (Trial one)

                                                    Sum of
        Source                      DF             Squares      Mean Square    F Value    Pr > F

        Rep                          2           9.8466667        4.9233333       0.65    0.5570
        Trt                          3         132.8866667       44.2955556       5.81    0.0330
        Error                        6          45.7133333        7.6188889
        Corrected Total             11         188.4466667

                       R-Square         Coeff Var        Root MSE        HT6 Mean
                       0.757420       11.19014  2.760233        24.66667
```

```
Height at 70 days after planting sole maize (Trial one)

                                                    Sum of
        Source                      DF             Squares      Mean Square    F Value    Pr > F

       Rep                          2            4.934067         2.467033       0.06    0.938
       Trt                          3         1455.441733       485.147244      12.59    0.0053
       Error                        6          231.238467        38.539744
       Corrected Total             11         1691.614267

                       R-Square         Coeff Var        Root MSE         H 70 DAP Mean
                       0.863303         6.208039         6.458858        96.11667
```

```
Height at 84 days after planting sole maize (Trial one)

                                                    Sum of
        Source                      DF             Squares      Mean Square    F Value    Pr > F

        Rep                          2         1361.166667       680.583333       2.13    0.1995
        Trt                          3         7582.250000      2527.416667       7.93    0.0165
        Error                        6          1913.50000        318.91667
        Corrected Total             11         10856.91667

                        R-Square        Coeff Var       Root MSE      H 84 DAP Mean
                        0.823753         9.944262       17.85824       179.5833
```

```
Height at 28 days after planting for sole maize (Trial two)
                                                    Sum of
        Source                      DF             Squares      Mean Square    F Value    Pr > F

        Rep                          2         21.66500000      10.83250000      10.17    0.0118
        Trt                          3         25.30916667       8.43638889       7.92    0.0165
        Error                        6          6.38833333       1.06472222
        Corrected Total             11         53.36250000

                        R-Square        Coeff Var       Root MSE       H 28 DAP Mean
                        0.880284         7.228398       1.031854       14.27500
```

Height at 42 days after planting for sole maize (Trial two)

```
                                        Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Rep                          2      66.4800000      33.2400000       9.52    0.0138
Trt                          3     151.3158333      50.4386111      14.45    0.0037
Error                        6      20.9466667       3.4911111
Corrected Total             11     238.7425000

                R-Square     Coeff Var      Root MSE     H 42 DAP Mean
                0.912263      5.843476      1.868452      31.97500
```

Height at 28 days after planting for mixed maize (Trial one)

```
                                        Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Rep                          2      1.70666667      0.85333333       1.56    0.2846
Trt                          3      8.49000000      2.83000000       5.18    0.0421
Error                        6      3.28000000      0.54666667
Corrected Total             11     13.47666667

              R-Square     Coeff Var      Root MSE     H 28 DAP Mean
              0.756616      7.189975      0.739369      10.28333
```

Height at 56 days after planting for mixed maize (Trial one)

```
                                        Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Rep                          2     296.8466667     148.4233333       3.77    0.0870
Trt                          3     342.5966667     114.1988889       2.90    0.1236
Error                        6     236.1133333      39.3522222
Corrected Total             11     875.5566667

                R-Square     Coeff Var      Root MSE     H 56 DAP Mean
                0.730328      9.388578      6.273135      66.81667
```

Height at 84 days after planting for mixed maize (Trial one)

```
                                        Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Rep                          2      360.500000      180.250000       0.57    0.5921
Trt                          3     6792.916667     2264.305556       7.19    0.0206
Error                        6     1888.833333      314.805556
Corrected Total             11     9042.250000

                R-Square     Coeff Var      Root MSE    HT12 Mean
                0.791110      9.425105      17.74276     188.2500
```

Height at 28 days after planting for mixed maize (Trial two)

```
                                        Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Rep                          2     10.42166667      5.21083333       8.59    0.0173
Trt                          3     41.92916667     13.97638889      23.05    0.0011
Error                        6      3.63833333      0.60638889
Corrected Total             11     55.98916667

                R-Square     Coeff Var      Root MSE     H 28 DAP Mean
                0.935017      5.276407      0.778710      14.75833
```

```
Height at 70 days after planting for mixed maize (Trial two)

                                                Sum of
Source                          DF             Squares     Mean Square    F Value    Pr > F

Rep                              2         519.331667      259.665833       7.77    0.0216
Trt                              3        3741.776667     1247.258889      37.33    0.0003
Error                            6         200.448333       33.408056
Corrected Total                 11        4461.556667

              R-Square     Coeff Var      Root MSE    H 70 DAP Mean
              0.955072      4.992057      5.779970         115.7833
```

```
Height at 42 days after planting for sole beans (Trial one)

                                                Sum of
Source                          DF             Squares     Mean Square    F Value    Pr > F

Rep                              2          3.62646667      1.81323333       2.06    0.2083
Trt                              3          2.56356667      0.85452222       0.97    0.4656
Error                            6          5.27833333      0.87972222
Corrected Total                 11         11.46836667

              R-Square     Coeff Var      Root MSE    H 42 DAP Mean
              0.539748      7.589495      0.937935         12.35833
```

```
Height at 56 days after planting for sole beans (Trial one)

                                                Sum of
Source                          DF             Squares     Mean Square    F Value    Pr > F

Rep                              2         101.9266667      50.9633333       1.63    0.2720
Trt                              3          63.2366667      21.0788889       0.67    0.5986
Error                            6         187.5933333      31.2655556
Corrected Total                 11         352.7566667

              R-Square     Coeff Var      Root MSE    H 56 DAP Mean
              0.468208      21.24722      5.591561         26.31667
```

```
Height at 56 days after planting for sole beans (Trial two)

                                                Sum of
Source                          DF             Squares     Mean Square    F Value    Pr > F

Rep                              2          317.555000      158.777500       2.64    0.1504
Trt                              3         2760.960000      920.320000      15.31    0.0032
Error                            6          360.685000       60.114167
Corrected Total                 11         3439.200000

              R-Square     Coeff Var      Root MSE    H 56 DAP Mean
              0.895125      11.04463      7.753333         70.20000
```

```
Height at 28 days after planting for mixed beans (Trial two)

                                                Sum of
Source                          DF             Squares     Mean Square    F Value    Pr > F

Rep                              2          1.50000000      0.75000000       1.13    0.3847
Trt                              3         29.75000000      9.91666667      14.88    0.0035
Error                            6          4.00000000      0.66666667
Corrected Total                 11         35.25000000

              R-Square     Coeff Var      Root MSE    H 28 DAP Mean
              0.886525      5.354076      0.816497         15.25000
```

Height at 42 days after planting for mixed beans (Trial two)

```
                                              Sum of
        Source                      DF       Squares     Mean Square    F Value    Pr > F

        Rep                          2   185.5216667      92.7608333       9.70    0.0132
        Trt                          3    97.1000000      32.3666667       3.38    0.0951
        Error                        6    57.3850000       9.5641667
        Corrected Total             11   340.0066667

                        R-Square     Coeff Var      Root MSE     H 42 DAP Mean
                        0.831224      9.213303      3.092599      33.56667
```

Diameter at 56 days after planting for sole maize (Trial one)

```
                                              Sum of
        Source                      DF       Squares     Mean Square    F Value    Pr > F

        Rep                          2    0.21736867      0.10868433       3.36    0.1049
        Trt                          3    0.24987300      0.08329100       2.58    0.1495
        Error                        6    0.19402600      0.03233767
        Corrected Total             11    0.66126767

                        R-Square     Coeff Var      Root MSE    D 56 DAP Mean
                        0.706585      7.524657      0.179827      2.389833
```

Diameter at 42 days after planting for sole maize (Trial two)

```
                                              Sum of
        Source                      DF       Squares     Mean Square    F Value    Pr > F

        Rep                          2    0.03423117      0.01711558       0.37    0.7034
        Trt                          3    0.39829358      0.13276453       2.89    0.1241
        Error                        6    0.27516017      0.04586003
        Corrected Total             11    0.70768492

                        R-Square     Coeff Var      Root MSE    D 42 DAP Mean
                        0.611183      13.25661      0.214150     1.615417
```

Diameter at 42 days after planting for mixed maize (Trial one)

```
                                              Sum of
        Source                      DF       Squares     Mean Square    F Value    Pr > F

        Rep                          2    0.05949600      0.02974800       0.45    0.6564
        Trt                          3    0.65695600      0.21898533       3.33    0.0980
        Error                        6    0.39496800      0.06582800
        Corrected Total             11    1.11142000

                        R-Square     Coeff Var      Root MSE    D 42 DAP Mean
                        0.644628      14.85638      0.256570     1.727000
```

Diameter at 42 days after planting for mixed beans (Trial two)

```
                                              Sum of
        Source                      DF       Squares     Mean Square    F Value    Pr > F

        Rep                          2    0.01105650      0.00552825       7.40    0.0240
        Trt                          3    0.01616225      0.00538742       7.22    0.0204
        Error                        6    0.00447950      0.00074658
        Corrected Total             11    0.03169825

                        R-Square     Coeff Var      Root MSE    D 42 DAP Mean
                        0.858683      4.729325      0.027324     0.577750
```

Leaf Area of beans at flowering for mixed beans (trial one)

```
                                        Sum of
 Source                      DF        Squares      Mean Square    F Value    Pr > F

 Rep                          2    25149.43314      12574.71657       1.00    0.4216
 Trt                          3    37709.88640      12569.96213       1.00    0.4546
 Error                        6     75393.3790       12565.5632
 Corrected Total             11    138252.6985

            R-Square     Coeff Var      Root MSE      LA Mean
            0.454670      339.6221      112.0962     33.00617
```

Number of Branches per plant for sole bean (trial two)

```
                                        Sum of
 Source                      DF        Squares      Mean Square    F Value    Pr > F

 Rep                          2     1.05500000       0.52750000       4.58    0.0621
 Trt                          3     3.41583333       1.13861111       9.88    0.0098
 Error                        6     0.69166667       0.11527778
 Corrected Total             11     5.16250000

            R-Square     Coeff Var      Root MSE      NB Mean
            0.866021      13.18547      0.339526     2.575000
```

Number of Leaves at tasseling for sole maize (trial one)

```
                                        Sum of
 Source                      DF        Squares      Mean Square    F Value    Pr > F

 Rep                          2     1.16666667       0.58333333       0.51    0.6232
 Trt                          3     5.66666667       1.88888889       1.66    0.2735
 Error                        6     6.83333333       1.13888889
 Corrected Total             11    13.66666667

            R-Square     Coeff Var      Root MSE      NL Mean
            0.500000      10.85275      1.067187     9.833333
```

Diameter of Cobs in mixed maize (trial two)

```
                                        Sum of
 Source                      DF        Squares      Mean Square    F Value    Pr > F

 Rep                          2     0.00954200       0.00477100       0.61    0.5738
 Trt                          3     0.37964367       0.12654789      16.19    0.0028
 Error                        6     0.04690333       0.00781722
 Corrected Total             11     0.43608900

            R-Square     Coeff Var      Root MSE      DC Mean
            0.892446      1.849881      0.088415     4.779500
```

Number of pods per bean plant (trial two)

```
                                        Sum of
 Source                      DF        Squares      Mean Square    F Value    Pr > F

 Rep                          2     1.50000000       0.75000000       0.61    0.5745
 Trt                          3    64.76916667      21.58972222      17.52    0.0023
 Error                        6     7.39333333       1.23222222
 Corrected Total             11    73.66250000

            R-Square     Coeff Var      Root MSE      NP Mean
            0.899632      13.49611      1.110055     8.225000
```

BEY intercrop (trial one)

```
                                              Sum of
Source                         DF            Squares     Mean Square    F Value    Pr > F

Rep                             2         2.14709322      1.07354661       0.45    0.6576
Trt                             3        62.19977526     20.73325842       8.69    0.0133
Error                           6        14.31656076      2.38609346
Corrected Total                11        78.66342925


               R-Square     Coeff Var      Root MSE    BEY intercrop Mean

               0.818002      14.22509      1.544699              10.85897
```

Aggressivity for maize (trial one)

```
                                              Sum of
Source                         DF            Squares     Mean Square    F Value    Pr > F

Rep                             2         0.00006551      0.00003275       0.76    0.5073
Trt                             3         0.00001657      0.00000552       0.13    0.9397
Error                           6         0.00025808      0.00004301
Corrected Total                11         0.00034016


               R-Square     Coeff Var      Root MSE    A ab Mean

               0.241305      54.76223      0.006558    0.011976
```

Intercrop Advantage for bean (trial one)

```
                                              Sum of
Source                         DF            Squares     Mean Square    F Value    Pr > F

Rep                             2        1907.188392      953.594196       3.98    0.0795
Trt                             3        2165.511931      721.837310       3.01    0.1163
Error                           6        1438.965712      239.827619
Corrected Total                11        5511.666036


               R-Square     Coeff Var      Root MSE    IA bean Mean

               0.738924     -1223.075      15.48637       -1.266184
```

BEY sole (Trial two)

```
                                              Sum of
Source                         DF            Squares     Mean Square    F Value    Pr > F

Rep                             2         1.13602821      0.56801411       0.99    0.4239
Trt                             3        31.18524854     10.39508285      18.18    0.0020
Error                           6         3.42987393      0.57164565
Corrected Total                11        35.75115067


               R-Square     Coeff Var      Root MSE    BEY sole Mean

               0.904063      6.182362      0.756073         12.22951
```

Competitive Ratio for maize (trial two)

```
                                              Sum of
Source                         DF            Squares     Mean Square    F Value    Pr > F

Rep                             2         0.99606912      0.49803456       0.99    0.4258
Trt                             3         9.41387445      3.13795815       6.22    0.0285
Error                           6         3.02581742      0.50430290
Corrected Total                11        13.43576099


               R-Square     Coeff Var      Root MSE    CR maize Mean

               0.774794      16.21158      0.710143    4.380467
```

Actual Yield Loss

```
                                             Sum of
Source                      DF              Squares      Mean Square    F Value    Pr > F

Rep                          2           0.03320988       0.01660494       0.08    0.9202
Trt                          3           0.12346921       0.04115640       0.21    0.8866
Error                        6           1.18090494       0.19681749
Corrected Total             11           1.33758403

               R-Square     Coeff Var      Root MSE    AYL ab Mean
               0.117136      1742.298      0.443641       0.025463
```

Organic Carbon (maize/bean samples)

```
                                             Sum of
Source                      DF              Squares      Mean Square    F Value    Pr > F

Rep                          2            0.5000000        0.2500000       1.09    0.3955
Trt                          3          408.3825000      136.1275000     591.86    <.0001
Error                        6            1.3800000        0.2300000
Corrected Total             11          410.2625000

               R-Square     Coeff Var      Root MSE       OC Mean
               0.996636      1.123804      0.479583      42.67500
```

Total Nitrogen (maize/bean)

```
                                             Sum of
Source                      DF              Squares      Mean Square    F Value    Pr > F
Rep                          2           0.00686667       0.00343333       1.36    0.3255
Trt                          3           0.99929167       0.33309722     132.06    <.0001
Error                        6           0.01513333       0.00252222
Corrected Total             11           1.02129167

               R-Square     Coeff Var      Root MSE       TN Mean
               0.985182      1.596452      0.050222      3.145833
```

Fertilization and Management Advice

9-12-2014 15:01:16
Esther Muturi
Kingongo

Nyeri Kenya

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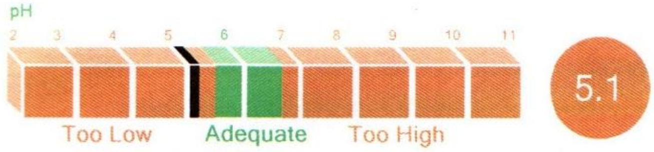
General Information

Sample No : ATAC700499A14	Soil Texture : Clay	Name Field : MF +TDB field
Client No :	Field Size : 0,5 acre	For Crop : cabbage

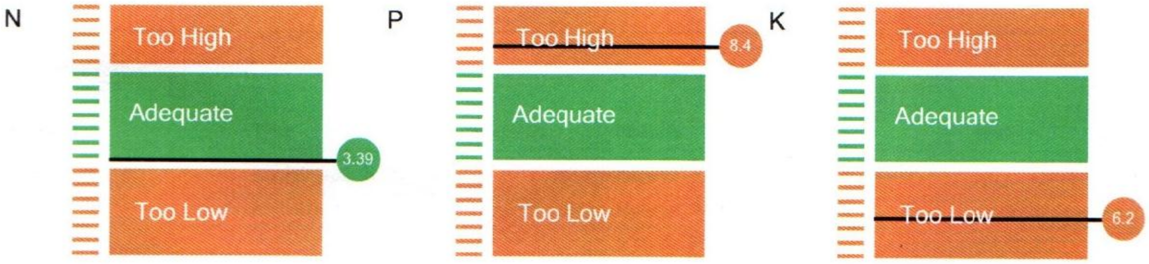


Soil Acidity

Your pH is too low for cabbage. You need to raise the pH. Therefore we recommend you apply **750 kg** of Agricultural lime to your field. Apply lime widespread (wear gloves and dust mask) 1 or 2 weeks before rain and planting and incorporate it into the soil immediately. Lime needs te react with Hydrogen (H+) in the soil to reduce acidity. Therefore do not mix it with your compost and plant only after lime application.

Soil Fertility

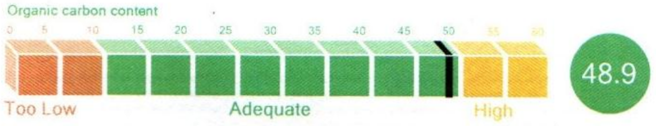
The N, P and K levels of your soil are 3.39 Total Nitrogen (N, g/kg), 8.4 Phosphorus (P, mmol P/kg) and 6.2 Potassium (K, mmol+/kg). Your fertilizer advice is based on the potential supply of your soil for N, P and K for the coming season.



The most limiting in your soil is Potassium (K). After this Nitrogen (N) is important. We recommend you to fertilize your field at planting with:

18 kg of N:P:K - 0:0:60 for your field.

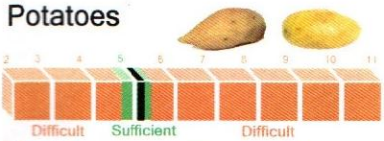
Put the fertilizer at the bottom of the planting holes, put 10 centimeter of soil on top, then add the seed and cover the seed with soil.



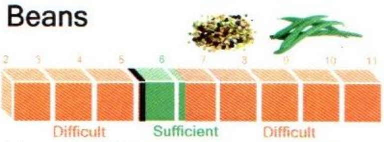
Soil Health

The level of Soil Organic Carbon is adequate. However we still advise you to increase the organic carbon level by using a minimum maintenance application of **2500 kg** compost or animal manure. This improves the water retaining capacity, disease resistance and structure of your soil.

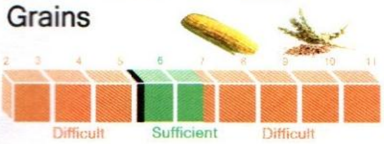
Potatoes



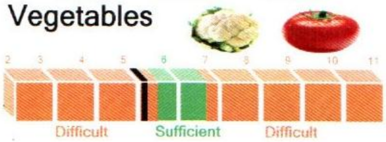
Beans



Grains



Vegetables



Suitable Crop Types:

Your soil is suitable for groing potatoes. Growing grains, vegetables and beans will be more difficult.

General Advice

- Use improved/certified seeds
- Carry out sufficient weeding - otherwise you fertilize the weeds and not your crop
- Make continuously compost to have sufficient volume for your field
  - Use crop residues, animal manure and organic material from your kitchen for your compost heap
  - Built your compost heap in the shade of a tree and keep it slightly moist
  - Incorporate your compost into the soil by harrowing or ploughing before you plant your crop and before you use fertilizers, or spread it around your crops during the growing season
- In case you experience problems with Striga do the following
  - Plant resistant varieties of your crop
  - Weed the Striga plant before it produces seed
  - Increase Nitrogen fertilization - this suppresses Striga
- Practice crop rotation after each season to prevent diseases

Advice for your Field

Product	Time	Quantity
Agricultural Lime	Start of season	750 kg
Fertilizer 0:0:60	At Planting	18 kg

Information:

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Analytical results

Results	Unit	Value
Organic carbon content	g/kg	48.9
Mg(exch. Magnesium)	mmol+/kg	41.8
K (exch. Potassium)	mmol+/kg	6.2
pH	pH Value	5.1
Phosphor stock	mmol P/kg	8.4
Cation Exchange Capacity	mmol+/kg	180
Total nitrogen content	g/kg	3.39
Ca (exch. Calcium)	mmol+/kg	102
Clay content	g/kg	680
Sand content	g/kg	170

Disclaimer

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