IMPROVING AGRONOMIC EFFICIENCY IN CASSAVA- BASED FARMING SYSTEMS IN THE DEMOCRATIC REPUBLIC OF CONGO USING ORGANIC AND INORGANIC INPUTS

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DECLARATION

Declaration by the Candidate

This thesis is my original work and has not been presented for a degree in any other University or any other award. No part of this work should be reproduced without the prior permission of the author and/or Kenyatta University.

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To my dear parents for their love and enormous support

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

AE	Agronomic Efficiency
ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
$\text{cmol}_c\ \text{kg}^{-1}$	Centimole per kilogram
$Ca (NO_3)_2$	Calcium nitrate
CIALCA	Consortium for Improving Agriculture-Based Livelihoods in Central Africa
CIAT	International Centre for Tropical Agriculture
CNE	Crop Nutrient Equivalents
CTA	Technical Centre for Agriculture and Rural Cooperation
DM	Dry matter content
FAO	Food and Agriculture Organization
FCNE	Fertilizer Crop Nutrient Equivalents
g	gram
h	hours
ha	hectare
HCN	Hydrogen cyanide
IFAD	International Fund for Agricultural Development
IITA	International Institute for Agriculture Development
IPNI	International Plant Nutrition Institute
kg	kilogram
LAI	Leaf Area Index
LER	Land Equivalent Ratio
m	metre
ppm	part per million
ton	tonne
TSP	Triple Super Phosphate
UNEP	United Nations Environment Programme

ABSTRACT

Cassava is an important food crop in small-holder farming systems in DR. Congo. Due to the limited use of organic and inorganic inputs, soil fertility becomes a major problem in cassava production systems. Inorganic inputs for small-holder farmers are often too expensive to apply at optimal rates and combining use of organic and inorganic fertilizer inputs is a suitable management principle for small-holder farmers. A study involving 15 households was carried out in DR. Congo with the following objectives: (ii) to determine the effect of an improved variety and fertilizer on agronomic efficiency in cassava or groundnut monocropping, (iii) to establish the effect of the combined use of inorganic and organic inputs on fertilizer response in cassava intercropping and (iv) to evaluate the influence of agronomic practices on the productivity of cassava-legume intercrops. Field trials were conducted to determine the use of improved variety and fertilizers at different rates on agronomic efficiency in the pure cassava or groundnut, the effect of combined application of inorganic and Chromolaena inputs, the effect of three legumes on yields in the cassava intercrops, the optimal cowpea spacing in the cassava-cowpea intercrop and the optimal cassava planting time in the cassava-groundnut intercrop in the two study sites. Data on rainfall, biomass, grain and root yields were collected. Significance differences between yields and varieties or soil types were tested using univariate analysis of variance. The CROSSTAB procedure using Pearson Chi Square analysis was used to test for significance effects of varieties on yields and farmer fertility score within site. Yield data were subjected to ANOVA and means separated using LSD ($P < 0.05$). Different soil types did not influence cassava root yields while different cassava varieties influenced cassava root yield in all surveyed sites. The use of improved variety and fertilizer application significantly ($P = 0.017$ and $P = 0.016$) increased crop yields by 48 to 173% and 58 to 156%, respectively over the control in both pure cassava and groundnut in both sites. Sole NPK, sole Chromolaena or combined use of NPK and Chromolaena significantly ($P = 0.013$, $P = 0.003$ and $P = 0.03$) increased casssava yields by about 45%, 43% and 77%, respectively relative to the controls in both sites. Cassava intercropping with soybean or cowpea was significantly ($P < 0.001$) superior over the pure cassava in terms of cassava tubert yield and the net benefits in both sites. Closer intra-row spacing of cowpea (30 cm) significantly ($P =0.02$) increased the net benefits by about 101% over the wider spacing (50 or 70 cm). Cassava planted 3 weeks after the groundnuts significantly ($P = 0.042$) decreased cassava tuber yields by 48 to 60% relative to cassava planted at the same time as groundnut. The results of this study showed that farmers should use an improved variety and apply fertilizer to improve the cassava and groundnut monocropping systems. Sole fertilizer or Chromolaena and the combined use of fertilizer and Chromolaena increased the yields and profitability of a cassava-groundnut intercrop. Cassava intercropped with soybean or cowpea has benefits in the cassava intercropping systems. The closer spacing (30 cm) of cowpea gave a higher income than the wider spacing (50 or 70 cm) in a cassava-cowpea intercrop. Cassava should be intercropped with groundnut within 2 weeks after sowing of groundnut. This study recommended that to improve cassava-based production systems, famers should use improved varieties and apply both organic and inorganic fertilizer, legume intercrop, space and plant at times when optimum yields are obtained as per the findings of this study.

CHAPTER 1
INTRODUCTION

1.1 Background

Declining land productivity is a major problem facing the small-holder farmers in sub-Saharan Africa (SSA) due to low soil fertility, limited available resources to farmers and nutrient mining (McCann, 2005). The fertility of Africa's soil is inherently low since African soils are very old and lack volcanic rejuvenation (Bationo, 2009) with nitrogen (N) and phosphorus (P) commonly deficient in these soils. The population pressure coupled with limited land forces the farmers to grow crop after crop, over-burdening the soils leading to depletion of soil nutrients in Central Africa (UNEP, 2000). Gruhn *et al.* (2000) reported that about 55 % of the soils in the sub-humid zones have inherent low reserves of nutrient with the limited use of inorganic inputs among the small-scale farmers in SSA. Moreover, intensified cropping activities on available cropland resources have resulted in alternation of their natural physical and chemical properties and an overall decline in soil fertility status (Omotayo and Chukwuka, 2009). Soil fertility depletion is, therefore, a major contributor to low agricultural productivity in small-holder farms in Central Africa (Sanchez and Jama, 2002).

African agriculture is mainly dominated by small-holder farmers and most have limited access to markets, credit and technology, in addition to low crop production from year to year. Under the intensification of farming systems in most of Africa, small-holder farmers cultivate less productive and increasingly on marginal areas. Cassava (*Manihot esculenta* Crantz) is generally grown by small-holder farmers in marginal areas (FAO, 2000; Howeler, 2002, Otieno, 2012) as it can grow well on poor soils and under adverse climatic conditions (Howeler, 2002). During the last five decades total cassava production in Africa has increased from 31 to 118 million tons per year (FAOSTAT, 2009). Most of the increased production in Africa might be due to increase in land area under production rather than increase in yield per hectare (Hillocks, 2002). Small-holder farmers often consider the cassava suited for poor soils and not requiring fertilizer; although cassava shows response to fertilizer application (Fermont *et al.*, 2010; Pypers *et al.*, 2011), small-holder farmers farmers rarely apply inorganic fertilizer to cassava. As a result of the limited use of nutrient inputs, soil fertility is a main cause of decreasing cassava production in Central Africa (CIALCA, 2006).

The application of nutrient inputs is required for improvement and sustainability of agricultural production in SSA (Mokwunye and Bationo, 2002). Since inorganic fertilizer is an expensive commodity for small-holder famers, Integrated Soil Fertility Management (ISFM) has been increasingly adopted by the research and development community as a framework for increasing crop productivity. ISFM practices consist of proper fertilizer management, the use of improved variety, the combination of organic and fertilizer inputs and the adoption of input application rates to within-farm soil fertility gradients (Vanlauwe and Zingore, 2011). These practices focus on increasing agronomic efficiency (AE) of moderate quantities of inorganic fertilizer and supplementation by organic resources for small-holder farmers (Vanlauwe *et al.*, 2010). Since fertilizer inputs for small-holder farmers are often too expensive for them to apply at an optimal rate (Vanlauwe *et al.*, 2001a), combined application of organic and fertilizer inputs is a suitable management practice for them. Both organic and inorganic inputs are also needed in the long-term sustainability of soil fertility and crop production for small-holder farmers in the tropics (Vanlauwe *et al.*, 2001b). Therefore, it is necessary to focus on making increased and sustained cassava yields in small-holder farmers through improving the AE of organic and inorganic fertilizer inputs.

1.2 Statement of the problem and justification

For small-holder farmers in developing countries, low land productivity is mainly due to low fertility of soil and nutrient depletion that continue to present a major problem to achieving needed harvests (Sanginga and Woomer, 2009). In DR. Congo, depletion of soil fertility is recognized as the fundamental reason for low agricultural production (Sanchez and Jama, 2002). Therefore, improving use of fertilizer is a necessary practice for soil fertility management in SSA (Sanginga and Woomer, 2009). Most of the cassava growers have generally poor access to credit, markets and technology, leading to the practice of low input cassava agriculture (Aerni, 2004). Due to the limited use of organic and inorganic fertilizer inputs, soil fertility becomes a major problem in cassava production systems (CIACAL, 2006). As a result, cassava productivity in DR.Congo has been lowered further.

To consider nutrient use efficiency, the application of adequate and balanced quantities of nutrients is an important aspect in increasing crop productivity. In the past, there was not much improvement in fertilizer use efficiency in most regions because of the blanket fertilizer recommendation that does not take into account the indigenous soil nutrient supply in specific sites (Khurana et al., 2008). Therefore, Integrated Soil Fertility Management (ISFM) which aims at increasing the availability and agronomic efficiency of nutrients through the combined use of organic inputs and inorganic fertilizer was adapted for enhancing crop productivity in Africa (Vanlauwe et al., 2010).

In addition, African farmers are particularly faced with the challenge of diseases such as viral mosaic disease, brown streak, and bacterial blight (Boher and Verdier, 1994; Hillocks, 1997) without sufficient resources for controlling these diseases (Hillocks, 2002) that cause root yield reduction in cassava based farming systems. To increase this productivity, there is a need to identify high-yielding, disease-resistant varieties with good agronomic attributes (Egesi *et al.*, 2007; Okechukwu and Dixon, 2008). Moreover, the optimum spacing of cowpea and the relative planting time of cassava have not been commonly studied in the cassava-groundnut or cowpea intercropping system in DR. Congo. There is also a need to consider the relative cost and profitability of these technologies with the respect to their adoption by small-holder farmers.

1.3 Research questions

This study endeavoured to answer the following questions:

i. What are the factors influencing the present cassava production emanating from the local farming practices?

ii. How does the use of improved variety and fertilizer enhance agronomic efficiency of fertilizer in cassava and groundnut mono cropping system under different soil conditions?

iii. How does the combined application of mineral inputs and organic resources influence fertilizer response in cassava intercropping under different soil conditions?

iv. How do the agronomic measures influence cassava legumes intercropping system under different soil conditions?

1.4 Research objectives

The overall objective of this study was to have a better understanding of how the agronomic efficiency of nutrients applied in cassava based farming systems in DR.

Congo can be improved with the use of organic and inorganic inputs. This was addressed through the following specific objectives:

i. To determine the factors of soil type and cassava variety influencing cassava production in the study area
ii. To determine the effect of an improved variety and fertilizer use on agronomic efficiency, yield and economic returns in cassava or groundnut mono cropping system under different soil conditions
iii. To establish the effect of the combined application of inorganic and organic nutrient resources on fertilizer response and economic returns in cassava intercropping under different soil conditions
iv. To evaluate the influence of agronomic practices on the productivity and profitability of cassava intercropping systems under different soil conditions

1.5 Research hypotheses

The study was guided by the following research hypotheses:

i. Soil type and crop variety significantly influence cassava production under local farming conditions.
ii. Application of fertilizer to improved variety of cassava significantly increases the crop yield and improves agronomic efficiency in a cassava or groundnut mono cropping system under different agro-ecological conditions.
iii. Combining fertilizer inputs and organic resources significantly improve the yield and economic returns in the cassava-groundnut intercrop under different agro-ecological conditions.
iv. Performance of legumes, the relative time of planting and plant spacing significantly influence productivity in cassava-legume intercropping systems under different agro-ecological conditions.

1.6 Significance and anticipated output

Knowledge generated from this study will facilitate better understanding of the factors governing the production of cassava cropping systems under local conditions. This study was also expected to generate knowledge of the optimization of the combined application of fertilizer and organic inputs to improve fertilizer AE and crop yield while maintaining or enhancing soil nutrient conditions. The findings of this study will contribute to the development of a set of soil fertility management practices that include the use of improved variety, inorganic and organic inputs combined with the knowledge of how to adapt these management practices to current local conditions through maximizing agronomic efficiency of the applied nutrients, specifically for cassava-based systems in the humid lowlands. In addition, productivity in cassava-legume intercropping systems will be improved by developing agronomic practices and implementation of soil fertility management practices in multi-locational conditions. Economic analysis of applied nutrient inputs and various agronomic practices will give a broader understanding of the practices in terms of economic returns especially for the farmers to adopt them. The findings of this study will be important in assisting small-holder farmers to increase their productivity in cassava-based farming systems. Consequently, livelihood of small-holder farmers in cassava-based cropping systems will likely be improved and thus enable them to improve food-self-sufficency, reduce poverty and improve economic growth in cassava-based production areas in Africa.

1.7 Conceptual Framework

Intensive agriculture with limited use of agricultural inputs is a major cause of declining soil fertility in cassava production systems. This leads to poor cassava yields in DR. Congo. In addition, most of small-holder farmers use low yielding varieties and are faced with pest and disease pressure in their production systems. As a consequence, the productivity further decrease in cassava based farming systems. Figure 1.1 shows that

Integrated Soil Fertility Management (ISFM) options have a potential to deliver the improvement of cassava yields in Africa.

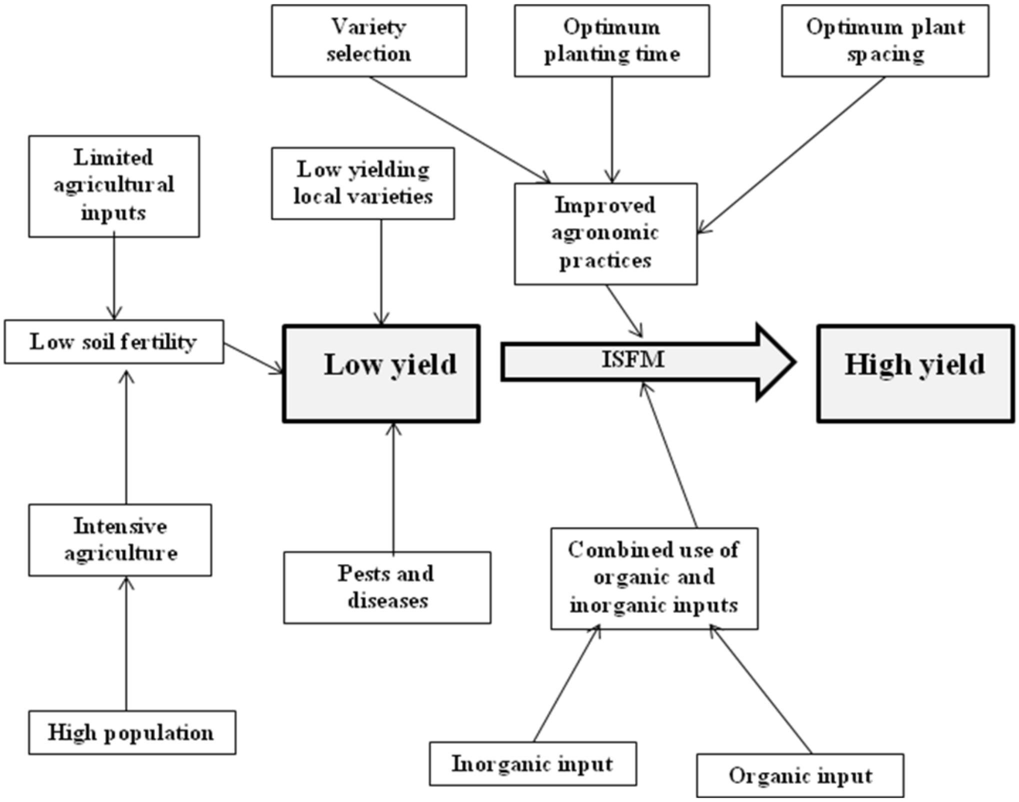

Figure 1.1: Schematic diagram of conceptual framework (Vanlauwe et al., 2010).

ISFM strategies focus on the combined use of inorganic fertilizer and organic inputs (crop residues, compost and green manure). In addition, improved agronomic practices such as variety selection, optimum planting time and spacing are adapted to local conditions to enahce agricultural productivity. Thus, ISFM results to improved soil qualtity and agronomic efficiency of applied fertilizer and thereby increasing the crop yield.

1.8 Definition of terms

Agronomic efficiency	Incremental return to applied inputs or kg crop yield increase per kg nutrient applied
Ferrasols	Red and yellow weathered soils with colors which result from an accumulation of metal oxides, particularly iron and aluminum
Haplic Acrisols	Coarse sandy clay soil with yellowish brown to brownish yellow
Plinthic Ferrasols	Ferrasols having plinthite within 125 cm of the surface
Threshold	The level above which an urgent response is required

1.9 Limitation of the study

The study was carried out in a rain fed conditions and the variability in rainfall/storms and temperature may affect the research outcome. The study did not also address the issues of pests, diseases, and animal which may also affect the research plots.

CHAPTER 2
LITERATURE REVIEW

2.1 General overview

Soil fertility depletion in small-holder farms is the main reason for declining per capita food production in sub-Saharan Africa (SSA) (Drechsel *et al.*, 2001). Gregory and Bump (2006) reported that during the last 30 years an average of 660 kg N ha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1} has been depleted from about 200 million ha of cultivated land in 37 African countries. Traditional soil fertility maintenance strategies, such as fallowing land, cereal-legume intercropping and mixed crop-livestock farming were not capable of adjusting quickly enough to rapid population growth combined with reducing farm size and soil fertility (Bartiono *et al.*, 2006). Thus, soil fertility replenishment in small-holder farms should be considered as an investment in SSA (Sanchez and Jama, 2002).

Cassava is a crop that is suited for poor soils because it has a potential to produce reasonable good yields on eroded and degraded soils (Howeler, 2002). However, like other crops it shows response to inorganic fertilizer application (Fermont *et al.*, 2010; Pypers *et al.*, 2011). Although SSA produces about half of world cassava production (FAOSTAT, 2004), its average yield is about 50 and 66 % lower than that of Asia and Latin America, respectively (Howeler, 1991). Most cassava growers in Africa are resource poor and there is almost no inorganic fertilizer application to cassava in their crop production system (Sanginga and Woomer, 2009). Since inorganic fertilizers are scarce and expensive agricultural inputs for small-holder farmers, this has led to poor adoption. Moreover, due to increasing rates of population growth, intensive agriculture system with limited soil fertility replenishment is practiced in most countries in DR. Congo (UNEP, 2000). This has resulted, to further decrease in productivity in the cassava based farming system in DR. Congo. Integrated soil fertility management (ISFM) has a potential to deliver alternative options. In recent years, this has been considered as the underlying technical framework for the sustainable intensification of production system in African small-holder farms (Vanlauwe, 2012). The sections that follow give introductory background of factors influencing the cassava based farming system in Central Africa, cassava response to fertilizer and organic inputs, and ISFM options.

2.2 Factors influencing the cassava-based farming system in DR. Congo

Due to increasing rates of population growth and food demand, most countries in DR. Congo are changing from extensive agriculture systems to intensive systems without adequate soil fertility replenishment (UNEP, 2000). Ultimately, this leads to soil degradation and low crop yield. Maintaining soil fertility through traditional methods such as shifting cultivation and grazing are thus no longer viable in these regions. Moreover, the dominant portion of agricultural soils in DR. Congo is largely characterized by acidic Ferralsols that is developed from strongly weathered parent materials and dominantly contains kaolinite clays (Deckers, 1993; Braun *et al.*, 1997) with low capacities of nutrient supply and nutrient retention (Bationo *et al.*, 2006). Therefore, declining soil fertility is a major concern for crop production in Central Africa (Franzel, 1999; Sanchez and Jama, 2002).

Based on the base line survey data of CIALCA (2009a) in DR Congo, a cassava-based farming system is characterized by small farm size, limited land availability, poor soils, costly and inefficient labour availability as well as little access to the improved variety in Central Africa (CIACA, 2007). Limited use of inorganic fertilizers and organic inputs thus might lead to soil fertility as a main factor that can reduce crop production system across all study area (CIALCA, 2006). Moreover, farm households have relatively little access to credit and agricultural services in their production system (CIALCA, 2009b). The output market is also poor, with the main market channel for selling cassava products being the farm gate or the local market.

On the other hand, small-holder farmers are faced with the numerous biotic stresses such as pests and diseases due to lack of enough resources to control those pests and diseases (Hillocks, 2002). In addition, lack of reliable post-harvest facilities and infrastructure such as roads, means of communication and input supply system becomes some of the constraints in cassava based farming system (Mbwika *et al.,* 2001). Therefore, cassava production per capita in DR. Congo is declining due to cassava pests and diseases, poor soils and lack of access to inorganic fertilizers as well as a breakdown of local cassava trade due to ongoing civil wars (Aerni, 2004).

2.3 Cassava

Cassava (*Manihot esculenta* Cranz) is a shrubby perennial plant of 1-4 m height with leaves varying in size and shape. Cassava is a tuberous crop that produces long and tapered storage roots that are a major source of energy and carbohydrates. Depending on the cultivars and growing conditions, these large storage roots are harvested 6 to 24 months after planting [MAP] (Alves, 2002) and can remain in the soil for 1 to 2 years without decaying particularly under drought conditions (Nweke *et al.*, 2002). During its growth, the cassava develops alternating periods of vegetative growth and carbohydrate storage in its roots (Alves, 2002). Under favorable conditions, the photosynthesis process can participate in plant growth after the true leaf appears at about 1 MAP. Most of the leaves and stems develop during 3 to 6 MAP. Since the leaves can intercept most of light incidence during the first 3 MAP, maximum canopy size may reach at 6 MAP (Hillocks, 2002). The fibrous roots can absorb water and nutrients in the soil at 1 MAP and storage roots may initiate when few fibrous root become storage roots from 2 to 6 MAP (Howeler, 2002). The storage of carbohydrate from leaves to roots may occur within 6 to 10 MAP. To get maximum crop productivity, the balance of sink capacity (photoassimilate of active leaves) and source activity (the number of storage roots and their mean weight) is crucial for the cassava crop during its growth (Alves, 2002).

In humid and sub-humid tropical regions cassava is extensively grown and the maximum root production is expected to occur in the tropical lowlands below 150 m altitude (FAO, 1983). It can be grown in a wide range of altitude (sea level to 2300 m altitude) and rainfall conditions from less than 600 mm in unimodal rainfall areas to above 2000 mm in bimodal rainfall zones (Alves, 2002). In general, cassava is grown by small-holder farmers in marginal areas and has a capacity to produce reasonable yields on poor or degraded soils where other crops do not produce well (Howeler, 2002). Compared with many other crops, the plant has greater water use efficiency and can tolerate water shortage (El-Sharkawy and Cock, 1986). This response to water stress is related to control of stomata closure which lessens the photosynthetic rates and decline in transpiration losses. During the prolonged water stress, cassava can reduce leave canopy by reducing the total leaf area resulting to less light interception (El-Sharkawy, 2007). It is well adapted to acid soils (low pH) and high level of exchangeable aluminum (Howeler, 2002). Moreover, it can withstand low concentration of phosphorus (P) in the soil due to the association with mychorrhiza fungi in the soil that can increase the uptake and transport of P to the roots and increase the explored soil volume (Howeler, 2002).

2.3.1 Inorganic fertilizer response in cassava

As most African farmers consider cassava suited for poor soils and no need to apply fertilizer, farmer rarely apply inorganic fertilizer to cassava (Nweke, 1994). Due to the limited use of organic and inorganic fertilizer inputs, soil fertility becomes a major limiting factor in cassava production system (CIALCA, 2006). Thus, the application of supplementary nutrients plays an important role in improving production as well as to maintain a positive nutrient balance. There is no doubt the response of cassava to inorganic fertilizer as it requires a high amount of potassium (K), and also nitrogen (N), phosphorus (P) to produce high root yield (Nguyen *et al.*, 2002). Past work reported that cassava responds to good soil fertility and inorganic fertilizer application (Fermont *et al.*, 2010; Pypers *et al.*, 2011; 2012; Uwah *et al.*, 2013). Pypers *et al.* (2012) found that cassava yields were increased by 42 to 212 % with the application of NPK fertilizer in western DR. Congo.

Uwah *et al.* (2013) reported that N fertilizer application at the rate of 120 kg N ha^{-1} increased the tuberweight and yield of cassava by 48 % and 36 %, respectively. In a series of on-farm experiments in Uganda and Western Kenya, Fermont (2009) demonstrates that cassava was significantly responsive to N fertilizer application. Under field conditions N, used by the storage root, can be lost through leaching (Stewart *et al.,* 2006) and run-off processes (Drury *et al.,* 1993). In addition, applied N fertilizer may be lost during the long period to maturity (12 to 18 months) with wider plant spacing leading to waste for poor resource farmers (Daniel *et al.,* 2009). Consequently, there was more significant response to N followed by K and P in Asia especially in Thailand (Hagens and Sittibusaya, 1990). At the expense of root bulking N enhances shoot growth that builds up in photosynthesis providing enough assimilate to initiate roots. Accordingly, numbers of tuberous roots were increased by N fertilizer application (Kasele *et al*., 1983). Ashokan *et al.* (1988) also reported that cassava response to N fertilizer can be enhanced with the addition of K fertilizer.

Although cassava can extract soil P nutrient efficiently from low P soil through mycorrhizal symbiosis (Omorusi and Ayanru, 2011), its tuber development may be affected by soil P deficiency (Olasantan *et al*., 2007) without expression of recognizable symptoms (Kang and Okeke, 1983). Cassava responds markedly to P application particularly on oxisols, ultisols and inceptisols having highly P fixing in Latin America (Howeler, 2002). Similarly, Fermont (2009) found the response of cassava to applied P fertilizer in Uganda and Western Kenya. The author also reported that average yield response to P nutrient was 45 to 106 kg of fresh root of cassava per kg of applied P fertilizer. The response of P application may depend on soil mycorrrhizal potential, available P supply in soil, fine root length and tuber sink strength of cassava varieties (Pellet and El-Sharkawy, 1993).

Continuous cassava cultivation without adequate K fertilizer may become a major limiting factor in production, since cassava requires large quantities of K in the tuberproduction (Howeler, 2002). Data from long term experiments also show that yields of without K applied treatments were reduced to about 3.5 times in continuous cultivation of cassava for 10 years in India (Kabeerathumma *et al.,* 1990). This might be due to the fact that K can stimulate leaf net photosynthetic activity and accelerate the translocation of photosynthates into tuberous roots (Mathewadoa, 2009). Response of K application is often found in soils with low pH and Cation Exchange Activity [CEC] (Kang, 1983) and frequently appears in strongly acid Acrisols from Easten Nigeria (Sanginga and Wommer, 2009). Fermont (2009) reported that K fertilizer application significantly increased the cassava tuberyields in Uganda and Western Kenya. With the application of K fertilizer storage cell size was increased by the acceleration of cambium activity (Kasele *et al.*, 1983). Furthermore, tuberization forms earlier at about 20 days after planting in either K fertilizer application alone or in combination with N and K fertilizer application (Kasele *et al.,* 1983).

In addition, an adequate and balanced application of macronutrients, secondary nutrients and micronutrients were required for high yielding cassava in India (Kamaraj *et al.,* 2008). A review by Howeler (2002) indicated that there were significant responses of cassava to the application of calcium, magnesium and sulfur fertilizers. Calcium (Ca) supports the supply and regulation of water in cassava plant, while Magnesium (Mg) is a basic component of chlorophyll for photosynthesis (Howeler, 2002). Results from experiments in Carimagua, Columbia show that highly significant responses to Ca and Mg applications were observed on sandy loam soil (CIAT, 1985). In eastern Nigeria Mg deficiency and significant response to Mg fertilizer application were found on strongly acid soils (Kang, 1983). Howeler (2002) stated that sulfur (S) which is the basic component of certain amino acids is an essential for producing protein and there is a high response of S application up to 20 to 40 kg S ha^{-1}. As S content is generally low in many tropical soils, there may be S response to cassava in tropical Africa (Sanginga and Woomer, 2009). The addition of zinc (Zn) together with NPK fertilizer significantly increased cassava yield by 12% in the field trials conducted in Central Tuber Crops Research Institute (CTCRI, 1992). Cassava tuber yield was increased by Zn application in soil with low Zn contents (CIAT, 1985) because cassava is quite susceptible to Zn deficiency (Howeler, 2002).

2.3.2 Organic input response in cassava

Planting cassava without application of inorganic fertilizer is a common practice among small-holder farmers. Many cassava famers often apply animal manure or compost to cassava. Although nutrient contents of animal manure is generally lower than that in most compound fertilizer, they contain Ca, Mg, S and some micronutrients (Fe, Zn, Mn, Cu, B and Mo) which are not included in most inorganic fertilizers (Sahu and Samant, 2006). Okoli *et al.* (2010) found that the growth and yield of cassava were increased by the application of poultry manure at 4 ton ha^{-1} in Southeastern Nigeria. This might have contributed to increasing the nutrient availability in the soil and thereby increasing the tuberyield of cassava (Ojeniyi *et al.*, 2012). Osungnoen (2004) also found that the application of manures (cattle manure, broiler manure with litter and pig manure) significantly increased the fresh root yields and tended to provide higher number and weight of roots per plants relative to the control or sole inorganic fertilizer application.

Apart from the application of animal manure, green manure application is well known for improving the soil physical properties through increasing the stability of soil aggregates and decreasing the soil bulk density (Masri and Ryan, 2005). The application of green manure to cassava significantly increased the fresh tuber yields of cassava (Okonofua *et al.,* 2007). Recently, Pypers *et al.* (2012) reported that cassava tuber yields were significantly increased by 36 to 158% with the application of green manure (tithonia or Chromolaena) in DR. Congo.

Intercropping cassava with leguminous plants and incorporating the residue after harvest can also improve soil fertility (especially if the intercrops are fertilized) and provide additional food income to farmers without seriously reducing cassava yields (Ennin and Dapaah, 2008). In acid sandy soils mulch application especially that of leguminous species increased cassava yields in Africa (Hulugalle *et al.*, 1991). During eight consecutive years, annual application of dry *Panicum maximum* grass at 12 ton ha^{-1} without inorganic fertilizer supply increased cassava yields and root dry matter as well as reduced HCN content (Cadavid *et al.*, 1998). As compared to the manure application the application of compost is lower in nutrients but when applied in large quantities (10 to 15 ton ha^{-1}) they may supply considerable amounts of nutrients and improve the soil physical properties and water holding capacity (Howeler, 2002).

2.3.3 Combined application of inorganic fertilizer and organic input responses in cassava

Although most farmers aware of the increased crop production through application of inorganic fertilizers, the adoption of this strategy has faced major restrictions according to high costs, highly variable nature of soils and inherent low nutrients (AGRA, 2007). On the other hand, organic resources cannot replenish soil fertility decline by themselves alone as they are generally not available in sufficient quantities in most farms to fulfill the nutrient requirement of crops (Buresh *et al.*, 1997). Low nutrient content and high demand of labour in processing and application of organic resources also constraints their use (Mugwe *et al.*, 2008; 2009; Mucheru-Muna *et al.*, 2013). It has been accepted that inorganic fertilizer and organic inputs cannot be completely substituted by one another and are both needed for sustainable agricultural production (Vanlauwe *et al.*, 2010a).

Therefore, combining use of organic and mineral fertilizers has been shown to be a sound management principle for small-holder farmers in the tropics to sustain soil fertility and crop production (Vanlauwe and Zingore, 2011). This might be due to (i) inorganic fertilizer or organic inputs alone may not practically support sufficient amounts for alleviating specific constraints to crop growth (Sanchez and Jama, 2002); (ii) the potential added benefits formed through positive interactions between organic and inorganic fertilizers in the short term (Place *et al*., 2003); and (iii) both organic and inorganic inputs play a major role in the long term agricultural sustainability (Vanlauwe *et al*., 2010a).

The combined application of organic fertilizer (poultry manure plus decomposed urban refuse) and NPK fertilizer at the rate of 400 kg ha^{-1} could increase the tuberyield of cassava (3 to 5 ton ha^{-1}) (Ayoola and Makinde, 2007). Ayoola (2011) also found that the cassava root yield was increased by 73 to 95 % with the combined application of organic input and inorganic fertilizer in Nigeria. This could be attributed by the increasing nutrient availability of cassava with the combined application of poultry manure and NPK fertilizer (Ojeniyi *et al*., 2012). It is described that cassava responds to the combined application of inorganic fertilizer and green manure (Escalada and Ratilla, 1998; Pypers *et al*., 2012). The combined application of green manure (*Leucaena leucocephala*) and PK fertilizer can increase the growth parameters (LAI and plant height), resulting in the increased production of tradable root and total root yields of cassava (Escalada and Ratilla, 1998). Pypers *et al*. (2012) also observed that the combined application of green manure (Tithonia or Chromolaena) can increase the profitability of cassava production relative to the common slash and burn practice in DR. Congo.

2.4 Groundnut

Groundnut (*Arachis hypogaea* L.), native to South America, Mexico and Central America, is known by many names including peanut, earthnut, monkey nut and poor man's nut. In many sub-Saharan African countries, it is one of the important food crops (Wangai *et al.*, 2001) and mostly grown as a subsistence and cash crop (Freman *et al.*, 1999). Besides being a source of income for resource poor farmers, it provides protein and other nutrients which make a substantial contribution to human nutrition (Ahmad and Rahim, 2007). Since the grain is a rich source of edible oil (Knauft and Ozias-Akins, 1995), about two thirds of world production is crushed the grain for oil production (Gowda *et al.*, 2009).

Groundnut belongs to the family *Leguminoase*, sub family *Papilionoidae*, genus *Arachis* and species *hypogaea* (Isleib *et al.*, 1994). The genus name *Arachis* comes from a-rachis (Greek, meaning without spine) and the species name *hypogaea* comes from hop-ge` (Greek, meaning below earth). Krapovickas and Gregory (1994) stated that sub-specific and variety classification are mainly based on flower location on the plant, reproductive node patterns on branches, the number of trichomes and pod morphology. Thousands of groundnut varieties are grown, with four main variety groups (Spanish, Runner, Virginia and Valencia) which are being the most popular among the groundnut variety groups (http://en.wikipedia.org/wiki/Peanut/13 August 2013). Groundnut is a self-pollinated, tropical annual herbaceous plant and about 30 to 50 cm tall. Natural cross pollination occurs at the rates of 1 to 6 % due to atypical flowers or bee activity (Coffelt, 1989).

Groundnut seed contains two cotyledons, stem axis and leaf primordial, hypocotyls and primary root. All primordial leaves and above-ground structures appear within the first few weeks after germination. During the germination, the hypocotyl pushes the seed to the soil surface and is easily distinguished during early stages of growth. The elongation of hypocotyl stops when light strikes the emerging cotyledon. Within four to five days, the tap root develops very fast and reaches a length of 10 to 12 cm. Lateral roots starts to appear about three days after germination (Gregory *et al.*, 1973). Initial plant growth is slow and rapid plant growth can be seen between 40 and 100 days after emergence (Ramanatha, 1988).

The leaves are opposite, pinnate with four leaflets (two opposite pairs), each leaflet 1 to 7 cm long and 1 to 3 cm broad (Veeramani and Subrahmaniyan, 2011). The flowers of groundnut are a typical pea flower in shape (2 to 4 cm across) and yellow with reddish veining. The bright yellow flowers with both male and female parts are located on inflorescences. The first flower appears at 4 to 6 weeks after sowing and maximum flower production occurs at 6 to 10 weeks after planting (Putnam *et al.*, 1991). After pollination, the flower stalks elongates resulting it to bend until the ovary touches the ground (http:// en.wikipedia. org /wiki / Peanut/ 13 August 2013). Stalk continued grow and pushes the ovary underground where the mature fruit develops into a legume pod (Young, 1980). The pods are 3 to 7 cm long and ripen 120 to 150 days after seed sowing. The pod contains two to five seeds depending on the types of variety. Seeds may be round or elliptical and have pointed or flattened ends. Seed size ranges from 0.15 to more than 1.3 g per seed but some of wild species produce the small seed with a size of about 0.0479 per seed (Singh and Simpson, 1994).

Groundnut is grown on nearly 23.95 million ha worldwide with the total production of 36.45 million ton ha^{-1} in 2009 (FAOSTAT, 2011). According to Ntare *et al.* (2008), groundnut production is mostly concentrated in Asia and Africa (56 % and 25 % of the world production, respectively) where small-holder farmers mostly grow the crop with limited agricultural inputs under rainfed conditions. In African countries the production of groundnut is low due to a combination of factors such as drought (mostly non-irrigated), pest and disease problems, limited use of improved variety and increased cultivation on marginal land (http:// www. tradeforum. org/ Exporting-Groundnuts/13 August 2013).

2.4.1 Inorganic fertilizer response in groundnut

Improving of the mineral nutrition is the key to improve groundnut production as groundnut has a very high nutrient requirement (Veeramani and Subrahmaniyan, 2011). In order to increase groundnut yields without depleting soil stocks, application of inorganic fertilizer plays important role in improving production. Several authors have reported that application of inorganic fertilizer (NPK fertilizer) increased the yields of groundnut as compared to the control (Shinde *et al.*, 2000; Subrahmaniyan *et al.*, 2000; Mucheru-Muna *et al.*, 2011). Parasuraman *et al.* (1998) reported that the increased availability of nutrients by fertilizer application enhanced the crop growth and thereby increased the yield of groundnut.

Although groundnut can satisfy part of its nitrogen needs through beneficial N fixation, groundnut crop shows response to N fertilizer application (Gogoi *et al.*, 2000;

Singh and Singh, 2001; Kandil *et al.*, 2007). Barik *et al.* (1994) found that the plant height was significantly increased by the application of N fertilizer. N fertilizer application significantly increased the dry matter production, leaf area index (LAI) and 100-seed weight of groundnut (Yakadri *et al.*, 1992; Barik *et al.*, 1998). In addition, application of N to groundnut significantly improved pod yields (Singh and Singh, 2001; Kandil *et al.*, 2007) as well as grain yields (Deka *et al.*, 2001; Gohari and Niyaki, 2010).

According to Kamara *et al.* (2011), P is an important nutrient for crop growth and groundnut yields. Application of P to groundnut increased the plant height, number of leaves per plant, the number of mature pods per plant and dry matter production over the control (Kamara, 2010). Moreover, 100-seed weight and shelling percentage were significantly increased by application of P (Sharma and Yadav, 1997). Kamara *et al.* (2011) reported that P fertilizer application significantly improved the pod and grain yields due to the important role played by P in the physiological process of plants. Protein content and oil content were also affected by application of P to groundnut (Gobarah *et al.*, 2006).

Since oil seed crops require large amounts of potassium (Singh, 2004), groundnut crop shows a high yield response to K application (Khera *et al.*, 1990). Jana *et al.* (1990) found that the number of pods per plant, 100-seed weight, pod yields and oil yields were increased by application of K up to 50 kg ha^{-1}. Several authors also observed that K application increased the grain yields of groundnut (Lakshmamma *et al.*, 1996; Patra *et al.*, 1996; Singh and Vidya, 1996). In addition, K application had effect on growth characters such as plant height (Singh and Vidya, 1996) and dry matter production of groundnut (Kankapure *et al.*, 1994).

Among secondary nutrients, Ca deficiency results to several problems for groundnut including poor germination, production of unfilled pods, darkened plumules in the seed (Grichar *et al.*, 2002), and reduced the yields (Meena *et al.*, 2007). Where a crop is grown on Ca deficient soil, a high percentage of pods is improperly filled and aborted (Ntare *et al.*, 2008). Rahman (2006) observed that calcium application at the rate of 150 kg Ca ha^{-1} significantly increased the plant height, the number of branches per plant aand pod yields compared to the control. Gashti *et al.* (2012) also found that pod yield, grain yield and oil contents of groundnut were increased by application of Ca. Ca fertilizer application also had a positive effect on the number of filled pods, shelling percentage and 100-seed weight which invariably resulted in higher pod and grain yields of groundnut (Kamara *et al.*, 2011).

2.5 Cassava-legume intercropping system

In order to maintain soil fertility and crop yields, intercropping which has been a common practice in small-holder crop production, is one of the available options in agricultural production. Intercropping system is the cultivation of two or more crops in the same space during the same season which uses environmental resources efficiently better than the crops grown separately (Ghosh *et al.*, 2006; Sobkowicz, 2006). Besides improving soil fertility (Shen and Chu, 2004; Dahmardeh *et al.*, 2010) and stabilizing higher yield (Dapaah *et al.,* 2003), the benefits associated with intercropping are reducing risk of crop failure (Mutsaers *et al.,* 1993), decreasing disease severity (Zinsou *et al.*, 2005), controlling weed pressure (Hernández *et al.*, 1999a; 1999b) and achieving more efficient utilization of environmental resources relative to the pure cropping system (Li *et al.*, 2003; Li *et al.*, 2006; Zhang and Li, 2006).

In this system, cassava intercropping is very popular among farmers because of yield stability and greater profitability per unit area of land relative to the pure cassava (Ezulike *et al.*, 1993). Cassava, a long duration, wide spaced crop covering the ground only 3 months after planting, is often intercropped with short duration crops such as cereal grains and grain legumes (Amanullah *et al.*, 2007). Among these crops, legumes are well-suited with cassava in terms of growth pattern, canopy development and nutrient demands, as they require mostly P and can satisfy part of their N needs through soil bacteria *Rhizobia* in their root nodule (Giller, 2001), while cassava requires large amounts of K for tuberformation and N for leaf production (Carsky and Toukourou, 2005). Moreover, the advantages of legume plant in intercropping include transferring some N to the component cereal crops and some residual N to the following crops (Adu-Gyamfi *et al.,* 2007). Because of environmental damage such as nitrate pollution by applying inorganic fertilizers, legume intercropping also presents an alternative and sustainable supply of N into lower input agro ecosystems (Fustec *et al.*, 2010). The other nutrients are also conserved through the return and crop residue decomposition (Rahman *et al.,* 2009).

Borin and Frankow-Lindberg (2005) found that cassava-legume intercropping can greatly increase total biomass yield without affecting cassava biomass production. Intercropping with leguminous plants (common beans, cowpea, groundnut, pigeon pea or soybean) generally increases productivity (land equivalency ratios [LER] of 1.2 to 1.9), with cassava yields either unaffected or decreased and legume yields least affected for species with short maturity periods (Ennin and Dapaah, 2008; Hidoto and Loha, 2013). Several authors also reported that intercropping with legumes did not show a significant effect on the yields of cassava relative to the pure cassava (Polthanee and Kotchasatit (1999) in a cassava-mungbean intercrop; Ennin and Dapaah (2008) in cassava-legume intercrops; Sikirou and Wydra (2004) in a cassava-cowpea intercrop; Njoku and Muoneke (2008) in a cassava-cowpea intercrop). This could be attributed to the suitable compatibility of legumes and cassava as intercrops due to the wide maturity gap between the two crops and the slow initial growth rate of cassava (Udealor and Asiegbu, 2005; Njoku and Muoneke, 2008; Lebot, 2009).

The tuberinitiation and bulking of cassava may not be subjected to any intercrop competition with legume since legume is harvested earlier before cassava tuberization process started (Mbah and Ogidi, 2012). The study conducted by Prabhakar and Nair (1992) revealed that the economic benefits could be achieved by intercropping with groundnut relative to the pure cassava in the cassava-groundnut intercrop.

2.5.1 Land equivalent ratio

It has been recognized that intercropping can often improve crop productivity as compared to sole crops (Szumigalski and Van Acker, 2008). In assessing the degree of yield advantage in intercrops, land equivalent ratio (LER) is an important tool to measure the levels of intercrop interference going on the cropping system (Mohammed, 2012). It also shows the efficiency of intercropping for using the environmental resources relative to the pure cropping system with the value of unity to be the critical value (Lithourgidis *et al.*, 2011). According to Dariush *et al.* (2006), LER is calculated as follows:

$\mathrm{LER} = \sum (Y_I/Y_M)$

where Y_I represents the yield of each crop in the intercropping system and Y_M is the yield of each crop in the monocropping system.

Theoretically, if the agro-ecological characteristics of each crop in intercrop are exactly the same, the total LER should be 1.0 and the partial LERs should be 0.5 for each crop (Morales-Rosales and Franco-Mora, 2009). On the other hand, if the total LER is greater than 1, the intercropping favours the yields of crops, indicating yield advantage (Dariush *et al.*, 2006). However, if the total LER is less than 1, the intercropping negatively affects the yields of the crops when the crops were intercropped relative to both crops separately (Edje, 1987). A LER of 1.5 for instance, indicates that the area planted to mono cropping would need to be 50% greater than the area planted to intercrop for the two crops to produce the same combined yields.

2.6 Effect of agronomic practices in the cassava-legume intercropping system

Agronomic research aiming at improving agronomic practices has been conducted to realize the optimal yield in the cassava intercropping system. Several authors reported that many factors including variety selection, planting density and planting time of the component crops can greatly affect the growth and productivity of the species used in the intercropping (Caballero *et al.*, 1995; Carr *et al.*, 2004). Because of the slow initial growth of cassava, a sole cassava crop does not efficiently use the growth resources such as space, light, water and nutrients during its early growth stages (Leihner, 1983). Therefore, a short-duration legume crop should be selected to make more efficient use of these growth factors in the cassava-legume intercropping system. Fukai *et al.* (1990) also stated that cassava has time to recover from the competitive effects of the legume if the intercropped legume matured before competition developed between the two crops.

The selection of legume variety is one of the important factors for higher production in the cassava-legume intercropping system. A study conducted in Vietnam revealed that intercropping with mungbean or soybean can be successful in sometimes but other times it can be failed due to the complete crop loss by drought or severe insect or disease problems (Howeler, 1992). However, groundnut does not suffer severe disease and insect problems and also reduce soil erosion, resulting successful in the cassava intercropping system (Howeler, 1992). Oguzor (2007), Mbah *et al.* (2010) and Umeh *et al.* (2012) found that intercrop with soybean can increase the root yield of cassava relative to the pure cassava while cassava root yields were decreased by intercropping with cowpea (Polthanee *et al.*, 2001; Sikirou and Wydra, 2004).

In order to enhance complementarities and to decrease competition between the component crops, spatial arrangements and planting densities of the component crops have been manipulated to maximize the physiological advantage from combining crop components (Ofori and Stern, 1987). Bezerra-Neto and Robichauz (1996) found that the alternation of spatial arrangement and planting density might affect the component yields and biomass production. During longer periods before canopy closure an increase in “rectangularity” of the cassava crop tends to enhance transmission of light to the legume crop (Midmore, 1993). Leihner (2002) suggested that maintaining cassava planting density of 10,000 plants ha^{-1} is well suited in the arrangement of the cassava crop without compromising on tuberyield. According to Ikeorgu and Odurukwe (1990), the performance of cassava-legume association is dependent upon the population density of the legume crops. For instance, intercropping cowpea with the population density of 8000 plants ha^{-1} could get higher benefits due to higher tuberyield of cassava relative to the pure cowpea or cassava in Nigeria.

The relative planting time can also affect the crop yields in the cassava intercropping system. Earlier planting of intercrop not only considerably decreased cassava yield but also growth and yield of intercrop were reduced by shading and competition of growth factors between the two crops (Leihner, 2002). In addition, delayed planting of soybean (later than 5 weeks after cassava) significantly decreased soybean yield while cassava yield was unaffected in the cassava-soybean intercropping (Tsay *et al.*, 1988). Leihner (2002) also stated that the root yields of cassava can be significantly reduced if the intercrop is planted earlier than cassava due to the strong interspecific competition for the growth resources at a time when cassava is still weak competitor. Nevertheless, this effect of earlier planting was not seen in Nigeria and Australia as well as Indonesia (Wilson, 1983).

2.7 Integrated soil fertility management

Most soils have low level of nutrients and have a high propensity towards nutrient loss given their fragiledd nature (Juo and Wilding, 1996). In addition, unsustainable farming activities have severely depleted soil nutrients throughout much of the region (Sanchez, 2002; FAO, 2003). Therefore, soil nutrient depletion is considered as the major biophysical factor contributing to decreased or stagnating crop yields and per capital food production in SSA (Henao and Baanante, 2006). Since inorganic fertilizer is an expensive agricultural input for small-holder farmers in Africa, the Alliance for a Green Revolution in Africa (AGRA) and others have adapted integrated soil fertility management (ISFM) as a framework for increasing crop productivity (Abuja Fertilizer Summit, 2006). ISFM is an ecological approach which uses inherent soil nutrient stocks, locally available amendments and inorganic fertilizers in an integrated way (Ngetich *et al.*, 2011).

Recently, Vanlauwe *et al.* (2010) defined that ISFM is a set of soil fertility management practices that necessarily include the use of inorganic fertilizer, organic inputs, and improved variety combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic efficiency of the applied nutrients and improving crop productivity. ISFM embraces a suit of environmental conditions that allow farmer investment in soil fertility management, a greater access to farm input supplier, fair produce markets and favourable policies as well as properly functioning instituitions, especially agricultural extension (Fairhurst, 2012). The ISFM definition includes a number of concepts as follows:

i. Focus on agronomic efficiencies

Ineffective management of inputs finally contributes to nutrient losses and inefficient utilization by crops. Moreover, both inorganic fertilizer and organic inputs are scarce resources in the regions where agricultural intensification is needed. ISFM thus focuses on increasing agronomic efficiency of both inputs (Vanlauwe and Zingore, 2011). Agronomic efficiency (AE) is defined as the additional yield obtained per unit of applied nutrient. AE and crop yield can be affected by a number of factors including nutrient uptake efficiency (the efficiency by which a nutrient is assimilated by crop) and utilization efficiency (the efficiency by which a crop transforms assimilated nutrient into yields) as well as the levels of soil organic matter resulting from biomass production and recycling (Sanginga and Woomer, 2009).

ii. Inorganic fertilizer and improved variety

Fertilizer responses to crop yield were largely variable and to some extent related with the types of soils (Fermont *et al.*, 2010). In terms of fertilizer response to management, two types of soils are generally distinguished: (1) soils which show significant response to fertilizer (Path A), and (2) soils which show non-significant or no response to fertilizer according to other constraints besides the nutrients contained in the fertilizer (Vanlauwe and Zingore, 2011). These soils (1 and 2) are classified as ‘responsive soils’ and ‘poor, less-responsive soils’, respectively.

In some cases, a third type of soil exits where crops show response little to fertilizer as the soils are fertile where land is newly opened or where fields are close to home steads and obtain large amount of organic input. These soils are classified as ‘fertile, less-responsive soils’ and only need to maintain the soil fertility status (Vanlauwe and Zingore, 2011a). Vanlauwe *et al.* (2011) stated that on responsive soils fertilizer application to the improved variety may increase crop yield and improve the AE to the current local farmer practice in SSA which is characterized by the local varieties with too low and inadequate management of nutrient inputs (Path A). To improve crop production on responsive fields within Path A, there should include the use of disease resistant and improved variety, crop and water management practices, and application of fertilizer at right source, at right amount, at right time and at right place that contributes an important basic for optimizing nutrient utilization efficiency within an ISFM framework (Vanlauwe and Zingore, 2011a).

iii. Combined application of organic and inorganic fertilizer inputs

The use of inorganic fertilizer has been considered as the complementary option for increasing crop production over years in SSA (Omotayo and Chukwuka, 2009). However, the application of inorganic fertilizer has faced some important limitations in the crop production due to higher costs, highly variable nature of soils and inherent low nutrient conversion efficiency (AGRA, 2007). Consequently, there is a need to explore the efficient use of the available organic resources that led to improve crop yields (Chivenge *et al.,* 2009). Therefore, ISFM comprising combined application of inorganic and organic inputs is a possible approach to solve soil fertility limitations in crop production (Abedi *et al.,* 2010; Kazemeini *et al*., 2010). According to positive interactions and complementarities between them, both organic and inoorganic inputs can maintain soil fertility and sustain the crop production (Buresh *et al*., 1997; Vanlauwe *et al.,* 2002). Moreover, combinations of organic inputs and inorganic fertilizer respond positively to improved output markets and crop prices (Murithi, 1998; Freeman and Coe, 2002). In terms of profitability, positive returns are often observed in the application of inorganic fertilizers (Kelly *et al.,* 2002; Shapiro and Sanders, 2002; Pypers *et al.,* 2012) and in combined use of organic and inorganic inputs (Mekuria and Waddington, 2002).

iv. Adaptation to local conditions

Before adjusting for site-specific soil conditions by African Green Revolution, farming systems are highly variable at different scales. Soil fertility status can vary greatly between fields within a single farm and between farms with a significant impact on fertilizer use efficiency (Vanlauwe, 2012). Measures with adaptation of local conditions such as lime application on acid soils, water harvesting techniques on soils susceptible to crust under semi-arid conditions, or soil erosion control on hillsides, to address other constraints are needed to adjust the inorganic fertilizer and organic input management (Vanlauwe, 2012). Local adaptation considers the farmer's resource endowment and adjusts specific management practices for variability in soil fertility status within ISFM framework. Thus, the adaptation to local conditions should be integrated into the agricultural development process (Paudel *et al.,* 2011).

v. A move towards complete ISFM

Several intermediate phases are identified to support the famers' move towards ISFM from the current fertilizer application with local varieties (Vanlauwe *et al.*, 2010a). Each step is expected to provide better soil fertility management for increasing crop yield and AE improvements (Figure 2.1). Complete ISFM involves the use of improved variety, inorganic fertilizer application, appropriate organic resource management and local adaptation through maximizing AE of applied nutrients and improving crop productivity. For poor responsive soils, there is needed to invest in soil fertility rehabilitation such as organic manures before AE of fertilizer input will be enhanced (Sanginga and Woomer, 2009).

2.8 Summary of literature reviewed and research gaps

High population pressure coupled with limited land forces farmers to grow crop after crop, over-burdening the soils leading to soil nutrient depletion in Africa. Moreover, the use of inorganic fertilizers in crop production is decreasing since they are beyond the means of most small-holder farmers. Therefore, soil fertility decline is a fundamental cause for slow growth in crop production in SSA. Small-holder farmers are main growers of cassava in Central Africa and mostly grow cassava on marginal areas. Although, cassava shows response to fertilizer application, poor resource farmers rarely use fertilizer in cassava crop production. Limited use of inorganic fertilizers has led to declining soil fertility in cassava-based farming system in Central Africa. In this case, inorganic fertilizers in combination with organic inputs may be a sound management option for those small-holder farmers to sustain soil fertility and cassava production. In addition, farmers mostly grow low yielding local varieties of cassava. Since ISFM strategies appropriate to cassava based production system in the humid tropics are not yet fully developed, there is need to improve the agronomic use efficiency of nutrient inputs in cassava-based farming systems of DR. Congo to increase crop yields and economic returns.

Most small-holder farmers generally intercrop cassava with legumes by making more efficient use of the available growth resources and for nutrient requirements based on the complementary utilization of growth resources as well as market opportunity. Since the spatial arrangement influences on the utilization efficiency of environmental factors and the degree of competition between component crops, it is a main aspect in the productivity of an intercropping system. The effect of different legumes on the yields of component crops in the cassava-legume intercrop is not fully developed. Information on optimum planting density of component crop for maximum root yields of cassava is also not well documented in the cassava-cowpea intercrop. Moreover, the relative planting time of cassava has not been widely studied in the cassava-groundnut intercrop in DR. Congo. Therefore, studies need to be carried out to attain the information required to develop effective strategies for cassava-legume intercropping systems that will provide the additional yield in cassava-based cropping systems.

CHAPTER 3
METHODOLOGY

3.1 Description of the study area

This study focused on small-holder farming systems in Bas-Congo Province (5^{o} 20’01” S, 14^{o}50’37” E) in Democratic Republic of Congo (DR. Congo). The field trials were conducted in the four sites (Kipeti, M. Nzundu, Zenga (Acrisols) and Lemfu (Ferralsols)) of the Bas-Congo province in Democratic Republic of Congo (DR. Congo) as shown in Figure 3.1.

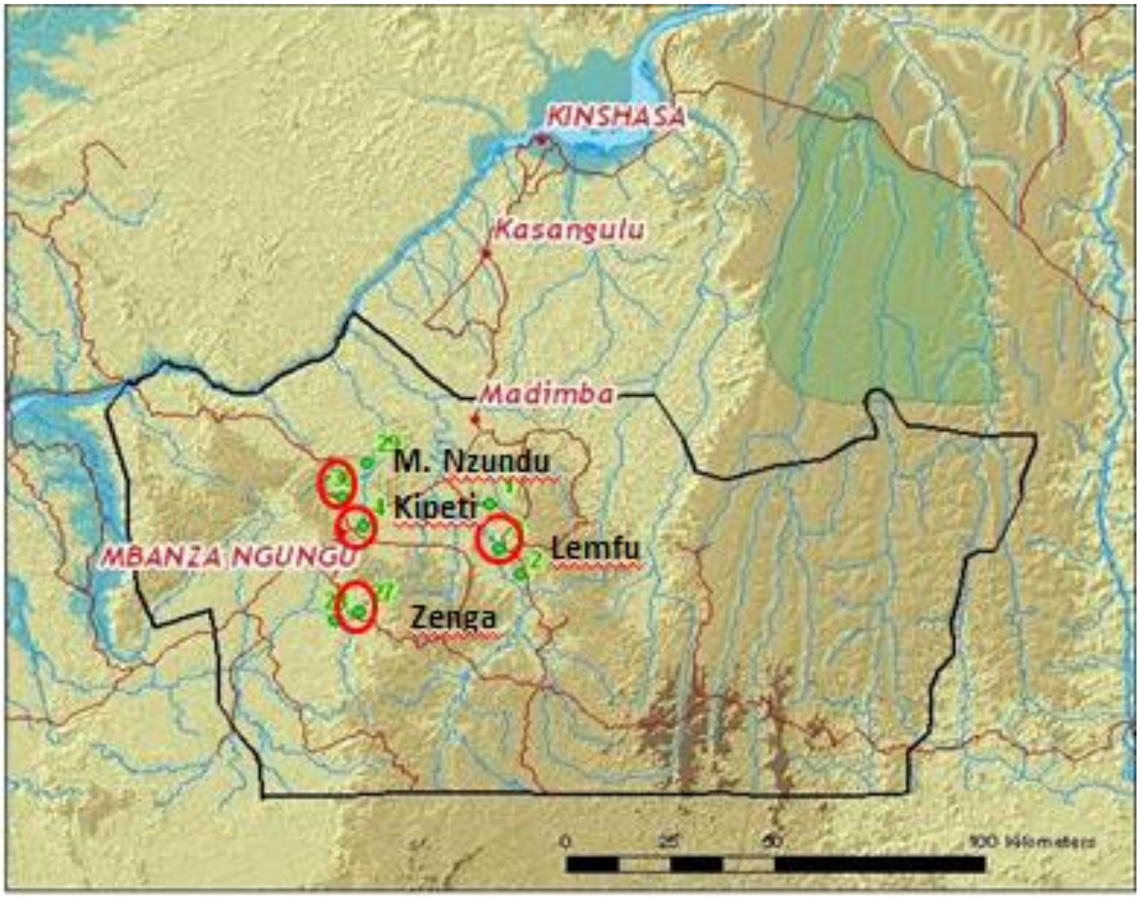

Figure 3.1: Location of the four study sites at Bas-Congo province in DR. Congo (Source: Adapted from Farrow *et al*., 2007)

The mean annual temperature is about 23°C and the area receives an average rainfall of 1300 to 1400 mm per year (Table 3.1). The rainfall is bimodal pattern with the

"1st" season (long rain) lasting from October to mid-February, and the "2nd" season (short rain) from early March to mid-May, followed by a short dry period, the "3rd" season. The annual growing period averages 290 days per year (Pypers *et al.*, 2011). The topography is generally flat to gently undulating, with altitudes varying between 400 and 750 m above sea level (Table 3.1). The plateau and hillsides are dominated by savannah vegetation, while in the valley bottoms, secondary or reconstituted Guinea forest and forest fallows are found. The dominant soil types are Humic Ferralsols (Kipeti, M. Nzundu and Lemfu) and Haplic Acrisols (Zenga) according to FAO /IIASA /ISRIC/ ISSCAS/JRC (2009). The selected bio-physical characteristics of the four sites (Kipeti, Lemfu, M. Nzundu, and Zenga) are shown in Table 3.1.

Table 3.1: Location and selected bio-physical characteristics of the four study sites

Sites	Growing season[1] (days)	Annual rainfall[1] (mm)	Elevation[1] (m)	Development domain[1] (Pop., Acess, Agri. Pot.)	No. households[2]	Population density[1] (Person /km²)
Kipeti	294	1365	583	High, High, High	100	62
M. Nzundu	298	1364	610	High, High, High	100	34
Lemfu	294	1422	582	Low, Low, High	100	62
Zenga	282	1310	450	Low, Low, High	100	62

[1] Farrow *et al.* (2007); [2] Ouma and Birachi (2011)

Cassava is the main staple food, grown by all farm households in all sites. Other important crops are maize (*Zea mays* L.) and legumes especially groundnut (*Arachis hypogaea* L.), common beans (*Phaseolus vulgaris* L.) and cowpea (*Vigna unguiculata* L.). Farmers mostly intercrop cassava with grain legumes especially groundnut, cowpea, common beans and soybean (*Glycine max*). Farmers rarely apply inorganic fertilizer to the crops.

3.2 Data collection

3.2.1 Farm characterization

Farm characterization was done in the four survey sites (Kipeti, Lemfu, M. Nzundu and Zenga) in Bas-Congo province, DR. Congo. The researcher obtained all the household names from the sub-chiefs of the respective sites. A simple random sampling technique was used to select fifteen households from each site. This sampling technique ensures that each cassava farmer was given equal chance of being selected. In total sixty households (95 % of confidene level) were selected for the household interviews. The study employed interview schedule, questionnaires and subsequent farm visits to capature the soico-economic characteristics of cassava farmers and the cassava production systems in the surveyed area. Interviews were held with the head of the household who makes the decision on farming activities. The data was collected using interview methods and with the aid of structured questionnaires (Appendix 1). Information obtained was cross-checked with other household members. The data collected from the farmers included farmers'demographic and socio-economic characteristics, production variables such as varieties use, input access and labour used for cassava cultivation, crop management, cassava yields and factors affecting cassava production and commercialization.

3.3 Determination of agronomic efficiency of applied nutrients

3.3.1 Trial management and trial establishment

Researcher-managed, field trials were performed in Zenga (Acrisols) and Lemfu (Ferralsols) sites. Cassava and groundnut were grown separately in April 2012. The field trials were installed in four farmer fields at each site. The trials were established by following a completely randomized design with the plot measuring 8 m × 6 m (48 m^2). Treatments were not replicated within each field; instead, four farmers per site were considered as replicates. The treatment details are shown in Table 3.2.

Table 3.2: Treatment structure for determination of agronomic efficiency of applied nutrients during the short rain season in Zenga and Lemfu sites

Variety	Fertilizer nutrients	Fertilizer rate (kg ha^{-1})
Local	-	-
	NPK	80N, 40 P_2O_5 (17 P), 80 K_2O (66 K)
Improved	-	-
	NPK	80N, 40 P_2O_5 (17 P), 80 K_2O(66 K)
	½NPK	40N, 40 P_2O_5 (17 P), 80 K_2O (66 K)
	PK	40 P_2O_5 (17 P), 80 K_2O (66 K)
	N½PK	80N, 20 P_2O_5 (8.5 P), 80 K_2O (66 K)
	NK	80N, 80 K_2O (66 K)
	NP½K	80N, 40 P_2O_5 (17 P), 40 K_2O(33 K)
	NP	80N, 40 P_2O_5 (17 P)
	NPK+Ca	80 N, 40 P_2O_5 (17 P), 80 K_2O (66 K), 60 $CaSO_4$ (13 Ca), 12 $MgSO_4$ (1.2 Mg),10 $ZnSO_4$ (2.2 Zn),1 H_3BO_3 (0.13 B)

For pure cassava, two varieties of cassava, a local variety 'Boma' and an improved variety 'RAV' were planted at a spacing of 100 cm and 100 cm inter- and intra-row, respectively. Nutrients were applied as N (urea), P (Triple Super Phosphate —TSP), K (potassium chloride —KCl), Ca (gypsum—$CaSO_4$), Mg (magnesium sulphate —$MgSO_4$), Zn (zinc sulphate—$ZnSO_4$), and B (boric acid —H_3BO_3). S was applied as

$CaSO_4$, $MgSO_4$, and $ZnSO_4$ fertilizers. Fertilizers were applied in a ring (20 cm diameter) around the plant base by mixing with the soil. Half amounts of N, P_2O_5, and K_2O and the total amounts of $CaSO_4$, $MgSO_4$, $ZnSO_4$, and H_3BO_3 were applied at 1 month after planting (MAP). The remaining amount of N, P and K were applied at 3 MAP. Weeding was done at 1, 3, 6, 8 and 10 months after planting. Since leaf-harvesting might negatively affect the tuberyields of cassava (Lockard *et al.*, 1985), farmers were not allowed to harvest cassava leaves during the growing period.

The treatment details for groundnut are shown in Table 3.3.

Table 3.3: Treatment structure for determination of agronomic efficiency of applied nutrients during the short rain season in Zenga and Lemfu sites

Variety	Fertilizer nutrients	Fertilizer rate (kg ha^{-1})
Local	-	-
	NPK	20 N, 46 P_2O_5 (20 P), 24 K_2O (20 K)
Improved	-	-
	NPK	20 N, 46 P_2O_5 (20 P), 24 K_2O (20 K)
	½NPK	10 N, 43 P_2O_5 (20 P), 24 K_2O (20 K)
	PK	46 P_2O_5 (20 P), 24 K_2O (20 K)
	N½PK	20 N, 23 P_2O_5 (10 P), 24 K_2O (20 K)
	NK	20 N, 24 K_2O (20 K)
	NP½K	20 N, 46 P_2O_5 (20 P), 12 K_2O (10 K)
	NP	20 N, 46 P_2O_5
	NPK+Ca	20 N, 46 P_2O_5 (20 P), 24 K_2O (20 K), 250 $CaSO_4$ (55 Ca)

Two varieties of groundnut, a local variety 'Mputu Mbuaki' and an improved variety 'ICGV-SM 96722'were planted at a spacing of 40 cm and 10 cm inter- and intra-row, respectively. For each treatment, plot measured 5 m x 5 m (25 m^2). The total quantities of N, P and K fertilizers were band applied at 2 weeks after sowing. Calcium fertilizer as gypsum (250 kg $CaSO_4$ ha^{-1}; 55 kg Ca ha^{-1}) was applied at sowing time. Weeds are regularly controlled during the growing period.

3.3.2 Agronomic efficiency of the applied nutrients

The agronomic efficiency (AE) was determined as the change in yield [kg ha^{-1}] per unit of fertilizer nutrient applied [kg ha^{-1}]: AE = Δ Yield/ $F_{appl;}$ where F_{appl} means the amount of applied fertilizer nutrient. For the calculation of N effect (the additional yield as a result of N application), the yields of two treatments with N and the yields of two treatments without N were used and calculated by the following formula: Δ Yield due to N = 0.5 $\cdot$ (NP + NK - Control - PK)

Similarly, the two treatments with P are NP and PK and those without P were control and NK. NK and PK treatments were the two containing K, whereas control and NP were the two treatments without K. Thus, P and K effects were calculated as follow:

Δ Yield due to P_2O_5 = 0.5 $\cdot$ ($Yield_{NP}$ + $Yield_{PK}$ - $Yield_{Control}$ - $Yield_{NK}$) (kg ha^{-1})

Δ Yield due to K_2O = 0.5 $\cdot$ ($Yield_{NK}$ + $Yield_{PK}$ - $Yield_{Contro}$l - $Yield_{NP}$) (kg ha^{-1})

For the calculation of $CaSO_4$ effect, the NPK with Ca treatment and the NPK treatment (without Ca) were used.

Δ Yield due to $CaSO_4$ = $Yield_{NPK+Ca}$ - $Yield_{NPK}$ (kg ha^{-1})

Δ Yield due to CaMgSZnB = $Yield_{NPK\ +\ (CaMgSZnB)}$ - $Yield_{NPK}$ (kg ha^{-1})

3.3.3 Agronomic efficiency of NPK

NPK effect was determined by the difference in yields of the NPK treatment and the control:

Δ $Yield_{NPK}$ (kg ha^{-1}) = $\Delta Yield_{NPK}$ - $\Delta Yield_{Control}$ (kg ha^{-1})

The AE of NPK was calculated as follows:

AE_{NPK} (kg ha^{-1}) = Δ $Yield_{NPK}$ /NPK_{appl} (kg ha^{-1})

where NPK_{appl} refers the amount of applied NPK fertilizer nutrients. In evaluating F_{appl} (NPK), it is always difficult to evaluate whether applied N, P, and K nutrients are taken in balanced proportions or not when the amounts of applied nutrients are given in kg ha^{-1}. To avoid that problem, fertilizer crop nutrient supply equivalent (FCNE) was applied in this study, which was derived from the idea of crop nutrient equivalent (CNE) (Janssen, 2009; 2011). In a study by Jannsen (2011), when the amounts of applied three nutrients (N, P, and K) are expressed in (k)CNE, it is possible to consider that equal quantities of NPK are taken up in a balanced plant nutrition. A (k)FCNE of applied nutrient is the amount of nutrient in applied fertilizer that has the same effect on the yield as one kg of the nutrient under a situation of balanced supply (Janssen, 2010). In this study, the agronomic efficiency of NPK was calculated as follows:

AE_{NPK} (kg ha^{-1}) = Δ $Yield_{NPK}/NPK_{appl}$ [(k)FCNE] (kg ha^{-1})

The values of (k)FCNE were derived from the standard values of N, P, and K uptake per ton of fresh storage roots; the values of PhE_{max} (maximum physiological nutrient efficiency) and AE_{max} (maximum agronomic efficiency) are shown in Table 3.4.

Table 3.4: The maximum PhE (PhE_{max}), the maximum AE (AE_{max}) and the conversion factors (CF) values for the conversion of 1 kg of N, P_2O_5 and K_2O into fertilizer crop nutrient equivalents (FCNE) for cassava storage roots and the groundut (pods)

Parameter	N	P_2O_5	K_2O
Cassava			
PhE_{max}	222	531	126
AE_{max}	111	53	63
CF (k)FCNE	1	0.48	0.57
Groundnut			
PhEmax	25	500	120
AEmax	13	22	50
CF kFCNE	1	1.69	3.85

The agronomic efficiency of the applied nutrient was calculated by multiplying the uptake efficiency of the applied nutrient (the recovery fraction (REC) and physiological efficiency (PhE). The recovery fraction is the proportion of the applied nutrient which is taken up from the input by the crop (Janssen, 2011). Physiological efficiency relates the yield of the economic plant components (e.g., storage roots) to the nutrient taken up by the whole crop (Janssen, 2009). The medium values of PhE (PhE_{med}) used in this study were derived from Howeler (2002). It was assumed that PhE_{max} would be 1.5 times as high as PhE_{med} (Janssen, 2011). The standard values of REC used in this study were 0.5 for N and K, and 0.1 for P (Janssen, 2011). The ratios $AE\text{-}P_{max}$:$AE\text{-}N_{max}$, and $AE\text{-}K_{max}$:AE-Nmax are used as multiplication factors for the conversion factor (CF)FCNE of P and K into kg .According to Janssen (2010), the amount of applied fertilizer nutrients was calculated as follows:

NPK_{appl} [(k)FCNE] (kg ha^{-1}) = N_{appl} . CF(k)FCNE of N + P_{appl} . CF(k)FCNE of P + K_{appl} . CF(k)FCNE of K (kg ha^{-1})

3.4 Evaluation of the effects of combined use of inorganic fertilizer and organic input in a cassava-groundnut intercrop

3.4.1 Trial establishment

In October 2011 twenty demonstration trials were installed by the farmers in their own farms in Zenga and Lemfu sites. In these demonstration trials, packages with input and information necessary for the implementation of adaptive trials were distributed among the farmer groups involved in these demonstration trials. The farmer groups performed all field operations and harvested the trials under the supervision of a team of agronomists. The field trials were established following a randomized complete block design. Treatments were not replicated within each field but twenty farmer groups per site were considered as replicate. Plots measured 54 m^2. Two rows of cassava were planted per planting bed. In all plots, planting beds of 90 cm were installed with a spacing of 90 cm between the beds. Cassava was planted in two parallel lines within a planting bed. Cassava was planted at a spacing of 90 cm x 90 cm inter- and intra-row, respectively. Groundnut was planted in two parallel lines with a planting bed between two lines of cassava. It was planted at a spacing of 30 cm x 20 cm inter- and intra-row, respectively. The treatment details are shown in Table 3.5.

Table 3.5: Treatment structure for the determination of the effects of combined use of inorganic fertilizer and organic input during the long rain season in Zenga and Lemfu sites

Treatment	NPK fertilizer (17:17:17) (kg ha^{-1})	Chromolaena (ton ha^{-1})
Control	-	-
NPK	100	-
Chromolaena (CH)	-	2.5
½ (NPK + CH)	50	1.25

Fresh Chromolaena materials were cut and carried to each of the trial sites, piled up in strips, chopped and buried in the planting bed at two weeks before planting. The dry matter content (DM) of Chromolaena was determined before application and equaled 19 %. NPK fertilizer was applied at planting time. The improved variety of cassava (Nsansi) and groundnut (JL 24) were used. Trial management was the same as section 3.3.1. Some selected nutrient contents of Chromolaena are shown in Table 3.6.

Table 3.6: Carbon/N ratio and N, P and K contents of Chromolaena applied during the second season in Zenga and Lemfu sites

Nutrient	Units	Chromolaena
C/N ratio		14.6
Nutrient contents		
N	g kg $^{-1}$	31.6
P	g kg $^{-1}$	1.67
K	g kg $^{-1}$	12.8
Application rates (1.25 ton ha^{-1})		
N	kg ha $^{-1}$	39.5
P	kg ha $^{-1}$	2.1
K	kg ha $^{-1}$	16.05
Application rates (2.5 ton ha^{-1})		
N	kg ha $^{-1}$	79
P	kg ha $^{-1}$	4.2
K	kg ha $^{-1}$	32.1

Application rates were calculated based on the rates of 1.25 ton ha^{-1} of Chromolaena
Source: adapted from Pypers *et al.* (2012)

3.5 Determination of the influence of agronomic practices on the productivity of an cassava intercropping system under different soil conditions

3.5.1 Agronomic performance of different legumes in the cassava legume intercropping system

3.5.1.1 Trial establishment and management

In October 2011 twenty demonstration trials were installed by farmer households in their own farms in Zenga and Lemfu sites. Experimental design and plot size were the same as in section 3.4.1. The detailed treatments are shown in Table 3.7.

Table 3.7: Treatment structure for the determination of the agronomic performance of different legumes in the cassava legume intercropping system during the long rain season in Zenga and Lemfu sites

Cropping system	NPK fertilizer (17:17:17) (kg ha^{-1})
Cassava-groundnut	100
Cassava-soybean	100
Cassava-cowpea	100
Pure cassava	50

Planting bed size and cassava spacing were also the same as 3.4.1. Three types of legumes (groundnut, soybean and cowpea) were planted in two parallel lines with a planting bed between the two lines of cassava. Groundnut, soybean and cowpea were planted at a spacing of 30 cm x 20 cm, 30 cm x 20 cm and 30 cm x 10 cm inter- and intera-row, respectively. Cassava improved variety 'Nsansi', groundnut improved variety 'JL 24', soybean improved variety 'TGX 888-49C' and cowpea improved variety 'Diamant' were used. Trial management was the same as section 3.3.1.

3.5.2 Determination of the optimal spacing of cowpea in the cassava-cowpea intercropping system

3.5.2.1 Trial establishment

In April 2011, field trials were performed in Zenga and Lemfu. The detailed treatments are shown in Table 3.8.

Table 3.8: Treatment structure for the determination of the optimal spacing of cowpea in the cassava-cowpea intercropping system during the long rain seson in Zenga and Lemfu sites

Cropping system	Cowpea spacing	Cowpea line	NPK fertilizer (17:17:17) (kg ha^{-1})
Cassava-cowpea intercrop	40 cm x 30 cm	2	100
	41 cm x 50 cm	2	100
	42 cm x 70 cm	2	100
Pure cowpea	40 cm x 30 cm	2	50
	41 cm x 50 cm	2	50
	42 cm x 70 cm	2	50
	40c m x 30 cm	4	50
Pure cassava	-	-	50

Field trials were researcher-managed. The trials were established following a randomized complete block design with three replicates in each site. Plot size, planting bed size and cassava spacing were the same as 3.4.1. Cassava improved variety 'Nsansi' and cowpea improved variety 'Diamant' were used. Trial management was the same as 3.3.1.

3.5.3 Determination of the optimal planting time of cassava in the cassava-groundnut intercropping system

3.5.3.1 Trial establishment

Researcher-managed field trials were conducted in Mvuazi research station, Zenga site. Experimental design, plot size, planting bed size and cassava spacing were the same as 3.4.1. Groundnut was planted in two parallel lines with planting bed between the two lines of cassava. Groundnut was planted at a spacing of 30 cm and 20 cm inter- and intra-row, respectively. Cassava improved variety 'Nsansi' and groundnut improved variety

'JL 24' were used. The experiment was carried out in two seasons. Trial management was the same as section 3.3.1. The detailed treatment structure is shown in Table 3.9.

Table 3.9: Treatment structure for the determination of optimal planting time of cassava in the cassava-groundnut intercopping system during the short and long rain seasons in Zenga site

Cropping system	Cassava planting time	NPK fertilizer (17:17:17) (kg ha^{-1})
Cassava-groundnut intercrop	same time as the groundnuts	100
	1 week after the groundnuts	100
	2 weeks after the groundnuts	100
	3 weeks after the groundnuts	100
Pure groundnut	-	50
Pure cassava	1 week after the groundnuts	50
	2 weeks after the groundnuts	50
	3 weeks after the groundnuts	50

3.5.3.2 Crop measurements

At two months after sowing, above ground biomass of legumes was collected from a 1 m strip within the net plot to determine the biomass yield. Legumes was harvested at full maturity from the net plot (2.4 m^2), when pods had dried in the field, and grains were collected. Biomass, pod and grains were oven-dried (65^o C) for 48 h and weighed. Cassava was harvested at 12 months after planting from the net plot (36 m^2). At harvesting, the yields of stem and tuberwere determined. Subsequently, storage roots were divided into large tradable and small non-tradable storage roots, counted, and sub-sampled for determination of the DM content of the flesh (parenchyma) and peelings.

Land use efficiency is determined by calculating land equivalent ratio (LER). The land equivalent ratio (LER) was calculated according to Willey (1985) by using the formula as follows:

Total LER = Patial LER of cassava + Partial LER of cowpea

$$\text{Partial LER of cowpea or cassava} = \frac{\text{Intercrop yield}}{\text{Pure crop yield}}$$

3.6 Soil sampling and chemical analysis

Soil samples were collected before the planting time at 0-15 cm depth. Soil samples were taken at six different spots per plot using an auger and then mixed to a composite sample. They were analyzed for organic carbon, total nitrogen, available P (Olsen), Ca, Mg and K and pH using standard methods (Okalebo *et al.*, 2002). Soil organic carbon and total N were analyzed by CN analyzer with using CN dry combustion method. Ca, Mg and K contents of the organic materials were determined by atomic absorbtion spectroscopy (AAS).

3.7 Economic analysis

The economic analysis was conducted to evaluate the profitability of inorganic fertilizers for determination of agronomic efficiency using partial budgeting. A simple financial analysis was also conducted to evaluate the profitability of the various treatments for evaluation of, combined application of inorganic fertilizers and organic inputs, and determination of agronomic practices. Economic analysis comprised calculation of total cost, total benefits and, and benefit-cost ratios relative to the control after adjusting the average yields i.e, the average yield adjusted downward to 10 % to reflect the difference between the experimental yield and the yield that a farmer could expect from the same treatment without the researchers' involvement (CIMMYT, 1988). Total costs included input costs (seed, cutting and inorganic fertilizer) and labour costs (land preparation, planting, weeding and harvesting) in the different treatments. The prices of fresh cassava storage root, legumes and inorganic fertilizers are shown in Table 3.10.

Table 3.10: Prices of fresh cassava storage root, groundnut, soy bean and cowpea grains and various inorganic fertilizers used in the study

Items	Period	Price ($ kg^{-1})
Crops		
Cassava	Oct 2012	0.13
	Apr 2013	0.13
Groundnut	Jan 2012	2.17
	Aug 2013	2.50
Soybean	Jan 2012	1.78
Cowpea	Jan 2012	1.96
Fertilizers		
Urea	Jan 2012	1.80
TSP	Jan 2012	1.20
KCl	Jan 2012	2.19
$CaSO_4$	Jan 2012	1.47
$MgSO_4$	Jan 2012	1.15
$ZnSO_4$	Jan 2012	1.76
H_3BO_3	Jan 2012	2.00
NPK (17:17:17)	Oct 2011	2.00

The labour was valued at a wage of $ 2.7 at Zenga site and $ 3.2 at Lemfu site for a 6 hours working day. For seed, grain price was used since most farmers recycle seed. Cassava stems were valued both as an input (planting material) and as produce at $ 0.04 m^{-1}. Total benefits were estimated using the unit prices for the grains of groundnut, soybean and cowpea, and fresh cassava tuberyields at the local markets.

Economic analysis did not take leaf production into account. An exchange rate of 920 Congolese francs to $ 1 was used. The BCR of fertilizer application was calculated as the ratio of total benefits over total costs and was considered favourable when exceeding 2 as invested by the farmer (CIMMYT, 1988). The MRR was calculated as the change in net benefits ($NB_{Treatment}$ - $NB_{Control}$) per the change in costs ($TC_{Treatment}$ - $TC_{Control}$):

MRR (USD USD^{-1}) = Δ net benefits/Δ costs (USD USD^{-1})

A treatment was considered favourable relative to the control if the MRR exceeds 1.18 (CIMMYT, 1988).

3.8 Statistical analysis

For survey data analysis, significance of differences between sites and wealth classes for selected socio-economic, crop acreage and crop income were tested using non-parametric Kruskal-Wallis one way ANOVA. Paired t-test was used to test whether characteristics and yields differed between cassava varieties. The CROSSTAB procedure using Pearson Chi Square analysis where appropriate was used to test for significance effects of varieties on the tuberyields and farmer fertility score of local soil type within site. The statistical significance of relations between cassava yields and weed management or farm fertility score were assessed by two tailed Pearson correlations. All statistical analyses were carried out using SPSS for Windows (version 16.0) and GenStat Discovery for Windows (edition 12).

For the experimental data, statistical analysis was carried out using a mixed model of the SAS software to assess the effects of (and interactions between) treatments and sites (SAS Institution, 2002). The effects of the various factors and their interactions were compared by computing least square means and standard errors of difference (SED). Significance of difference was evaluated at $P < 0.05$. Regression analysis was carried out to evaluate the crop response to applied nutrients (N, P and K) on soil nutrient contents in Zenga and Lemfu sites, using the REG procedure of the SAS software. Average crop response (the average nutrient affects at high and low rates of fertilizer) was plotted against soil nutrient content in each farmer’s field.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Rainfall data during the experimental period in Zenga and Lemfu sites

Zenga site receives on average 983 mm, 492 mm and 34 mm of rainfall in 1st (long rain), 2nd (short rain) and 3rd (dry) seasons, respectively. Total rainfall per season in Lemfu site is about 1071 mm in 1st season, 478 mm in 2nd season and 68 mm in 3rd season. During the study period Zenga and Lemfu received 885 and 1035 mm, 595 and 535 mm and 35 and 69 mm of rainfall in 1st, 2nd and 3rd seasons, respectively. Total rainfall data showed that Zenga and Lemfu received enough precipitation for growing cassava and legume crops during the study period. Actual rainfall data across the various seasons during the study period in Zenga and Lemfu sites is shown in Figure 4.1 and 4.2.

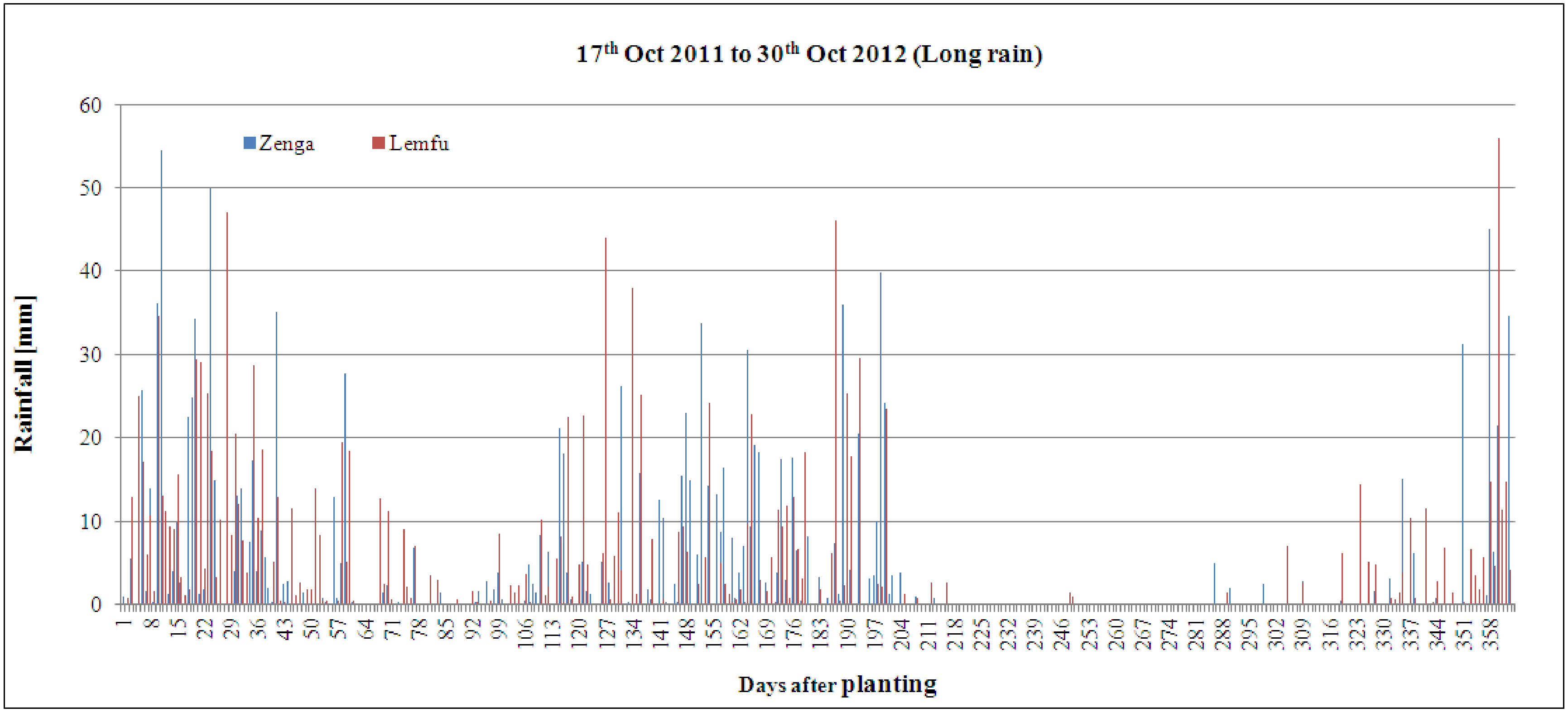

Figure 4.1: Actual rainfall in Zenga and Lemfu sites during the study period

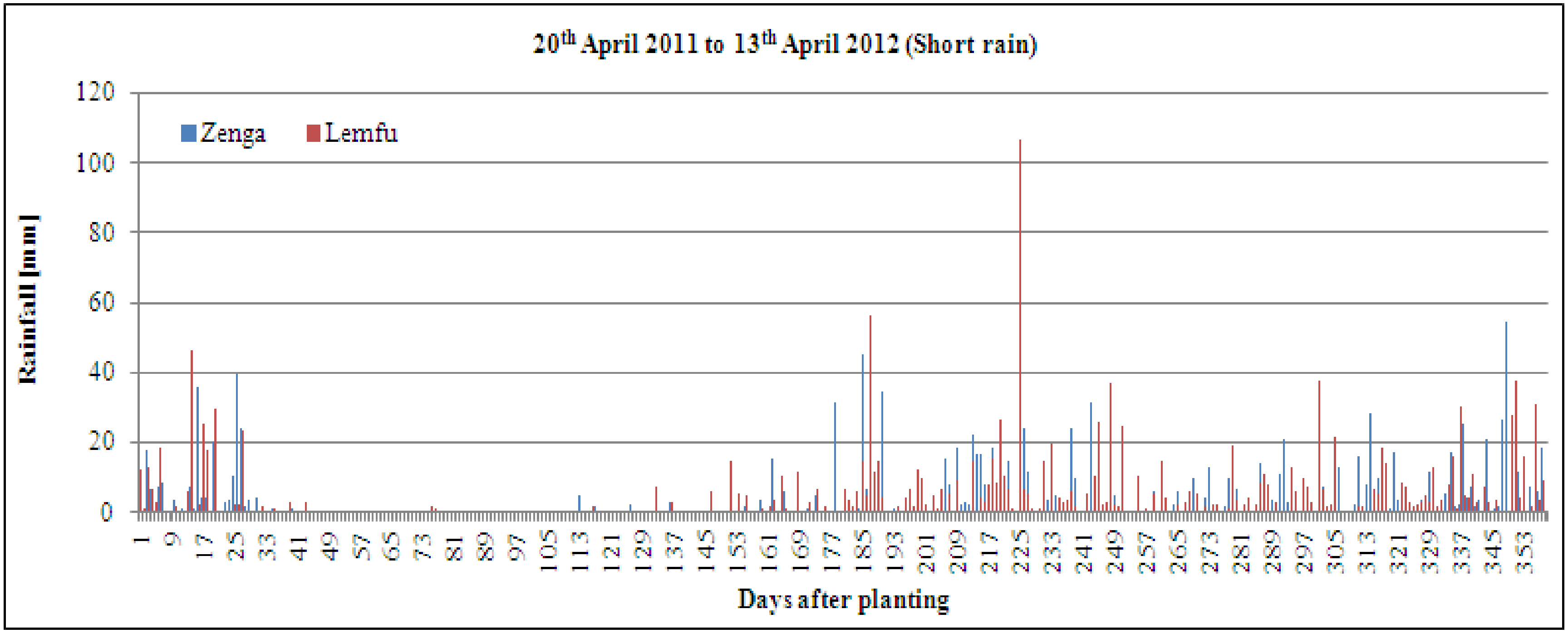

Figure 4.2: Actual rainfall in Zenga and Lemfu sites during the study period

Rainfall in Lemfu was higher by 71 mm in long rain 2012 (Figure 4.1) and 143 mm in short rain 2013 (Figure 4.2) than Zenga site. This means that leaching of applied nutrients could be higher in Lemfu since rainfall can leach the nutrients in the soils with low Cation Exchange Capacity and high sand % (Lehmann and Schroth, 2003).

Weekly rainfall data for the five seasons in which the experiment for investigation of optimum cassava planting time in the cassava-groundnut intercrop was conducted is presented in Figure 4.3. Total rainfall during the fourth week of April 2012 was lower by 52 to 172 mm, as compared to the first, second and third weeks of April 2012. Since cassava was planted the fourth week, low rainfall received could have contributed to the low yield recorded.

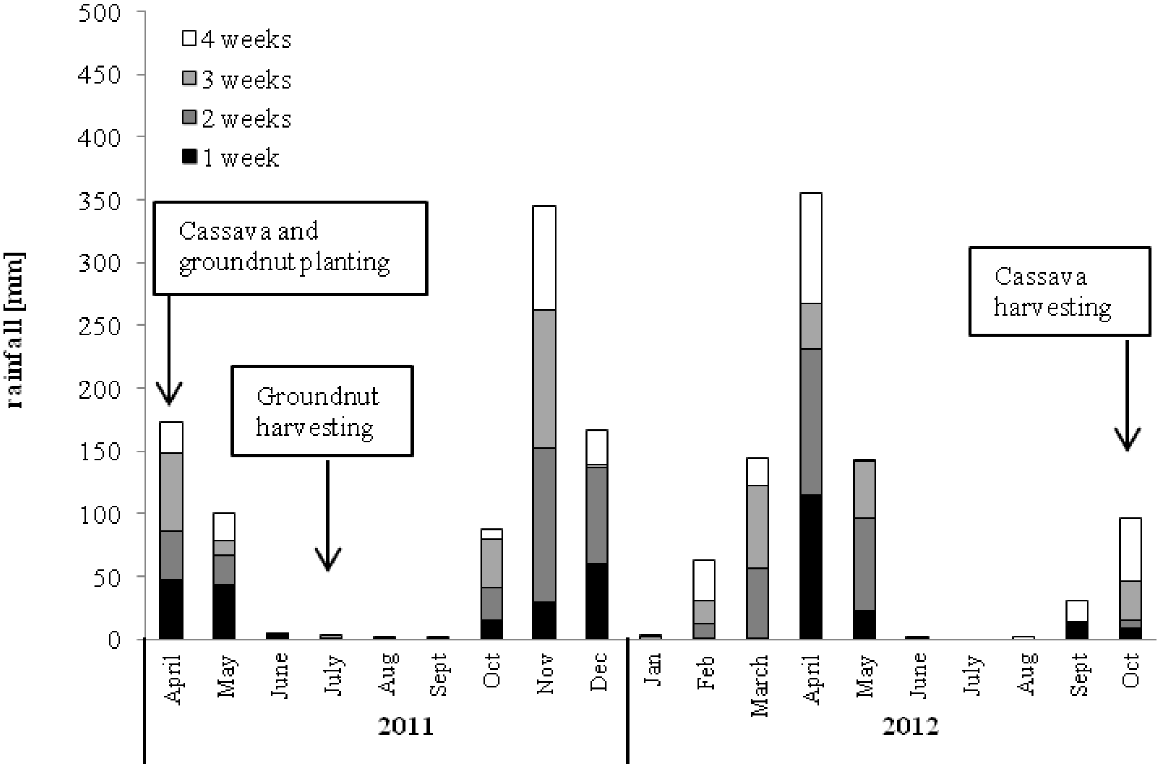

Figure 4.3: Weekly rainfall data in Zenga site during the study period (short, long and dry seasons 2011, short and dry seasons 2012). Planting and harvesting of cassava and groundnut are indicated.

4.2 Factors affecting cassava production system in the study area

4.2.1 Factors affecting cassava tuber yields in the study area

Various outcomes are recorded in the cassava production system with the respect to variety used, soil texture, soil fertility score and weeding operation. The factors are as discussed below:

4.2.1.1 Effect of variety on cassava tuber yields in the study area

The improved variety significantly influenced the tuber yields of cassava in comparison with the local variety in all sites except in Kipeti (Table 4.1).

Table 4.1: Effect of variety on cassava tuber yields in Kipeti, Lemfu, M. Nzundu and Zenga sites

Site	Cassava tuberyield (ton ha^{-1}) Local variety	Cassava tuberyield (ton ha^{-1}) Improved variety	*P value*
Kipeti	2.50	4.16	ns
Lemfu	2.77	6.94	0.027
N.Mzundu	1.9	5.11	0.005
Zenga	2.25	6.34	0.022
Overall means	2.35	6.52	

ns = non-significant at $P < 0.05$.

In all sites, types of cassava (local and improved) varieties significantly (P = 0.028) affected the cassava tuberyiels in all sites except in M. Nzundu as shown in Figure 4.4.

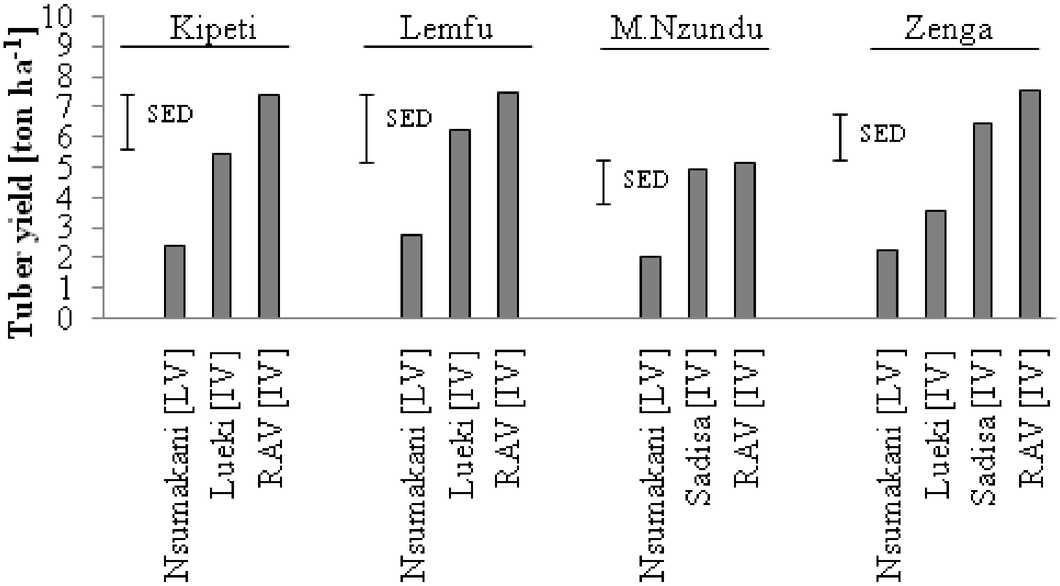

Figure 4.4: Effect of different varieties on cassava tuber yields in Kipeti, Lemfu, M. Nzundu and Zenga sites. *LV and IV mean local variety and improved variety, respectively.*

RAV (improved variety) recorded significantly (P = 0.009) higher cassava tuberyields than Nsumbakani (local variety). Maximum average root yields were recorded in the RAV variety in Kipeti, Lemfu, M. Nzundu and Zenga (7.39, 7.42, 5.17 and 7.54 ton ha^{-1}, respectively). In Zenga site, Sadisa (improved variety) significantly (*P* = 0.042) increased the root yields relative to Nsumbakani (local variety).

Considering farmers' own perception of overall benefits from the improved variety relative to the local variety, farmers preferred the improved variety because of high tuber yield, higher resistance to drought, resistant to pests and disease (especially resistant to cassava mosaic disease [CMD]) which had adversely affected cassava production. Ikpi *et al.* (1986) and Akoroda *et al.* (1985) also reported that farmers preferred the improved variety due to their higher yields, earlier maturity, high suppression of weeds, and higher resistance to diverse diseases and pests. According to farmers' perception, the improved variety showed higher tuber production and more resistant to pests and diseases or drought.

The use of improved varieties had influence on the tuber yields of cassava in comparison with the local varieties. Nweke (1996) reported that the improved varieties can produce one and half times higher yields than the local variety. Estimated cassava root yields of improved variety were about two times higher than that of local varieties. This might be due to more resistance of improved varieties to common diseases than the local varieties (Nweke, 1996). In all sites, types of cassava varieties had influence on the cassava tuber yields. Akinpelu *et al.* (2012) also stated that the production of cassava was influenced by the use of cassava varieties.

4.2.1.2 Effect of local soil types, soil texture, farmer soil fertility score on cassavatuber yields in the study area

Local soil types did not significantly influence on cassava tuber yields in all sites (Table 4.2).

Table 4.2: Local soil type, soil texture, farmer soil fertility score and cassava tuber yields score according to farmer description in Zenga, Lemfu, M. Nzundu and Zenga sites

Site	Local soil type	Soil texture[1]	Area [2] (%)	Farmer soil fertility score[3]	Cassava root yield (ton ha^{-1})
Kipeti	Buma	Clayey	84.6	2.6	6.1
	Mbombo	Sandy clay	15.4	2.4	7.9
SED				0.2	2.3
Lemfu	Buma	Clayey	14.3	2.7	10.4
	Kibuma	Sandy clay	26.7	2.8	2.8
	Nienge	Sandy	25.3	2.3	2.6
	Kanga	Sandy clay loam	23.2	2.2	5.2
	Voka	Humus	10.5	3.0	6.3
SED				0.4	4.3
M. Nzundu	Buma	Clayey	50.7	2.5	2.9
	Kibuma	Sandy clay	15.8	2.4	7.9
	Nienge	Sandy	33.5	2.6	3.5
SED				0.4	1.8
Zenga	Buma	Clayey	69.9	2.6	6.6
	Nienge	Sandy	15.4	2.7	2.3
	Kibuma	Sandy clay	14.7	1.9	6.9
SED				0.5	3.2

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[1] Texture characterization by farmers does not correspond to FAO texture criteria as farmers use relative scale.

[2] Relative importance of each soil unit is calculated on basis of total acreage surveyed.

[3] Farmers classified each field as having a poor (1), medium (2) and good (3) fertility level.

Classification of farm soil fertility score was based on the crop performance, stoniness of the soils and weed type establishment. Farmers planted cassava between medium to good farm soil fertility levels in all sites. Soil fertility scores were not significantly different between the local soil types. In Kipeti, cassava was mostly grown on clayey soils (84.4 % of total acreage surveyed). A similar trend was observed in Zenga. In Lemfu, cassava was mostly grown on sandy clayey soils followed by sandy, sandy clay loam, clayey and humus soils. Cassava was grown mostly on clayey followed by sandy and sandy clay soils in M. Nzundu. The results showed that soil types classified by farmers did not influence the tuber yields of cassava. Minimum tuber yields were recorded in sandy soils of Lemfu and Zenga because of the high potential of nitrate leaching (Wolkowski *et al.*, 1995) and phosphorus leaching (Kang *et al.*, 2011). The result indicates that the tuber yields were highly associated with the farm soil fertilizer scores ($R^2 = 0.49$, $P < 0.001$; Figure 4.5).

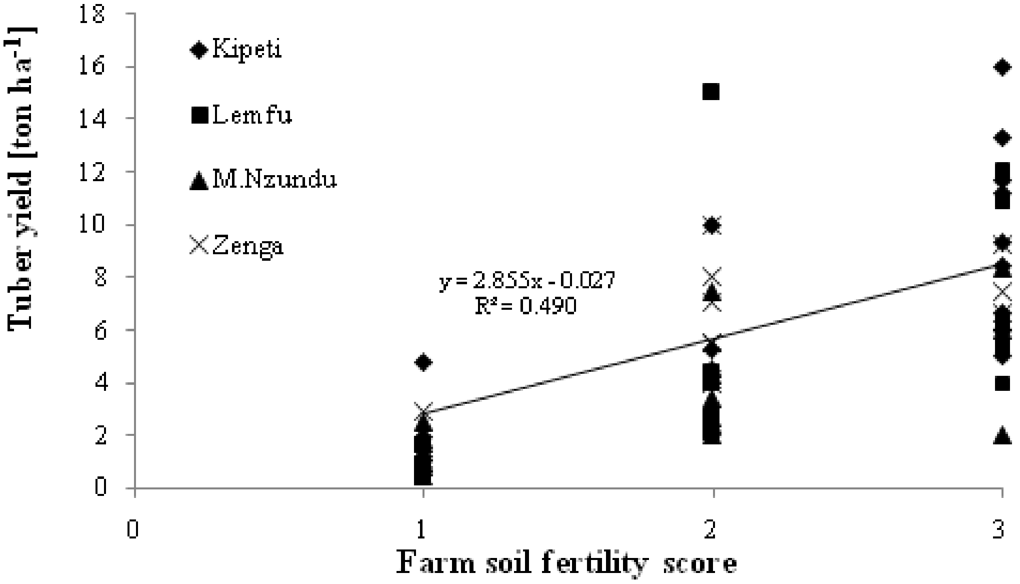


Figure 4.5: Correlation between soil fertility score as perceived by farmers and cassava tuber yields in Kipeti, Lemfu, M. Nzundu and Lemfu sites

In the surveyed area, farmers classified farm soil fertility score based on the crop performance, stoniness of the soils and weed type establishment. Mairura *et al.* (2007) reported that farmers usually classify and assess the fertility of their soils based on their own experiences through long term interactions with the environment and use of land resources. In Niger farmers distinguished their soil based on soil texture, reactions to precipitation and runoff, and workability with agricultural tools (Ambouta *et al.*, 1998). Similarly, farmers in the Siaya district of Kenya classified their soils based on the surface layer of the soil, colour, texture and heaviness of working (Mango, 1999). In another part of Kenya, indicators used to distinguish soil productivity also included ease of tillage, soil moisture retention, weed establishment and the presence of soil invertebrates (Murage *et al.*, 2000). In southern part of Rwanda, nine major soil types were classified based on criteria such as crop productivity, soil depth, soil structure and soil colour (Habarurema and Steiner, 1997). Corbeels *et al.* (2000) also reported that farmers in northern Ethiopia distinguished three major soil types based on crop yield, topography, soil depth, colour, texture, water holding capacity and stoniness. For soil fertility score, farmers classified based on crop performance, stoniness and weed establishment in the surveyed area. In the Siaya district of Kenya, farmers assessed soil fertility of their fields according to crop yields, soil colour, compactness, soil odour and the composition of vegetation (Mango, 1999).

The results of this study showed that soil types classified by farmers did not influence the tuberyields of cassava. This might be due to the fact that the fertility score perceived by farmers were not significantly different between soil types. Conversely, Asadu and Enete (1997) observed that the crop performance was influenced by soil types. Similarly, Tsegaye and Hill (1998) found that soil is one of the main factors that influenced crop yields. The result indicates that cassava tuberyields were correlated with soil fertility scores. This indicates that soil fertility might influence the growth of plant. Similarly, die Bie and Rugege (2000) observed that the farmer's assessment of the fertility status on orchard soils was positively correlated with fruit yields but not significant.

4.2.1.3 Effect of weeding operation on cassava tuber yields in the study area

In all surveyed farms, late first weeding (more than 1 month after planting) was associated with low cassava yields as estimated by farmers (Figure 4.6).

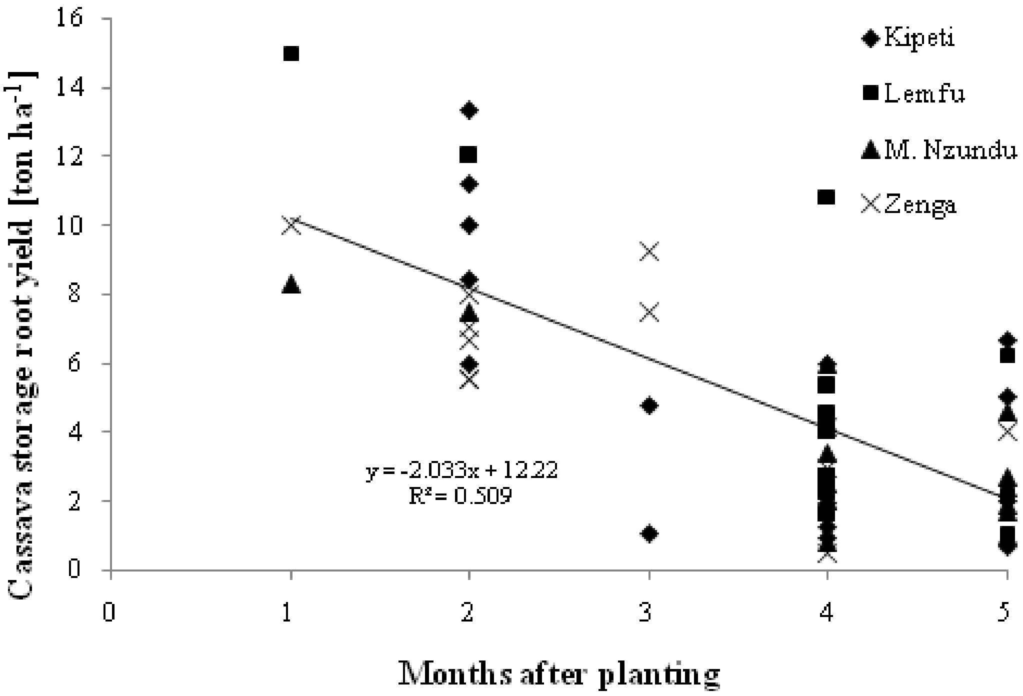


Figure 4.6: Correlation between timing of first weeding operation and cassava tuber yields in Kipeti, Lemfu, M. Nzundu and Zenga sites

The results of this study revealed that first weeding time was positively correlated with the tuberyields of cassava (R^2= 0.509, P = 0.035). Similar link between the tuberyields of cassava and time of first weeding was found by Fermont (2009) in Kenya and Uganda. This could be because cassava is a poor competitor and may suffer serious yield losses if it is not adequately weeded during the early stages of plant growth (Howeler, 2002).

4.2.2 Factors affecting cassava productivity in the study area

Weed pressure was most-frequently (38 to 72 %) mentioned as the most important factor affecting cassava production in all sites (Figure 4.7).

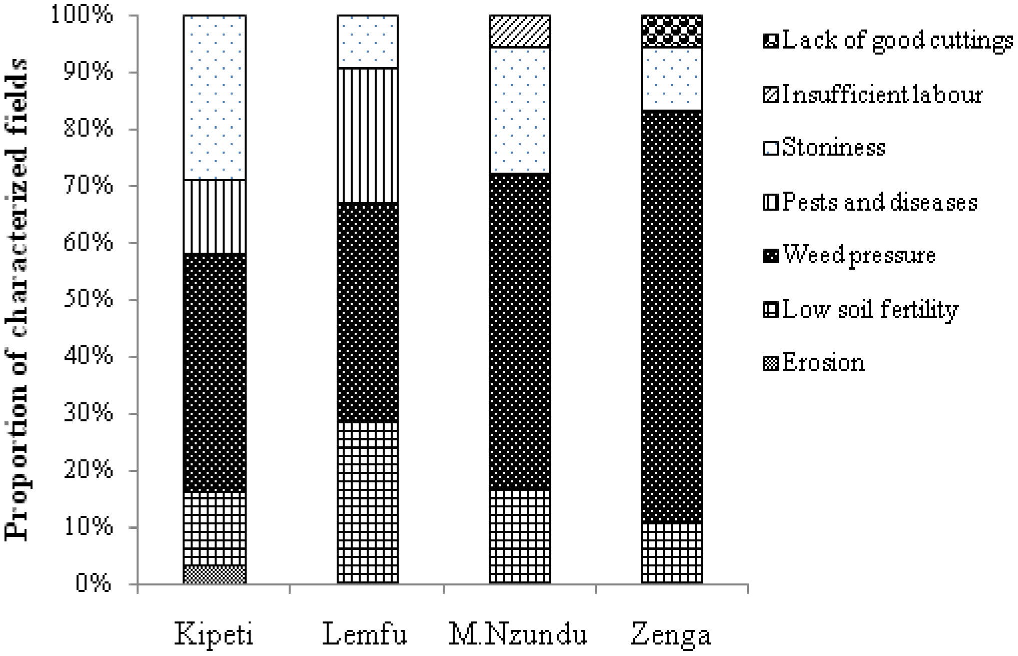


Figure 4.7: Factors affecting cassava production in Kipeti, Lemfu, M. Nzundu and Zenga sites according to farmers' responses

In Kipeti, stoniness or poor structure of the soils was the second most important factor influencing cassava cultivation, followed by low soil fertility, pests and diseases and erosion. In Lemfu, major factors were related to weed pressure, low soil fertility, pests and diseases and stoniness of the soils. The most important factors in M. Nzundu were weed pressure, stoniness, low soil fertility and insufficient labour, respectively. In Zenga, weeds were the most important factor for about 72% of characterized fields while other factors were related to low soil fertility, pests and diseases and lack of good cuttings.

In all sites, weed pressure was the most important factor influencing cassava production. Because of the slow initial growth of cassava (Udealor and Asiegbu, 2005; Njoku and Muoneke, 2008), it competes with weeds for growth resources such as soil, light, moisture and nutrients (Leihner, 2002). This might be mostly because of the low number of weed operations per crop cycle and partly because of late first weeding operation. The results suggests that the application of integrated weed management (IWM) which combine different cultural practices, especially at land clearing, planting bed preparation, planting and post-planting of growing cassava crop could be a possible solution to the weed problem in all sites. Improving the adoption of chemical control should also be considered as a component of IWM especially in M. Nzundu where labour is insufficient for cassava production. Akobundu (1987) reported that combining the manipulation of plant canopy (through row spacing management and spatial arrangement) with other methods of weed management, has been used either to reduce input levels in chemical or cultural weed control systems or to make them more effective.

According to farmers'perception, low soil fertility, pests and diseases were also the important factors that constraints cassava production in all sites. The improved variety that was tolerant to poor soil fertility, pests and diseases was found to reduce soil fertility and pest and disease constraints in the surveyed area. Use of improved variety increased cassava yields by up to 49 % in 20 sub-Saharan African countries (Manyong *et al.*, 2000a). On the other hand, Fermont (2009) and Pypers *et al.* (2012) found the profitability of inorganic fertilizer application in cassava fields. As most farmers in the surveyed area are resource poor, medium or low technologies such as fertilizer micro-dosing, the combined use of inorganic fertilizer and organic inputs, and intercropping or crop rotation options with dual-purpose legumes should be adapted to overcome soil fertility constraints for cassava cropping systems (Odendo *et al.*, 2006; Ojiem *et al.*, 2007).

4.2.3 Factors affecting cassava commercialization in the study area

Farmers mentioned various factors affecting cassava commercialization in the surveyed area (Table 4.3).

Table 4.3: Factors affecting cassava commercialization in Kipeti, Lemfu, M. Nzundu and Zenga sites according to farmers' responses

Factor	Kipeti (%)	Lemfu (%)	M.Nzundu (%)	Zenga (%)
Insufficient land	27	-	4	3
High renting price	4	-	-	3
Lack of capital/credit	-	9	7	21
Insufficient labour	12	18	14	17
Low soil fertility	8	3	-	-
Drought	4	9	-	-
Pests and diseases	8	9	7	-
Weed problem	-	-	-	3
Lack of improved varieties	-	3	4	
Lack of organic/mineral inputs	-	3	7	3
Lack of profitable market	12	0	-	-
Briberies to access markets	4	12	11	17
High taxes to access markets	4	0	11	10
Low price on markets	12	18	7	7
High price fluctuation	-	0	25	10
Storage facilities/product transformation	8	18	4	3

In Kipeti, insufficient land was the major factor (27 %) influencing cassava commercialization followed by insufficient labour (12 %), lack of profitable market (12 %) and low market prices (12 %). Despite the fact that land is insufficient in Kipeti, labour for cassava commercialization is limited even at peak growing season. This might be due to the fact that labourers prefer to work off-farm activities at Kinshasa which pays higher than farm activities. In Lemfu, insufficient labour (18 %), low prices (18%), and lack of storage facilities or product transformation (18 %) were the major factors followed by briberies to access markets (12 %), drought (9 %), pests and diseases (9 %), lack of capital or credit for commercialization of cassava products. High price fluctuation (25 %), insufficient labour (14 %), briberies to access market (11 %), high taxes (1 %), lack of capital or credit (7 %), pests and diseases (7 %), low prices (7 %) and insufficient input (7 %) were major factors for cassava commercialization in M. Nzundu. In Zenga, lack of credit or capital (21 %) was the major factor whilst other factors included insufficient labour (17 %), briberies (17 %), high taxes (10 %), price fluctuation and low prices (7 %) for cassava commercialization of cassava products.

Land is a limited resource for cassava commercialization in all sites except in Lemfu site. In the study area land acquisition for farming was mostly through inheritance. This system of land acquisition leads to land fragmentation since land is shared among family members. Thus, farmers in the ssurveyed area have struggled to produce more food and increase their productivity due to the limited availability of land.

In Africa, cassava commercialization is still very labour-intensive as compared to Asia and Latin America and the opportunity costs of labour for working in cassava commercial agriculture are high for local people (Aerni, 2004). Thus labour plays a crucial role in cassava commercialization in all sites. In the study area a larger proportion of the farmers made use of family labour. This could be attributed to the availability of family labour resulting from the relatively large household size of most farmers and also the small land holdings of some farmers made the use of only family labour sufficient to meet the labour requirement for cassava commercialization.

Capital or credit is also one of the important factors for commercialization of cassava in all sites. It was recognized as a necessary resource for basically payment of hired labour and purchase of agricultural inputs such as improved varieties, inorganic fertilizers and pesticides or insecticides. In the surveyed area the farmers who used borrowed credits complained of small amount of credits available to them. The probability of expanding their farms into large scale production and purchasing cassava processing equipments become limited as the farmers are characterized by small capital base.

Another factor that the farmers identified as necessary for cassava commercialization is the uncertainty of a stable market outlet for their products. This could be because most cassava products are traded on local markets where only surpluses are sold which makes market prices fluctuate greatly in the surveyed area. Storage facilities or post-harvest technologies and processing have also identified as an important factor affecting cassava commercialization. Mbwika *et al.* (2001) also reported that storage facilities are important for commercialization in DR. Congo as cassava is perishable. Cassava has to be processed for minimizing moisture content to increase its shelf life. In the surveyed area it is mainly processed using traditional methods. These methods are generally costly in terms of time, labour and wastage. The quality control of the resulting products is also absent. Another challenge is lack of using improved varieties in Lemfu and M. Nzundu. The use of local variety of stem cuttings could be attributed to the poor knowledge about improved varieties and poor extension services in the surveyed area.

4.3 Effect of improved variety and inorganic fertilizer on crop yield, agronomic efficiency and economic returns

The results presented in this section displayed the effect of variety used and inorganic fertilizer on crop yield, agronomic efficiency and economic returns in the cassava and groundnut mono cropping systems.

4.3.1 Pure cassava cropping system

4.3.1.1 Soil physico-chemcial propterties in Zenga and Lemfu sites

Some selected physico-chemical soil properties of the two study sites (Zenga and Lemfu) are presented in Table 4.4.

Table 4.4: Selected physico-chemical soil properties in Zenga and Lemfu sites for the pure cassava fields

Parameter	Units	Zenga	Lemfu	Probability
Organic C	%	2.1	1.6	ns
Total N	%	0.1	0.1	ns
Available P	ppm	7.3	5.4	ns
pH (H_2O)		5.1	5.3	ns
CEC	$cmol_c\ kg^{-1}$	10.4	5.3	*
Exchangeable K^+	$cmol_ckg^{-1}$	0.1	0.1	ns
Exchangeable Ca^{2+}	$cmol_c\ kg^{-1}$	3.9	1.6	ns
Exchangeable Mg^{2+}	$cmol_c\ kg^{-1}$	1.2	1.3	ns
Exchangeable Acidity	$cmol_c\ kg^{-1}$	4.5	1.5	*
Sand	%	48	69	**
Silt	%	26	15	*
Clay	%	26	16	*
Soil texture		Sandy clay loam	Sandy loam	

ns = not significant, * and ** = $P < 0.05$ and $P < 0.01$, respectively.

The results of total soil N, available soil P and soil exchangeable K^+ showed no significant difference between the two study sites. However, Cation Exchange Capacity

(CEC) of Zenga was significantly ($P = 0.046$) higher than that of Lemfu. This indicates that soil from Zenga had a greater capacity to hold and exchange cations. Percentage of sand, silt and clay were also significantly ($P = 0.002$, $P = 0.011$ and $P = 0.024$) different between Zenga and Lemfu, respectively. Higher clay percentage in Zenga indicates that soil from Zenga can provide a much greater surface area for adsorption of nutrients (Jones and Jacobsen, 2001) than that of Lemfu. The results of sand percentage also indicate that soil from Lemfu holds less water and fewer nutrients and is more susceptible to leaching of applied nutrients (Lehmann and Schroth, 2003) than that of Zenga. Leaching of applied nutrients could also be higher since Lemfu received higher rainfall than Zenga (Figure 4.2).

According to the nutritional requirements of cassava (Howeler, 2002), average soil values of exchangeable K^+ (0.11 to 0.14 $cmol_c\ kg^{-1}$) in both sites were below the critical level (0.15 $cmol_c\ kg^{-1}$) and can be classified as low. Availabe soil P level of Lemfu was also below the critical level (8 ppm).

4.3.1.2 Relationship between soil nutrient contents and crop nutrient responses in Zenga and Lemfu sites

In both Zenga and Lemfu sites, a higher response of N fertilizer was seen when the soil N value was lower ($R^2 = 0.73$ in Zenga; $R^2 = 0.91$, $P = 0.044$ in Lemfu) shown in Figure 4.8.

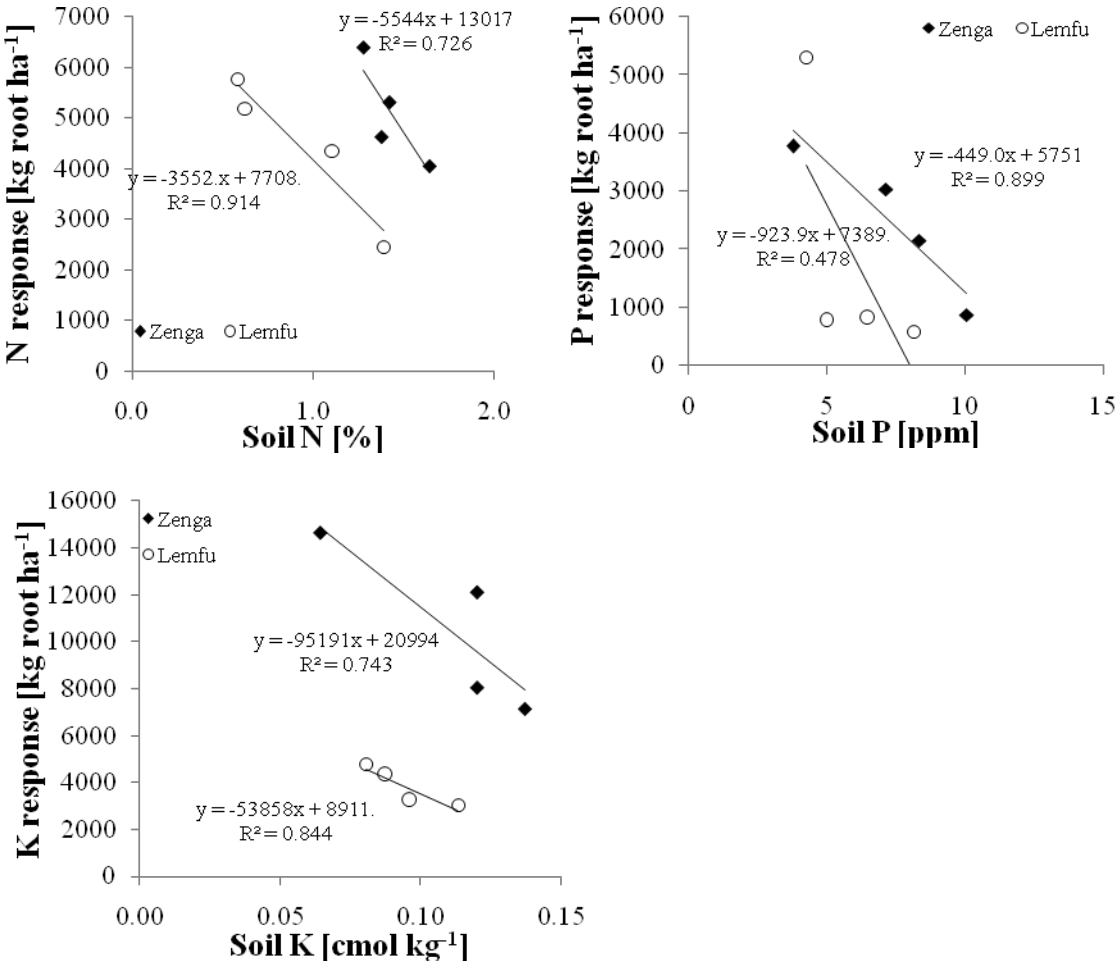


Figure 4.8: Relationship between soil nutrient contents and cassava crop nutrient responses in Zenga and Lemfu sites

There was also a negative relationship between the average P fertilizer response and soil P content (R^2 = 0.90, P = 0.051 in Zenga; R^2 = 0.47 in Lemfu). The results of correlation between the average K fertilizer response and soil K content indicate that the lower the K in the soil, the higher K fertilizer response in both sites (R^2 = 0.74 in Zenga; R^2 = 0.84 in Lemfu). For all applied nutrient responses (N, P and K), the responses of the storage cassava root yield were different between the two study sites.

The results indicate that a cassava yield response to fertilizer application is high if a soil nutrient level is low. The responses of applied fertilizer nutrients (N, P and K) were different between the two study sites. This difference in response could be a result of differences in soil fertility status (Vanlauwe *et al.*, 2006). This could also be due to the higher CEC in Zenga that can increase the retention of applied K (Table 4.4). The soil in Zenga also had higher clay %, which is important for sorption capacity to hold the applied P (Idris and Ahmed, 2012). In addition, the soil in Lemfu had higher percentage sand meaning that it has lower ability to hold applied nutrients. This readily leaches the applied nutrients from the soil exchange site.

4.3.1.3 Cassava tuber yield as affected by variety and inorganic fertilizer application in Zenga and Lemfu sites

The improved variety alone significantly ($P < 0.001$) increased the tuber yields by 74 to 173 % (6 to 11 ton ha^{-1}) relative to the local variety in both Zenga and Lemfu sites (Figure 4.9).

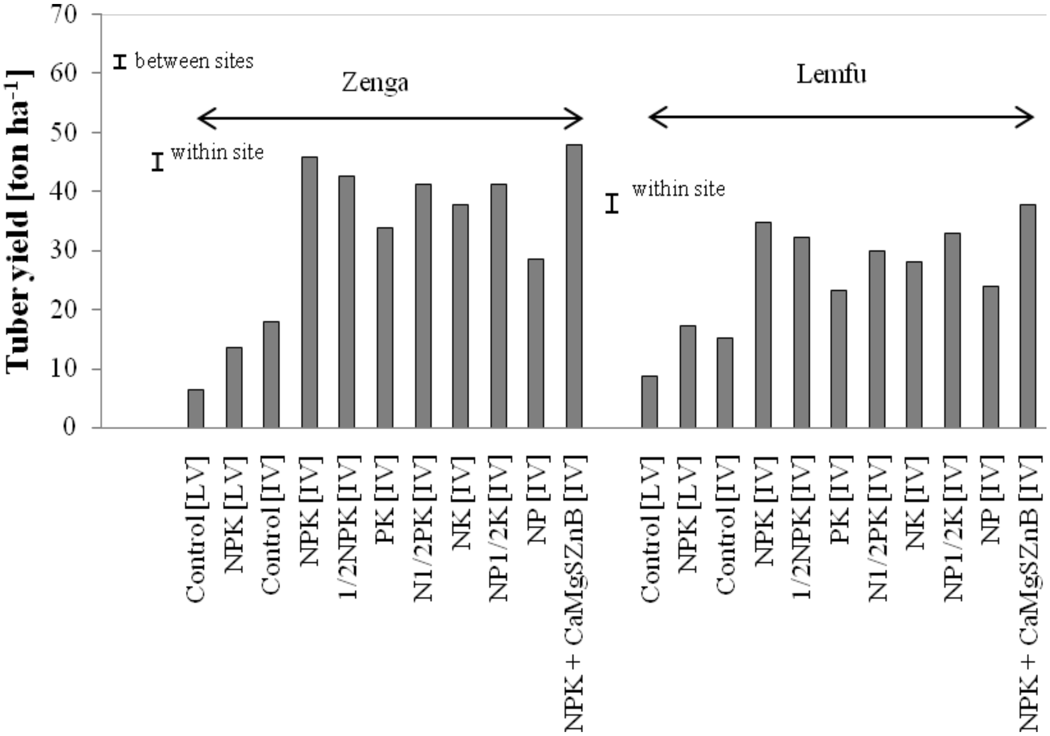


Figure 4.9: Cassava tuber yield as affected by variety and inorganic fertilizer application in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. LV and IV mean local variety and improved variety, respectively.*

This result suggests that the sole use of improved variety is sufficient to enhance the tuber yields of cassava. This finding is in line with the study conducted by Fermont (2009) who reported the increased cassava tuber yield of 30 % by the use of improved variety in Kenya and Uganda. This yield difference between the two varieties might be due to their differences in susceptibility to cassava mosaic disease and root rot disease (Alabi *et al.*, 2011; Théberge, 1985). Wydra and Msikita (1998) also reported that there can be high percentage (90 %) of loss in the tuber yields of cassava due to diseases. Wydra and Msikita (1998) also reported that due to diseases there can be high percentage (90 %) of loss in the tuber yields of cassava.

Cassava tuber yields of both varieties were significantly (*P* = 0.016) affected by the application of NPK fertilizer in both sites. NPK fertilizer application improved the root yields of local variety and improved variety by 98 to 108 % (7 to 9 ton ha^{-1}) and 130 to 156 % (20 to 28 ton ha^{-1}), respectively relative to the control. NPK fertilizer application improved the tuber yields of local variety and improved variety by about 123 % over the control. These results are consistent with those of other studies; for instance, the tuberyields were increased by 49 to 110 % in West Africa (Howeler, 2002), 60 % in East Africa (Fermont *et al.*, 2009) and 42 to 212 % in DR. Congo (Pypers *et al.*, 2012) with the application of NPK fertilizer. The positive response to NPK application might be associated with better photosynthesis activities leading to more photosynthates being produced and translocated to the sink (storage root) (Bagali *et al.*, 2012).

In both sites, NPK application to the improved variety significantly (*P* = 0.001) increased the root yield by 35 to 50 % relative to the treatments with no N nutrient application (PK). Fermont *et al.* (2009) and Uwah *et al.* (2013) also observed the increased root yields of cassava with the application of N nutrient in Kenya, Uganda and Nigeria. This N response might be due to the fact that N being integral constituents of nucleotides, proteins, chlorophyll and enzymes, involves in various metabolic processes (Chaturvedi, 2006) which have been reflected in the development and production of tuber. Leihner (2002) observed that the application of N fertilizer at the rate of 50 kg N ha^{-1} improved the tuber yield; however application of more than 50 kg N ha^{-1} decreased the tubert yield of cassava. According to Howeler (2002) many studies have also observed that high rate of N application increased vegetative growth and thereby reduced root growth. This was not found in this study as NPK treatment (high rate of N application, 80 kg N ha^{-1}) still gave significant higher tuber yield as compared to the treatments with no N application (PK). This might be due to low level of total soil N contents in both sites.

In both sites, the tuber yields were significantly ($P = 0.006$) increased by 21 to 25 % with the application of NPK fertilizer as compared to the treatments with no P fertilizer application (NK). This might be due to low average soil P content (5.4 to 7.3 ppm) in both sites and low soil Ca content (0.09 cmol$_c$ kg^{-1}) in Lemfu (Table 4.4). This is similar to the findings of Fermont *et al.* (2009) who reported increased cassava tuber yield with P application in Kenya and Uganda.

Cassava responds to K fertilizer application as NPK application significantly ($P <$ 0.001) increased the tuber yields by 46 to 61 % over the treatments with no K application (NP) in both sites. This might be due to the fact that K stimulates net photosynthetic activity and increases the translocation of photosynthates from the leaves to the storage roots (Mengel and Kirby, 2001). Fermont *et al.* (2009) and Uwah et al. (2013) also reported that K fertilizer application significantly increased the tuber yields of cassava in Kenya, Uganda and Nigeria. This could be due to the low level of average soil K levels in both sites. This might also be due to the fact that K stimulates net photosynthetic activity and increases the translocation of photosynthates from the leaves to the tubers (Mengel and Kirby, 2001).

In both sites, the tuber yield was not significantly affected by the addition of Ca, Mg, S, Zn and B fertilizers to NPK fertilizer application in both sites. This might be due to the sufficient amount (28 kg Ca ha^{-1}) of calcium from P fertilizer (TSP). This could also be attributed by medium level of soil Ca (1.61 to 3.99 cmol$_c$ kg^{-1}) and high level of soil Mg (1.23 to 1.32 $\text{cmol}_c\ \text{kg}^{-1}$) according to the nutritional requirement of cassava (Howeler, 2002) and probably sufficient levels of soil S, Zn and B for tuber production.

There was a significant ($P < 0.001$) difference on the tuber yield between the two study sites. Zenga produced 18 to 46 % higher cassava tuber yields of improved variety than Lemfu whereas Lemfu produced 27 to 33 % higher tuber yields of local variety than Zenga. This might be due to the difference in soil fertility status (Table 4.4) or rainfall distribution (Figure 4.2).

4.3.1.4 Cassava stem yield by variety and inorganic fertilizer application in Zenga and Lemfu sites

Use of improved variety significantly ($P = 0.004$) affected the stem yield of cassava in Lemfu (Figure 4.10).

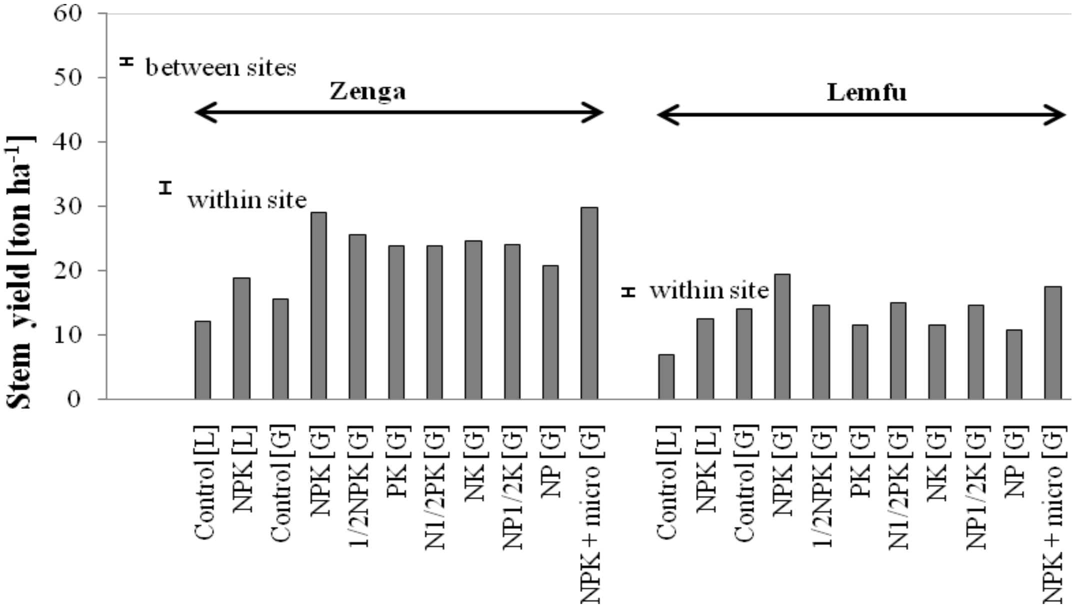


Figure 4.10: Cassava stem yield as affected by variety and inorganic fertilizer application in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. LV and IV mean local variety and improved variety, respectively.*

The improved variety increased the stem yields by 30 to 102 % relative to the local variety. This suggests that the improved variety was more efficient in the production of stem than the local variety. A significant ($P = 0.013$ and $P < 0.001$) response of cassava to NPK fertilizer was found in both Zenga and Lemfu, respectively. NPK fertilizer application increased the stem yields of local variety and improved variety by 56 to 80 % and 38 to 86 %, respectively relative to the control. This might be because NPK being the essential nutrients required for the production of the meristematic and physiological activities (leaves, roots, shoots, dry matter production, etc), leading to an efficient translocation of water, nutrients, interception of light and CO_2 (Law-Ogbomo and Law-Ogbomo 2009), resulting in an increased photosynthetic activity of adequate photosynthates for subsequent translocation to various sink (Jaliya *et al.*, 2008) and thereby production of higher stem yield. Similar improvement of cassava stem yields by NPK fertilizer application was found in DR. Congo (Pypers *et al.*, 2012).

NPK application to the improved variety significantly ($P = 0.01$ and $P < 0.001$) increased the tuberyields by about 33 % and 68 % relative to the treatment with half rate of N fertilizer (½NPK) or no N fertilizer (PK) application, respectively in Lemfu. The stem yields of improved variety were significantly ($P < 0.001$) increased by about 29 % and 68 % with NPK application as compared to the treatment with half rate of P fertilizer (N½PK) and no P fertilizer (NK) application, respectively in Lemfu. This could be due to low levels of soil N and P for cassava production in this site. In both sites, the stem yield of improved variety was significantly ($P = 0.025$) increased by 40 to 79 % in the treatments with NPK application as compared to the treatments with no K (NP) application. The application of K fertilizer increased about 43 % of the stem yield in both study sites.

Nevertheless, the study did not find significant effect of Ca, Mg, S, Zn and B nutrients along with NPK fertilizer on the stem yields in both study sites. A significant (*P* < 0.001) difference on cassava stem yields between the two study sites was found. Zenga produced higher cassava stem yields of local variety and improved variety by 51 to 74 % and 12 to 114 %, respectively over Lemfu.

4.3.1.5 Agronomic efficiencies of applied fertilizer nutrients as affected by rates of fertilizer applied in Zenga and Lemfu sites

Results of agronomic efficiencies of applied fertilizer nutrients (N, P and K) were shown in Figure 4.11.

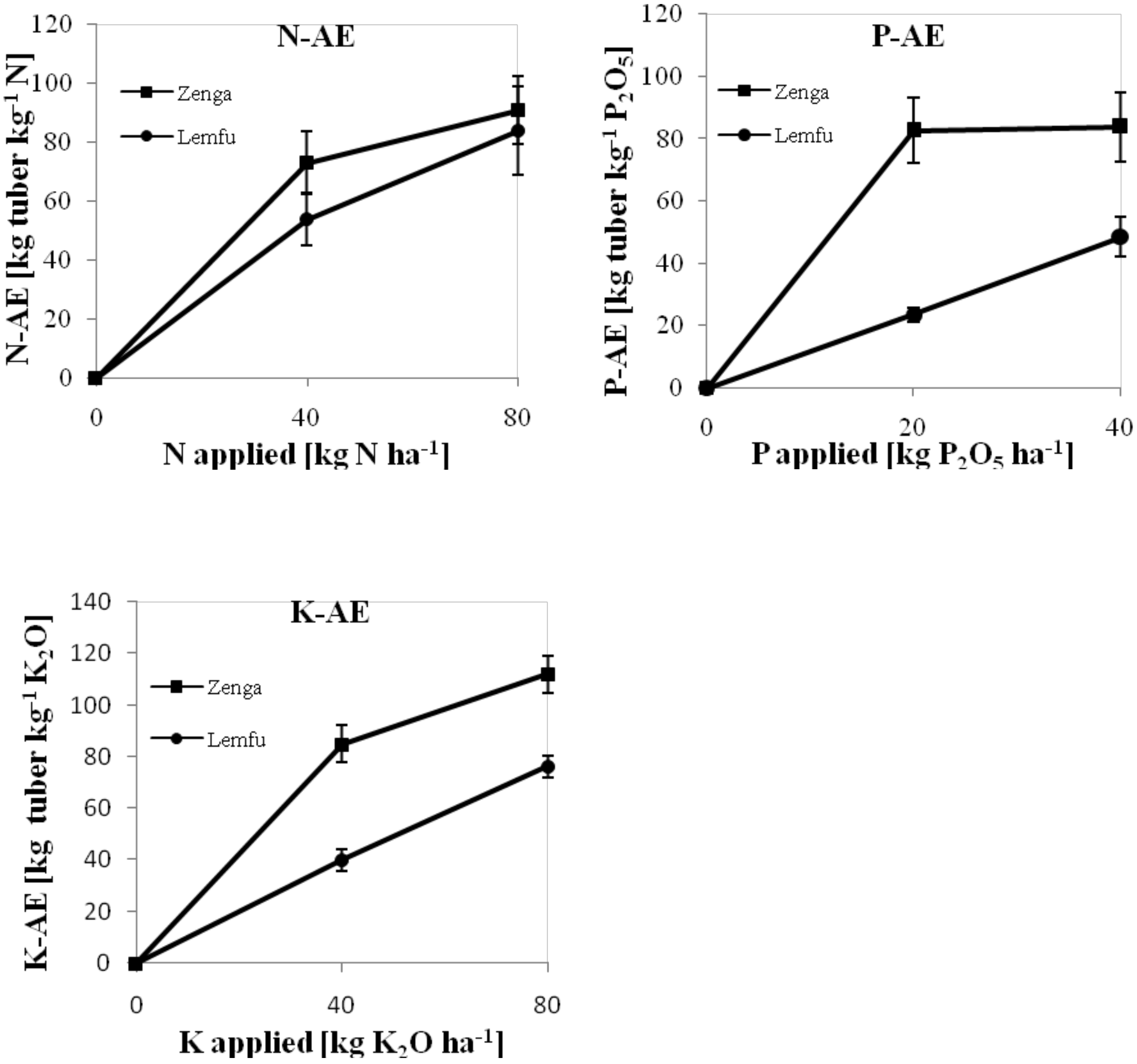


Figure 4.11: Agronomic efficiencies of applied N, P and K nutrients (kg root increase per kg of applied nutrient) of cassava improved variety as affected by rates of fertilizer nutrient applied in Zenga and Lemfu sites

At full rate of N fertilizer application (80 kg N ha^{-1}), the value of agronomic efficiency (N-AE) was 91 kg fresh root kg^{-1} of N fertilizer but this was not significantly (*P* = 0.34) higher than the agronomic efficiency (73 kg fresh root kg^{-1} of N) at half rate of N fertilizer (80 kg N ha^{-1}) in Zenga (Figure 4.8). This means that crop production efficiency or magnitude of yield production per unit of N application was better at high fertilizer rate in both sites. Umeh *et al.* (2012) also found that cassava nitrogen use efficiency increased linearly with increase in N levels (up to 60 kg N ha^{-1}) in the cassava-soybean intercropping system.

The high value of agronomic efficiency of P fertilizer (84 kg fresh root kg^{-1} of P_2O_5) was recorded at half rate of P (20 kg P_2O_5 ha^{-1}) in Zenga. In Lemfu, full rate of P fertilizer (40 kg P_2O_5 ha^{-1}) had a significant ($P = 0.052$) higher agronomic efficiency (49 kg fresh root kg^{-1} of P_2O_5) than low rate of P fertilizer (24 kg fresh root kg^{-1} of P_2O_5) (Figure 4.11). This means that at high rate of applied P the fertilizer nutrient absorbed by the plant was not converted into root efficiently in this site. The findings of this study generally agree that no further improvement in yield is possible until more of the nutrient is made available as stated by the law of limiting factors (Blackman, 1905). Average P-AE values of Zenga were significantly ($P = 0.019$) higher than those of Lemfu at both low and high rates of P fertilizer.

The agronomic efficiency of K (K-AE) value was significantly ($P = 0.05$) higher at the high rate of applied K (112 kg fresh root kg^{-1} of K_2O) than in the half rate of K in Zenga (85 kg fresh root kg^{-1} of K_2O). Similar trend was seen in Lemfu. Full rate of applied K (80 kg P_2O_5 ha^{-1}) had a significant ($P = 0.002$) higher agronomic efficiency (76 kg fresh root kg^{-1} of K_2O) than low rate of applied K (Figure 4.11). The agronomic efficiency of K was greatest among the applied nutrients in both study sites since cassava root extracts K nutrients predominantly (Howeler, 2002). Thus, K was observed to be the most limiting nutrient for cassava production system in both study sites. Average K-AE values of Zenga were significantly ($P = 0.002$) higher than that of Lemfu at both low and high rates of K fertilizer. This might be due to higher average CEC value of soil from Zenga (Table 4.4).

The improved variety had a significantly ($P = 0.019$ and $P = 0.013$) higher NPK-AE value than the local variety in Zenga and Lemfu (144 and 101 kg fresh root kg^{-1} of applied NPK), respectively (Figure 4.12).

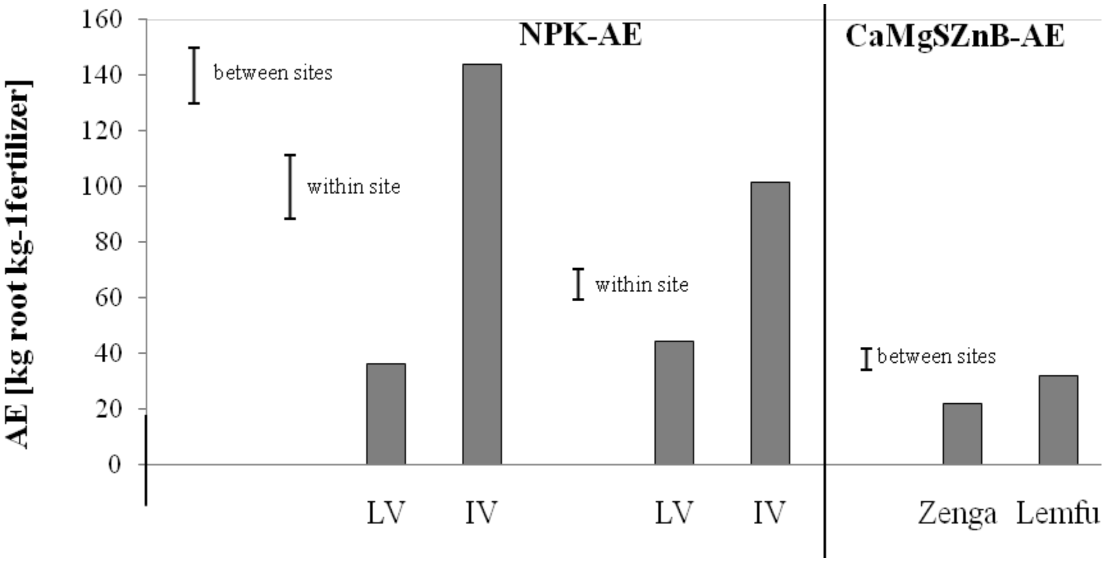


Figure 4.12: Agronomic efficiencies of NPK (kg root increase per kg of applied NPK fertilizer) and Ca, Mg, S, Zn and B fertilizers (kg root increase per kg of $CaSO_4$+ $MgSO_4$+ $ZnSO_4$+ H_3BO_3 fertilizers) in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. LV and IV mean the local variety and the improved variety, respectively.*

Average NPK-AE values did not differ between the two study sites. No significance difference of agronomic efficiency of applied Ca, Mg, S, Zn and B nutrients (micro-AE) was found between the two study sites (Figure 4.12). This might be probably due to no significant difference among soil exchangeable Ca (Table 4.4) or soil S, Zn and B nutrients between the two study sites. Maximum value of CaMgSZnB-AE (32 kg fresh root kg^{-1} of applied Ca, Mg, S, Zn and B nutrients) was recorded in Lemfu (Figure 4.12).

The agronomic efficiency of applied NPK fertilizer of improved variety was 1.3 to 3 times higher than that of local variety. This result confirms that the improved variety used in this study has better efficiency in utilization of applied nutrients for fresh root production than the local variety. Significant difference was found between the agronomic use efficiencies of applied NPK between the two study sites. This might be due to the different yield responses to NPK fertilizer between the two study sites.

4.3.1.6 Economic analysis of inorganic fertilizer application to local and improved varieties of cassava in Zenga and Lemfu sites

The use of improved variety with NPK application significantly ($P < 0.001$) increased the additional benefits or the additional net benefits relative to the local variety with NPK application in Zenga and Lemfu (Table 4.5). NPK fertilizer application significantly ($P < 0.001$) increased the net benefits by \$ 955 to 958 ha^{-1} and \$ 2828 to 4344 ha^{-1} in the local variety and the improved variety, respectively in both study sites.

Table 4.5: Economic analysis of inorganic fertilizer application to local and improved varieties in the pure cassava, including additional benefit (Ad. B), additional cost (Ad. C), additional net benefit (Ad. NB), benefit/cost ratio (BCR), and marginal rate of return (MRR) relative to the control in Zenga and Lemfu sites

	Zenga					Lemfu				
	Ad. B	Ad. C	Ad. NB	BCR	MRR	Ad. B	Ad. C	Ad. NB	BCR	MRR
Treatment	$ ha-1			$ $-1		$ ha-1			$ $-1	
Control [LV]	0	0	0	-	-	0	0	0	-	-
NPK [LV]	1373	449	925	3.1	2.1	1391	436	955	3.2	2.2
Control [IV]	0	0	0	-	-	0	0	0	-	-
NPK [IV]	4726	449	4278	10.5	9.5	3266	437	2828	7.3	6.5
1/2NPK [IV]	4473	352	4120	12.7	11.7	2971	341	2629	8.7	7.7
PK [IV]	3527	256	3271	13.7	12.8	2073	250	1823	8.3	7.3
N1/2PK [IV]	4251	389	3862	10.9	9.9	2798	381	2417	7.3	6.3
NK [IV]	3762	333	3429	11.3	10.3	2641	331	2310	8	7
NP1/2K [IV]	4605	382	4223	12.0	11.0	3079	374	2706	8.2	7.2
NP [IV]	2946	324	2622	9.1	8.1	2113	323	1790	6.5	5.5
NPK+ CaMgSZnB [IV]	4867	591	4276	8.2	7.2	3498	569	2929	6.2	5.1
SED (all treatments)	281***	2***	281***	0.9***		190***	3***	189***	0.6***	
SED (site)	114***	2***	113***	0.3**						

SED = standard error of difference. *, **, *** and **** = $P < 0.05$, $P < 0.01$, $P < 0.001$ and $P < 0.0001$, respectively. LV and IV mean local variety and improved variety, respectively.

The additional benefits with the application of NPK fertilizer could be due to higher tuberyields of cassava by the use of improved variety. According to Awoniy and Awoyinka (2007), the use of improved variety was found to enhance the economic benefits of yam production in Nigeria. The application of NPK fertilizer to both varieties was profitable as it resulted in a favourable BCR of \$ 3.1 to 10.7 $\$^{-1}$ and a favourable MRR of \$ 2.1 to 9.7 $\$^{-1}$. This finding is in agreement with that of Pypers *et al.* (2012) who reported the improved net benefits of about 101% with NPK application to cassava in the highlands of DR. Congo. The treatments with no N fertilizer application (PK) of the improved variety significantly ($P < 0.001$) decreased the additional net benefits by 23 to 36% relative to NPK application in both sites. The treatments with no P fertilizer application (NK) resulted in significant ($P = 0.011$) decreases in the additional net benefits by 18 to 20% relative to NPK treatments in both sites. The additional net benefits were also significantly ($P < 0.001$) decreased by 37 to 38% in the treatments with no K application (NP) relative to NPK fertilizer treatments. Although the addition of Ca, Mg, S, Zn and B nutrients to NPK fertilizer did not significantly increase the additional net benefits relative to the NPK application, the addition of Ca, Mg, S, Zn and B nutrients remained cost-effective with a favourable BCR of \$ 6.2 to 8.2 $\$^{-1}$ and a MRR of \$ 5.1 to 7.2 $\$^{-1}$ in both sites. Maximum MRR values were recorded in the treatments of no N application (\$ 12.8 $\$^{-1}$) and half rate of N application (\$ 7.7 $\$^{-1}$) in Zenga and Lemfu, respectively. The additional net benefits of inorganic fertilizer application to the improved variety were significantly higher by \$ 910 to 1560 ha^{-1} in Zenga than Lemfu. This might be due to lower labour costs, higher cassava tuber price and better tuber yields with the application of inorganic fertilizers in Zenga recorded.

4.3.2 Pure groundnut cropping system

4.3.2.1 Soil physico-chemcial properties in Zenga and Lemfu sites

Some selected physico-chemical soil properties of the two study sites (Zenga and Lemfu) are shown in Table 4.6.

Table 4.6: Selected physic-chemical soil properties in Zenga and Lemfu sites for the pure groundnut

Parameter	Units	Zenga	Lemfu	Probability
Organic C	%	2.2	1.7	ns
Total N	%	0.2	0.1	*
Available P	ppm	7.3	5.9	ns
pH (H_2O)		5.1	5.3	ns
CEC	$cmol_c\ kg^{-1}$	11.01	5.17	*
Exchangeable K^+	$cmol_c\ kg^{-1}$	0.2	0.1	ns
Exchangeable Ca^{2+}	$cmol_c\ kg^{-1}$	4.7	0.8	ns
Exchangeable Mg^{2+}	$cmol_c\ kg^{-1}$	1.6	0.6	ns
Exchangeable Acidity	$cmol_c\ kg^{-1}$	4.8	2.2	*
Sand	%	41	66	*
Silt	%	31	16	*
Clay	%	28	18	**
Soil texture		Clay loam	Sandy loam	

ns = non-significant, * and ** = $P < 0.05$ and $P < 0.01$, respectively.

Available soil P and soil exchangeable K^+ levels were not significant different between the two study sites. However, percentage of total soil N in Zenga was significantly ($P = 0.031$) higher than that in Lemfu. Average soil CEC levels of Zenga were significantly ($P = 0.046$) higher than those of Lemfu, There was also a significantly higher ($P = 0.012$ and $P = 0.003$) percentage of silt and clay in Zenga than in Lemfu soils, respectively while in Lemfu the sand percentage was significantly ($P = 0.04$) higher than that in Zenga soil. This indicates that soil from Zenga can hold more nutrients than that of Lemfu owing to a much higher adsorption surface area (Jones and Jacobsen, 2001). Soil from Lemfu also had less capacity to hold water and applied nutrients as well as being more susceptible to leaching (Lehmann and Schroth, 2003) than that of Zenga.

4.3.2.2 Relationship between soil nutrient contents and crop nutrient responses in Zenga and Lemfu sites

One of the field trials (replicates) in Lemfu site was flooded and therefore the data of groundnut could not be collected. In Zenga site, there was a negative relationship between the average N fertilizer response and soil N content ($R^2 = 0.87$; $P = 0.002$, Figure 4.13).

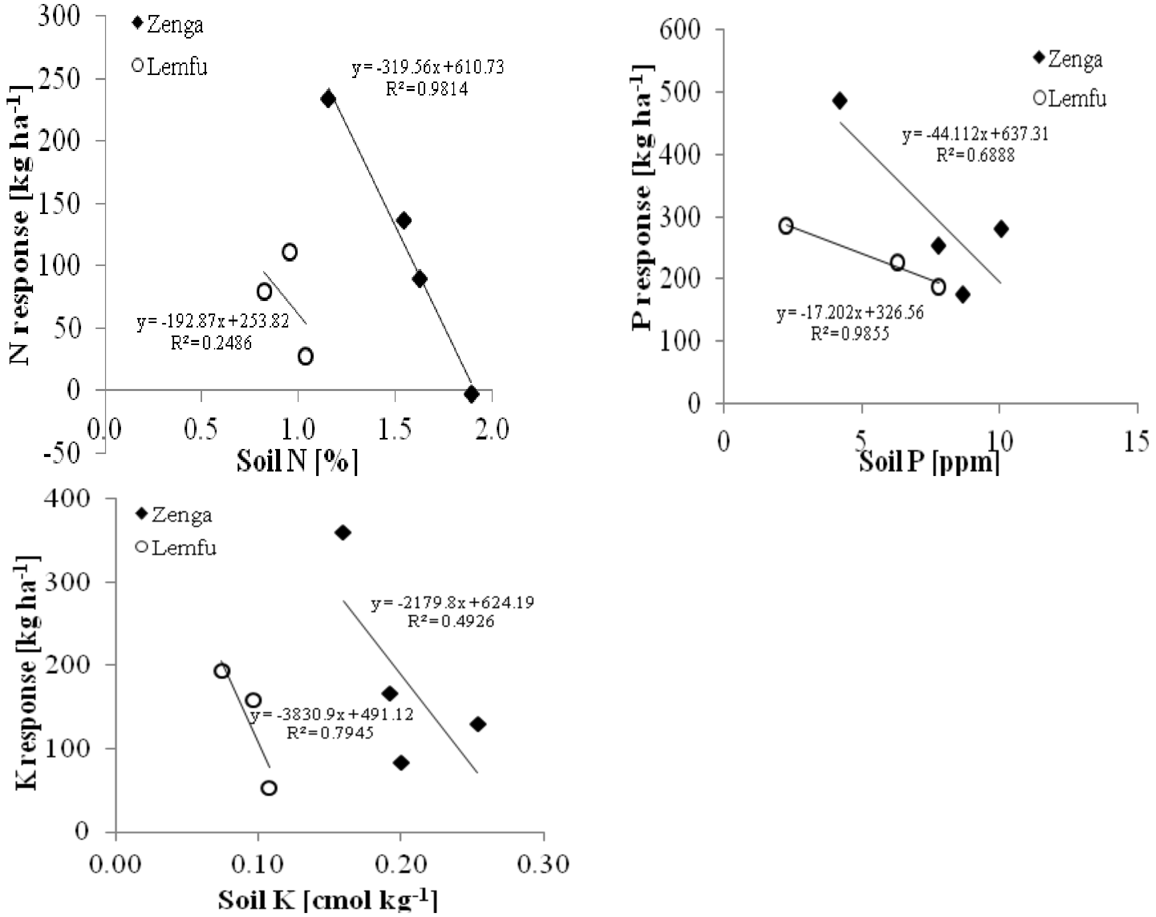


Figure 4.13: Relationship between soil nutrient contents and groundnut crop nutrient responses in Zegna and Lemfu sites

Groundnuts did not respond to applied N fertilizer when the soil N level was 0.19 % in Zenga. The results of correlation between the average P fertilizer response and soil P content indicate that the lower the P in the soil, the higher the P fertilizer response in both sites (R^2 = 0.32 in Zenga; R^2 = 0.98 in Lemfu, though not significant). Similarly, a higher response of K fertilizer was observed when the soil K value was lower in both sites (R^2 = 0.49 in Zenga; R^2 = 0.79 in Lemfu). Crop responses to applied fertilizer nutrients (N, P and K) were different between Zenga and Lemfu sites, though not significant. This difference in response could be a result of differences in soil fertility status (Vanlauwe *et al.*, 2006). This might also be due to the fact that the soil in Zenga had a higher CEC, which is important for retention of applied K nutrient (Korb *et al.*, 2002). The higher sand percentage of soil from Lemfu site (Table 4.6), which has lower ability to hold the applied nutrients, shows that applied nutrients would be readily leached from the soil exchange site prior to plant uptake. This might also be due to higher percentage of clay in soil of Zenga that can increase the P sorption capacity to hold the applied P (Idris and Ahmed, 2012).

4.3.2.3 Groundnut biomass yield as affected by variety and inorganic fertilizer application

There were no significant differences on the biomass yields of groundnut between the local variety and the improved variety in both Zenga and Lemfu sites (Figure 4.14).

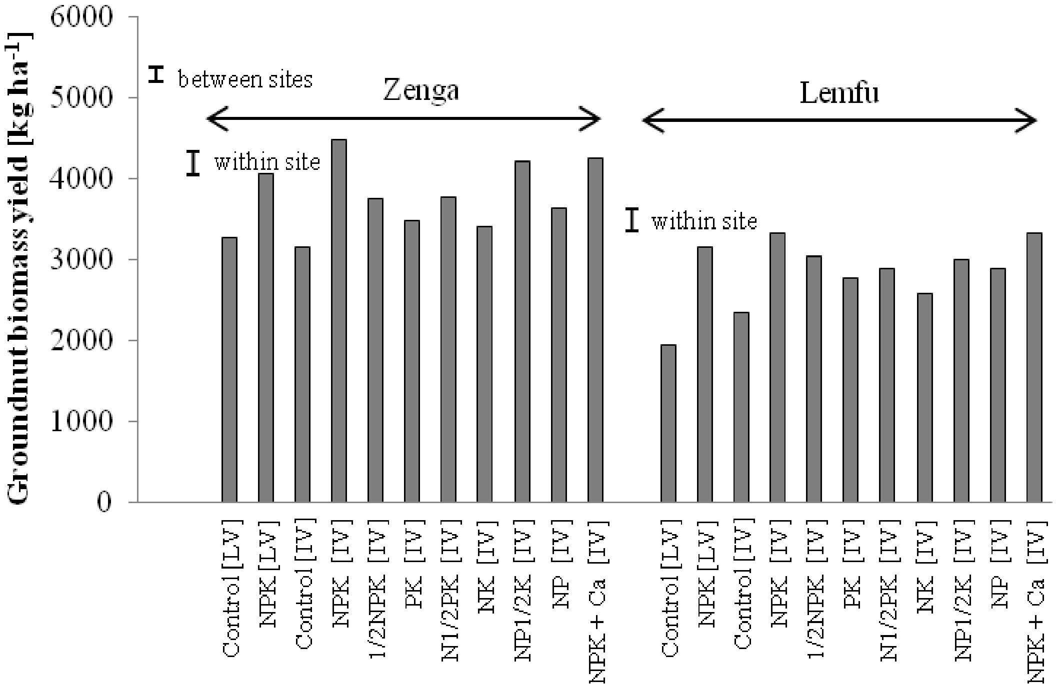


Figure 4.14: Groundnut biomass yield as affected by variety and inorganic fertilizer application in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. LV and IV mean local variety and improved variety, respectively.*

Application of NPK fertilizer significantly (*P* = 0.01) increased the biomass yields of the two varieties by 24 to 63 % (782 to 1079 kg ha^{-1}) in the NPK treatment of local variety and 42 % in the NPK treatment of improved variety relative to the control treatment. This could be due to increased uptake efficiency of nutrients with NPK fertilizer application (Laghari *et al.*, 2010). Such effect could be attributed to increase photosynthetic area and thereby more biomass production. Barik *et al.* (1994) also found increased biomass yields of groundnut with the application of NPK fertilizer.

The biomass yields of the improved variety were significantly (*P* = 0.015) increased by 567 to 1002 kg ha^{-1} (20 to 29 %) in the treatments with NPK application relative to the treatments with no N fertilizer application (PK). This might be due to the involvement of N in photosynthesis activity which might have direct impact on vegetative growth of the plants (Reddy, 2000). These findings are in agreement with the previous studies of Barik *et al.* (1998) in groundnut and Hasan *et al.* (2010) in cowpea, where they reported increased biomass yields with N fertilizer application.

The treatments with NPK application also significantly (*P* = 0.007) increased the biomass yields by 29 to 32 % relative to the treatments with no P application (NK), indicating the improvement of biomass yields by the application of P fertilizer. This could be due to the fact that P helps in the development of more extensive root system (Gobarah *et al.*, 2006) which has been reflected in the increased plant absorption of water and nutrients from the soil. This in turn could lead to greater production of photosynthates which was reflected in higher biomass (Gobarah *et al.*, 2006; Kamara, 2010).

Nevertheless, no significance differences were observed between the treatment with NPK application and the treatments with no K (NP) application. This indicates that K fertilizer application did not significantly influence the biomass yield of groundnuts. These results support the statement that K nutrient plays a role in catalytic activity and enzymatic reaction in nature rather than involves in structural development (Tisdale *et al.*, 1990). Senaratne *et al.* (1993) also reported that K application had no influence on the biomass yields of groundnut in Red Yellow Pozolic soil in Sri Linka. Conversely, Kankapure *et al.* (1994) reported a positive effect of K application on the growth factors including the biomass production in Vertisol soil in India.

Application of Ca fertilizer did not improve the biomass yields of groundnut as there were no significant differences on the biomass yields between the NPK fertilizer treatments and the NPK fertilizer plus Ca treatments in both sites. This might be due to the fact that soil Ca content (average 933 ppm; 4.66 $\text{cmol}_c\ \text{kg}^{-1}$) of Zenga was higher than the critical level of 600 ppm stated by Murat (2003). This might also be due to the sufficient amount (8 kg Ca ha^{-1}) of Ca (Table 4.6) from P fertilizer (TSP) for groundnut production in these study sites.

4.3.2.4 Groundnut pod and grain yields as affected by variety and inorganic fertilizer application

Regardless of NPK fertilizer application, the use of improved variety alone significantly ($P = 0.01$ and $P = 0.017$) produced higher pod and grain yields by 58 to 60 % (403 to 475 kg ha^{-1}) and 55 to 58 % (232 to 276 kg ha^{-1}), relative to the local variety in both Zenga and Lemfu sites, repectively (Figure 4.15).

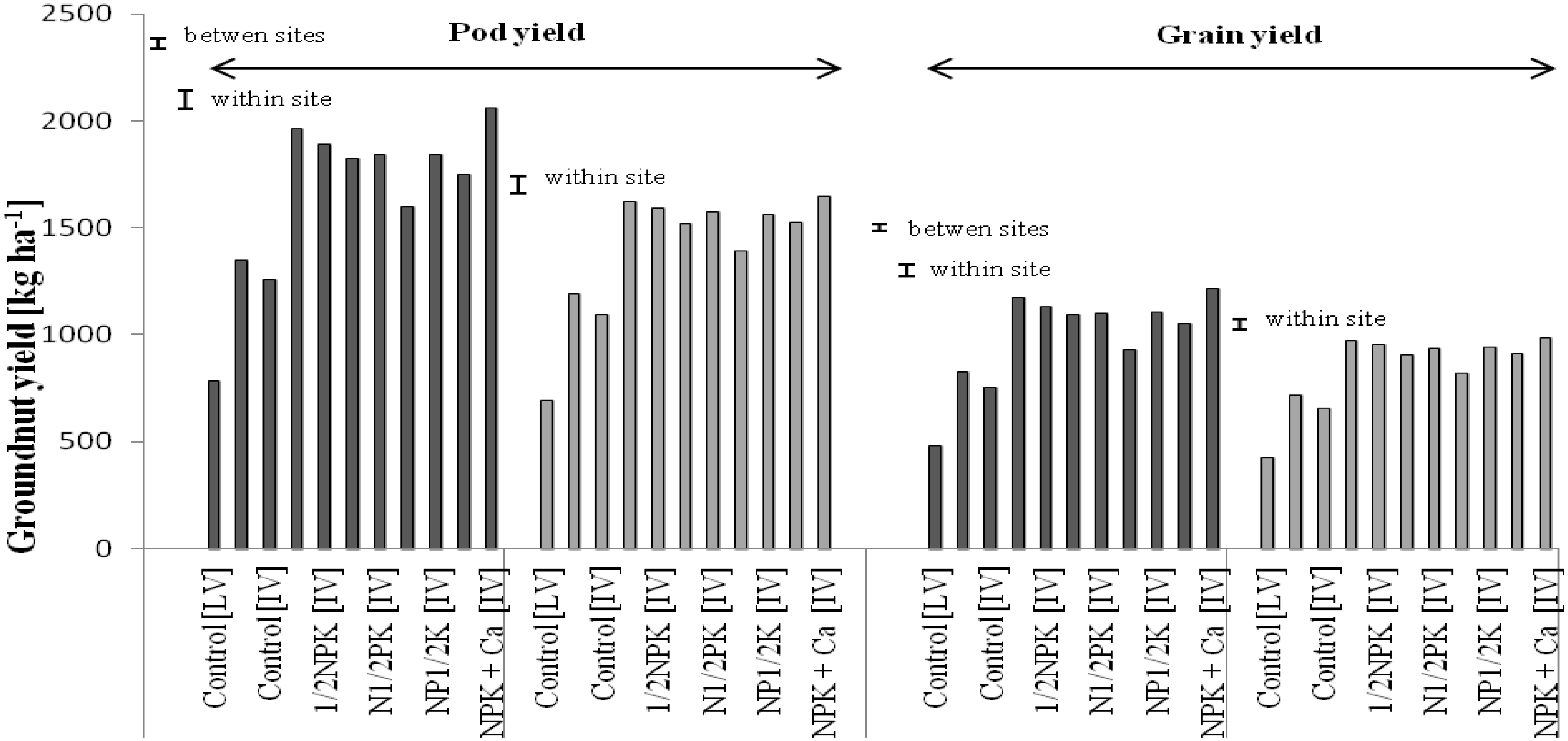


Figure 4.15: Groundnut pod yield and grain yield as affected by improved variety and inorganic fertilizer application in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. LV and IV mean local variety and improved variety, respectively.*

These results indicate that the improved variety used in this study can efficiently transmit photosynthates from sources toward sinks (pod) in a given environment. Annadurai *et al.* (2009) also stated that the use of an improved variety can improve the yield of groundnut by about 20 %. NPK fertilizer application significantly ($P = 0.012$ and $P = 0.003$) improved the pod and grain yields of both local variety and improved variety by 48.6 to 73.1 % (504 to 705 kg ha^{-1}) and 48.7 to 72.6 % (295 to 420 kg ha^{-1}), respectively in both study sites. This might be due to the increased nutrient availability in the soil solution by NPK application which facilitates nutrient uptake of the plant. Such effects could be attributed to favour better production of photosynthates and thereby increase the pod yields of groundnut. These findings are in line with previous studies (Patel *et al.*, 1994; Subrahmaniyan *et al.*, 2000; Laxminarayana, 2004) who reported increased groundnut yields after NPK application.

No significant differences were observed between the treatments with NPK fertilizer and the treatments with no N fertilizer (PK) in the improved variety in both sites. This could be probably due to the ability of groundnut plants to fix atmospheric N via rhizobia-legume symbiosis (Aliyu, 2012). This finding was not in line with previous studies of Singh and Singh (2001), Deka *et al.* (2001), Kandil *et al.* (2007) and Gohari and Niyaki (2010) in groundnut and Lestingi *et al.* (2010) in triticale, who reported increased grain yields with the application of N fertilizer.

Pod and grain yields of groundnut were significantly ($P = 0.048$ and $P = 0.032$) increased by 17 to 23 % (235 to 367 kg ha^{-1}) and 18 to 27 % (152 to 246 kg ha^{-1}), respectively in the treatment with NPK application relative to the treatment with no P (NK) application in both sites. This result shows a positive response to P fertilizer application on the grain yields. This might be due to the fact that P fertilizer application stimulates leaf expansion, hence better light interception for photosynthetic activity, high assimilated accumulation and thereby increases groundnut yield (Chiezey and Odunze, 2009). Similar results of increased grain yields with P application were reported by Rath *et al.* (2000) and Kamara *et al.* (2011) in groundnut and Xiang *et al.* (2012) in soybean.

No significance differences were observed between the treatments with NPK application and the treatments with no K (NP) application in both sites. This implies that K application did not influence on the pod yields of groundnut. The findings support the previous finding of Senaratne *et al.* (1993) in groundnut. In contrast, Patra *et al.* (1996) and Singh and Vidya (1996) reported the influence of K application on groundnut yields. These contradictory results indicate that the response of K application on crops grown under field conditions will depend on other prevailing environmental conditions which control available soil K and crop growth development (Jifon and Lester, 2008).

The addition of Ca+NPK fertilizer had no effect on groundnut pod and grain yields of improved germplasm relative to the NPK fertilizer application in both sites. This indicates that Ca application to groundnut had no influence on the pod yields. This might be due to the sufficient amount of Ca from TSP fertilizer for groundnut production. This could also be attributed to high levels of soil Ca (average 4.66cmol$_c$ kg^{-1}; 993 ppm) in Zenga. This finding is not in line with the previous studies by Kamara *et al.* (2011) and Gashti *et al.* (2012) who found that application of Ca significantly influenced groundnut yields. Zenga produced significantly (P = 0.004 and P = 0.008) higher pod yields and grain yields by 13 to 25 % and 13 to 23 %, respectively than Lemfu. This might be due to the different soil chemical properties (Table 4.6) or weed pressure between the two study sites.

4.3.2.5 Agronomic efficiencies of applied fertilizer nutrients as affected by rates of fertilizer applied

There were no significant differences of agronomic efficiencies of the improved groundnut variety between half rate and full rate of applied fertilizer nutrients (Figure 4.16).

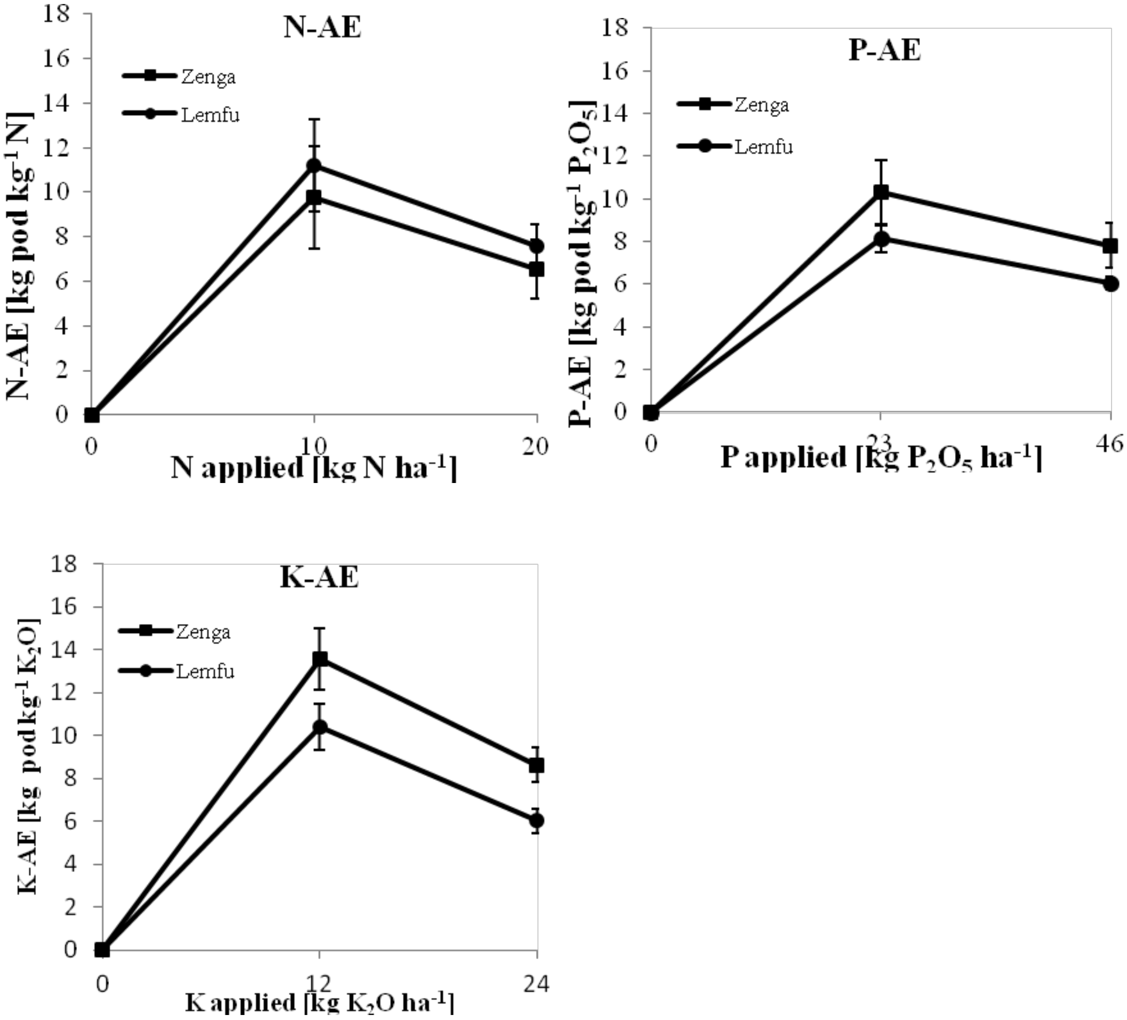


Figure 4.16: Agronomic efficiencies of applied N, P and K fertilizer nutrients (kg pod increase per kg of applied fertilizer nutrient) of groundnut improved variety as affected by rates of fertilizer nutrient applied in Zenga and Lemfu sites

Maximum average N agronomic efficiencies (9.8 and 11.2 kg pod N kg^{-1}) were recorded in Zenga and Lemfu, respectively at half rate of N (Figure 4.16). At half rate of applied P fertilizer, maximum average agronomic efficiencies (10.3 and 8.1 kg pod P_2O_5 kg^{-1}) were recorded in Zenga and in Lemfu, respectively. For agronomic efficiency of K fertilizer, a significantly ($P < 0.038$) lower agronomic efficiency was observed in both study sites. At the low rate of applied K fertilizer, K-AE values recorded 13.6 and 10.4 kg pod K_2O kg^{-1} in Zenga and Lemfu, respectively (Figure 4.16). No significant differences on the agronomic efficiency were found between the two study sites at both rates of applied N, P and K fertilizer nutrients. This means that at the higher rate of nutrient application the fertilizer nutrient absorbed by the groundnut plant was not converted into pod efficiently. This might be due to the fact that the application of excess nutrient was not effectively utilized by the crop where a higher nutrient rate resulted in luxury consumption of nutrient by the groundnut plant. These results are in close conformity with the previous findings of Chatterjee and Sanyal (2007) in rice, Nemati and Sharifi (2012) in maize and Gholipouri and Kandi (2012) in potato; who found that agronomic efficiency of applied nutrients decreased with increasing fertilizer levels. Agronomic efficiencies of applied NPK and Ca fertilizers are shown in Figure 4.17.

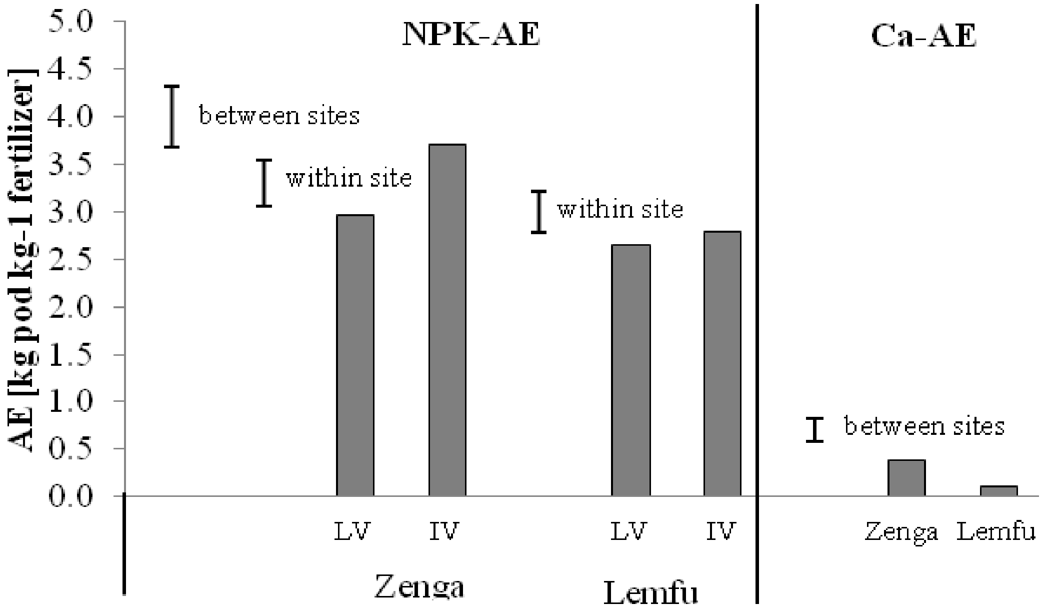


Figure 4.17: Agronomic efficiencies of NPK (kg pod increase per kg of applied NPK fertilizer) and Ca (kg pod increase per kg of $CaSO_4$ fertilizer) of improved variety in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. LV and IV mean local variety and improved variety, respectively.*

The results comparing the local variety and the improved variety plant ability to use NPK nutrients indicate that the improved variety was not superior to the local variety in terms of the agronomic efficiency of applied NPK fertilizer nutrients. It can be assumed that efficiency of production and partition of photosynthates to the reproductive sink (pods) by the application of NPK fertilizer did not differ between the two varieties used in this study. There were no significant differences on agronomic efficiency of applied Ca fertilizer between the two study sites. Maximum average Ca-AE was recorded 0.4 kg pod kg^{-1} $CaSO_4$ in Zenga followed by 0.1 kg pod kg^{-1} $CaSO_4$ in Lemfu.

4.3.2.6 Economic analysis of inorganic fertilizer applications to local and improved varieties of groundnut in the pure groundnut cropping system

The economic analysis of inorganic fertilizer applications is shown in Table 4.7. Profitability differed between sites ($P = 0.049$). Zenga produced higher benefits partly because of lower labour cost but mostly because of higher yield recorded.

Table 4.7: Economic analysis of inorganic fertilizer applications to local and improved groundnut varieties in the pure groundnut, including additional benefit (Ad. B), additional cost (Ad. C), additional net benefit (Ad. NB), benefit/cost ratio (BCR), and marginal rate of return (MRR) relative to the control in Zenga and Lemfu sites

Treatment	Ad.B	Ad.C	Ad.NB	BCR	MRR
		$\$\ \mathrm{ha}^{-1}$			$\$\ \$^{-1}$
Zenga					
Control [LV]	0	0	0	0	-
NPK [LV]	780	304	476	2.56	1.56
Control [IV]	0	0	0	0	-
NPK [IV]	945	305	640	3.1	2.1
½NPK [IV]	848	275	574	3.09	2.09
PK [IV]	764	243	521	3.14	2.14
N½PK [IV]	774	251	523	3.09	2.09
NK [IV]	391	196	196	2	1
NP½K [IV]	789	248	540	3.18	2.18
NP [IV]	664	229	435	2.9	1.9
NPK+Ca [IV]	1041	610	431	1.71	0.71
SED (all treatments)	81***	8***	78**	0.28***	
Lemfu					
Control [LV]	0	0	0	0	-
NPK [LV]	664	315	349	2.11	1.11
Control [IV]	0	0	0	0	-
NPK [IV]	718	315	403	2.28	1.28
½NPK [IV]	667	286	381	2.33	1.33
PK [IV]	567	254	312	2.23	1.23
N½PK [IV]	629	264	366	2.39	1.39
NK [IV]	376	211	165	1.78	0.78
NP½K [IV]	648	284	365	2.29	1.29
NP [IV]	570	250	321	2.28	1.28
NPK+Ca [IV]	743	612	131	1.21	0.21
SED (all treatments)	42***	42***	42***	0.19***	
SED (site)	ns	3*	81	0.29***	

Significant at $P < 0.05$; ** Significant at $P < 0.01$; SED = standard error of difference; ns = not significant.

A significant ($P = 0.045$) difference in both additional benefits and additional net benefits of NPK fertilizer application between the local variety and the improved variety in Zenga but not significant in Lemfu (Table 4.7). Manyong *et al.* (2000b) also reported that the use of improved maize variety gave the economic return of \$ 162 ha^{-1} as compared to the local variety in West and Central Africa. The improved groundnut variety with NPK application increased the net benefits by 15 to 34% relative to the local variety with NPK application in both sites (Table 4.7). NPK fertilizer application gave the additional net benefits of \$ 349 to 640 ha^{-1} in both sites, due to the increased grain yields with NPK application. The application of NPK fertilizer was cost-effective with a favourable BCR of about \$ 2.5 \$$^{-1}$ and a favourable MRR of about \$ 1.5 \$$^{-1}$ except the local variety with NPK application, whose MRR was 1.1 in Lemfu (Table 4.7). Law-Ogbomo and Emokaro (2009) also reported that the benefits would be achieved by NPK application with a favourable BCR at the rate of 100 to 300 kg NPK ha^{-1} relative to the control in Nigeria.

The application of no P fertilizer (NK) only resulted in a significant ($P < 0.001$) decrease in the additional net benefits of \$ 238 to 444 ha^{-1} as compared to the application of NPK (Table 4.7). This lower benefit could be attributed to lower yields when no P fertilizer was applied as compared to NPK application. The application of Ca along with NPK fertilizers was not satisfactory as the additional net benefits and BCR did not differ between Ca added treatment and NPK treatment in both study sites. The addition of Ca fertilizer was, therefore, not profitable because of the higher additional costs and no significant difference of yields compared to NPK application.

The maximum BCR (\$ 3.53 \$$^{-1}$) were recorded in the treatment with half rate of K fertilizer (NP½K) in Zenga while in Lemfu the treatment with half rate of P fertilizer (N½PK) recorded the maximum BCR (\$ 2.75 \$$^{-1}$) (Table 4.7). The results of marginal rate of return (MRR) indicate that all fertilizer applied treatments of the improved variety were favourable with MRR greater than \$ 1.18 $\$^{-1}$ (CIMMYT, 1988) over the control treatment in both sites except in the NK and NPK with Ca applied treatments. Hence, the application of fertilizer can be profitable, despite the higher price of the fertilizer in the two study sites.

4.4 Effect of combined application of inorganic fertilizer and organic input on crop yields and economic returns in the cassava-groundnut intercropping system

The results of this study showed the effect of combined application of inorganic fertilizer and organic input (Chromolaena) on the yield and the profitability of a cassava-groundnut intercropping system in Zenga and Lemfu sties.

4.4.1 Groundnut grain yield as affected by sole NPK, sole Chromolaena and the combined application of NPK and Chromolaena

Groundnut grain yield of NPK treatment was significantly ($P = 0.005$) increased by 37 % over that of the control treatment in Zenga in the cassava-groundnut intercropping system (Figure 4.18).

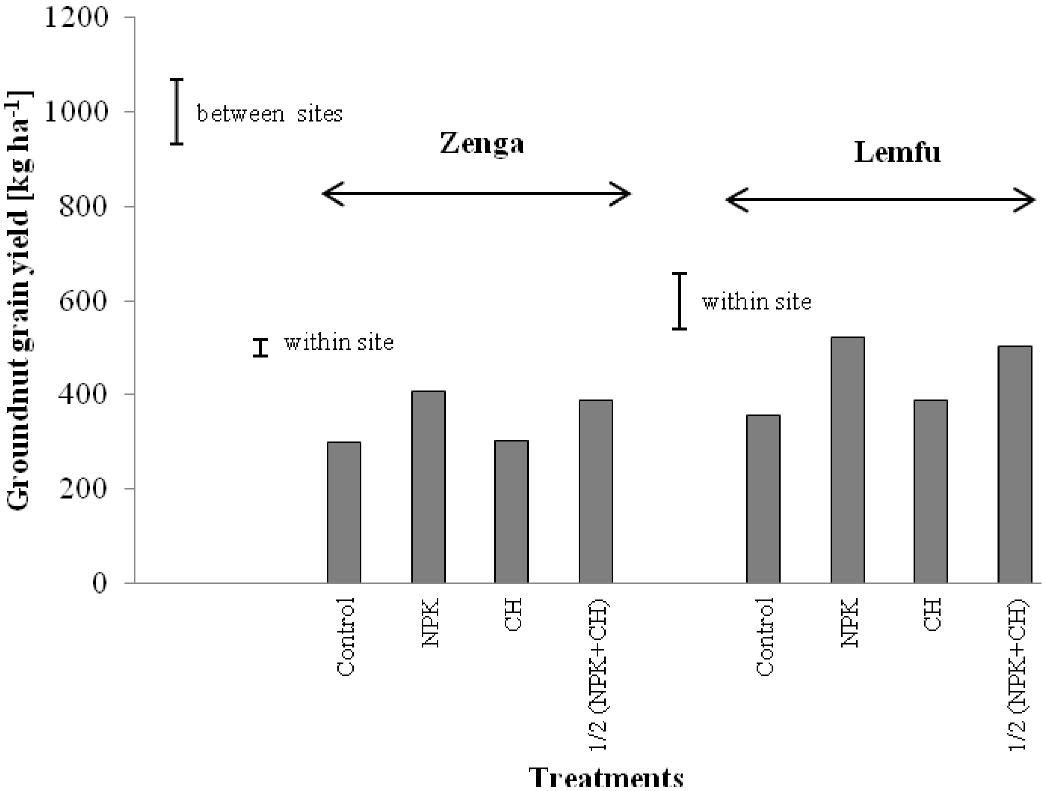


Figure 4.18: Groundnut grain yield as affected by Chromolaena application, inorganic fertilizer application and the combined application of Chromolaena and inorganic fertilizer in Zenga and Lemfu sites. *CH means Chromolaena. Error bars represent standard errors of difference for comparisons of all treatments.*

This groundnut response to NPK could be due to the fact that NPK application increases available nutrients in the soil solution which facilitates nutrient uptake efficiency of the plant. Such effects could be attributed to better production of photosynthates leading to increase the grain yields of groundnut. This might also be due to the stimulation effect of NPK application on the number and weight of nodules and N activity which in turn reflect the yield of groundnut (El-Dsouky and Attia, 1999). This finding was in line with the previous studies of Angadi *et al.* (1990) and Hameed *et al.*

(1993) in groundnut and Shubhashree *et al.* (2011) in French bean (*Phaseolus vulgaris*) who reported that NPK application increased the grain yields relative to the control.

No significant yield difference was found between the control treatment and the treatment with Chromolaena (CH) application (Figure 4.18). The combined application of half rate of NPK and Chromolaena [½ (NPK + CH)] significantly (*P* = 0.006) increased the grain yield by 30 % relative to the control (Figure 4.18). The combined application of NPK and CH increased the grain yield by 30 % relative to the control. This could be attributed to the positive interactions from combining organic and inorganic inputs in maize by better synchronization in release and uptake of N (Vanlauwe *et al.*, 2011). This might also be due to the increased nutrient availability and microbial activities by the integration of organic and inorganic inputs leading to better nutrient utilization by the plants and growth of crops (Chen, 2006; Lazcano *et al.*, 2012). Murthy *et al.* (2010) and De Ridder and Van Kaulem (1990) also reported that the integration of organic input and inorganic fertilizer could improve the availability and uptake of nutrients as well as water use efficiency. This result is in conformity with the findings of Bahulkar *et al.* (2000) in soybean, Murthy *et al.* (2010) and Kamalakannan and Ravichandran (2013) in groundnut.

4.4.2 Cassava tuber yield as affected by sole NPK, sole Chromolaena and the combined application of NPK and Chromolaena

The effect of NPK fertilizer, Chromolaena and combined use of NPK fertilizer and Chromolaena in the cassava-groundnut intercropping system on the tuber yield is shown in Figure 4.19.

Figure 4.19: Cassava tuber yield as affected by Chromolaena application, inorganic fertilizer application and the combined application of Chromolaena and inorganic fertilizer in Zenga and Lemfu study sites. *CH means Chromolaena. Error bars represent standard errors of difference for comparisons of all treatments.*

In both sites, NPK application to cassava significantly ($P = 0.013$) increased the tuber yields by 31 to 60 % relative to the control. This could be explained by the additional nutrient (N, P and K) inputs in the cassava intercropping system (Obigbesan, 1977). This might also result to better photosynthesis activities with NPK application, leading to more photosynthates being produced and translocated. Such effect could be attributed to better tuberdevelopment and production.

The CH treatment significantly ($P = 0.003$ and $P < 0.001$) increased the tuber yields of cassava by 38 to 48 % relative to the control treatment in both sites (Figure 4.19). This finding was in agreement with the previous studies of Pypers *et al.* (2012) in cassava and Oluwafemi (2012) in soybean who reported the improvement of yield by the application of Chromolaena. Howeler (1992) also stated that green manure application might be one of the options to increase soil organic matter and supply N to the cassava plant which was planted after incorporating or mulching of green manure. This could be associated with the increased availability of plant nutrients from a beneficial effect of organic materials by enhancing biochemical activity of micro-organisms (Murthy *et al*., 2010). Organic materials can reduce the P-sorption capacity of soil and increase P availability as well as improve P recovery, leading to better P utilization by plants (Easterwood and Sartain, 1990; Iyamuremye and Dick, 1996; Nziguheba *et al*., 2000; Nziguheba *et al*., 2002). Application of organic residues could also increase microbial activity, C and N mineralization rates, and enzyme activities and thereby affect nutrient cycling (Smith *et al*., 1993). Goyal *et al*. (1999) reported the improvement of fertilizer nutrient efficiency and soil organic matter level by organic inputs. A high level of organic matter in the soil also indicates reduced bulk density, improved soil structure, aeration and high water holding capacity (Hsieh and Hsieh, 1990). Such effect might encourage the plant root development, leading to higher tuberyields.

The tuber yields were significantly ($P = 0.03$ and $P < 0.001$) different between the treatments with combined application of half rate of NPK and CH and the control (Figure 4.19). This finding is in agreement with the previous studies of Pypers *et al*. (2012) in cassava and Murthy *et al*. (2010) in rice who reported the increased yields by the combined application of CH and inorganic fertilizer. Several authors have also reported increased crop yields with the combined application of organic input and inorganic fertilizer (Xiaobin *et al*. (1999) in maize; Mucheru-Muna *et al*. (2011) in maize; Suge *et al*. (2011) in egg plants; Muyayabantu *et al*. (2012) in maize). This might be due to the increased availability and uptake of nutrients as well as nutrient use efficiency by the integrating CH with inorganic fertilizer (Murthy *et al.*, 2010). De Ridder and Van Kaulem (1990) also reported that the combined application of organic input and inorganic fertilizer could result in synergism and improvement of nutrient as well as water use efficiency.

In Lemfu, there were significantly ($P < 0.001$) differences between the ½ (NPK + CH) treatment and the NPK treatment or the CH applied treatment (Figure 4.19). This might be due to the fact that Chromolaena sustains the soil condition suitable for optimal crop yield, leading to reduce the over dependency on inorganic fertilizers which usually increase the cost of production (Anyasi, 2012). This could also be as a result of improved synchronization of nutrient release and uptake by plants (Kapkiyai *et al.*, 1998). Such effect might be contributed to increase fertilizer use efficiency and provide more balanced supply of nutrients (Mugendi *et al.*, 1999; Vanlauwe *et al.*, 2002), leading to higher tuberyield.

4.4.3 Economic analysis as affected by sole NPK, sole Chromolaena and the combined application of NPK and Chromolaena

Profitability differed between sites ($P < 0.001$) (Table 4.8). Lemfu produced higher net benefits from 27 % to 143 % relative to Zenga because of higher cassava tuberyield recorded. The total benefits and net benefits were significantly ($P = 0.004$) differed between the control treatment and the NPK treatments in both sites (Table 4.8).

Table 4.8: Economic analysis in the cassava-groundnut intercropping system, including total benefits (TB), total costs (TC), net benefits (NB), benefit-cost ratio (BCR) and marginal rate of return (MRR), as affected by Chromolaena application, inorganic fertilizer application and combined application of Chromolaena and inorganic fertilizer in Zenga and Lemfu sites

	TB	TC	NB	BCR	MRR
	------------	\$ ha^{-1}	------------	—— \$ \$$^{-1}$	——
Zenga					
Control	2536	1171	1364	2.17	-
NPK	3355	1530	1825	2.19	1.26
CH	3260	1333	1927	2.45	3.47
$^{1}/_{2}$ (NPK+CH)	3225	1506	1720	2.14	1.06
SED (all treatments)	251*		251	0.2	
Lemfu					
Control	3052	1320	1731	2.31	-
NPK	5592	1703	3894	3.29	3.21
CH	4082	1445	2642	2.87	7.3
$^{1}/_{2}$ (NPK+CH)	5942	1769	4173	3.36	5.44
SED (all treatments)	875*		875*	0.5	
SED (site)	354*		354***	0.2**	

CH = *Chromolaena*; SED = standard error of difference; *, ** and *** = $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

The net benefits were increased by \$ 460 to 1226 ha^{-1} in the NPK treatments with a favourable BCR (\$ 2.19 to 3.29 \$$^{-1}$) and a favourable MRR (\$ 1.26 to 3.21 \$$^{-1}$) relative to the control treatments. This might be due to the fact that NPK application increased both yields of groundnut and cassava as compared to the control. The application of Chromolaena (CH) resulted in a significant ($P = 0.01$) increase in net benefits of \$ 562 to 911 ha^{-1} with a favourable BCR (\$ 2.45 to 2.87 \$$^{-1}$) and a favourable MRR (\$ 3.47 to 7.3 \$$^{-1}$) relative to the control in both sites due to the higher storage yields of cassava by the application of CH. Pypers *et al.* (2012) also reported that the net benefit was increased by application of green manure (Chromolaena).

Net benefits in the treatments with the combined use of NPK and Chromolaena application (½ (NPK + CH)) were on average \$ 355 to 2442 ha^{-1} higher than the control treatments in both sites. In Zenga, a MRR was not favourable (MRR less than 1.18 (CIMMYT, 1988) but a BCR remained larger than \$ 2 $\$^{-1}$. Combined use of NPK and Chromolaena application was profitable with a favourable BCR (\$ 2.45 to 2.87 $\$^{-1}$) and a favourable MRR (\$ 3.47 to 7.3 $\$^{-1}$) in Lemfu. The combined application of NPK and CH in the cassava-groundnut intercropping system could enhance the net benefits in both sites. This finding is similar with the previous study of Pypers *et al.* (2012) who found that the combined application of NPK and Chromolaena could improve the net benefits in the pure cassava cropping system.

4.5 The influence of agronomic practices on the productivity of the cassava-legume intercropping systems

The results of this section showed the effects of legume types, plant spacing and planting time on the yields and economic returns in the cassava-legume intercropping systems in Zenga and Lemfu sites.

4.5.1 Effect of legume types on the yields of component crops in the cassava-legume intercropping systems

4.5.1.1 Legume grain yields as affected by legume types

No significant difference was found between the grain yields of the different intercropped legumes (groundnut, soybean and cowpea) in Zenga site (Figure 4.20).

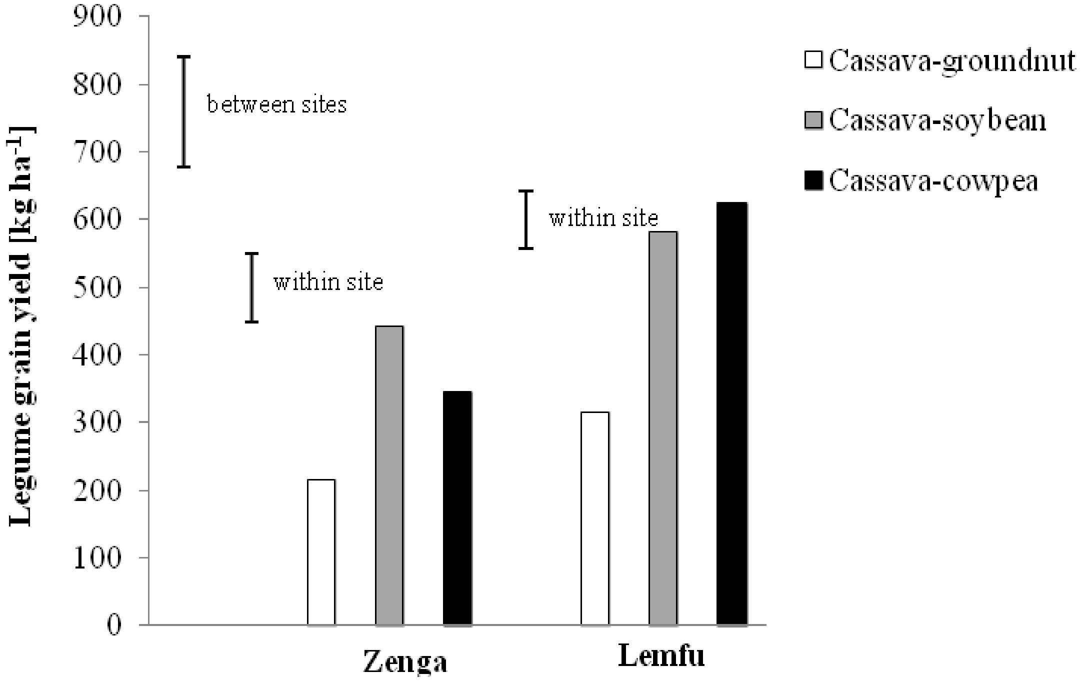


Figure 4.20: Legume grain yields as affected by the different intercropped legumes in cassava-legume intercropping system in Zenga and Lemfu sites. *Error bars represent standard error of difference (SED) for comparison of all treatments.*

Average grain yields recorded about 625 kg ha^{-1} in the cassava-cowpea intercrop and 582 kg ha^{-1} in the cassava-soybean intercrop while cassava intercropping with groundnut recorded about 315 kg ha^{-1} (Figure 4.20). Soybean recorded significantly (P = 0.007) lower grain yields than groundnut. This may be attributed to the same competition capacity of cassava intercropping with legumes, which has the same growth period of 90 days, used in this study.

In Lemfu, the grain yields significantly (P = 0.02) differed between the cassava-soybean intercrop and the cassava-groundnut intercrop. The lower yield of groundnut might be due to the fact that the groundnut plants were infected by the groundnut rosette disease in Lemfu study site since the rosette disease has been responsible for serious losses to groundnut production in Africa (Subrahmanyam *et al.* 2000).

4.5.1.2 Cassava tuber yield as affected by legume types in Zenga and Lemfu sites

There was a significant difference ($P < 0.029$) on the tradable tuber yields between the two study sites (Table 4.9). This might be due to the different soil chemical properties (soil fertility) within the two study sites. This could be caused by variation in rainfall, since this was comparable in both sites.

Table 4.9: Cassava tradable and non-tradable tuber yields as affected by the intercropping with different legumes in the cassava-legume intercropping system in Zenga and Lemfu sites

	Zenga		Lemfu	
	Tradable tuber	Non-tradable tuber	Tradable tuber	Non-tradable tuber
Treatment	ton ha^{-1}			
Cassava-groundnut	16.1	0.7	27.0	1.7
Cassava-soybean	16.2	1.6	34.0	1.2
Cassava-cowpea	15.3	1.3	37.5	1.4
Pure cassava	15.9	1.4	25.9	1.8
SED (treatment)	1.6	0.6	1.9***	0.5
SED (site)	1.6***	0.5		
SED (treatment*site)	3.8*	1.1		

SED = standard error of differences; * and *** = significant at $P < 0.05$ and $P < 0.001$, respectively.

In Zenga, there were no significant differences on both tradable and non-tradable tuber yields of cassava among different legume intercropping systems. This finding was in agreement with previous studies done by Osundare (2007) and Islami *et al.* (2011) in cassava-legume intercrops and Birteeb *et al.* (2011) in maize-forage legume intercrops where intercropping with different legumes did not significantly affect the yields of the component crop. It can be assumed that the different legume plants might have similar competition for resources with the cassava plants due to the same maturity period of legumes (90 days) in this study. In contrast, the type of legume in the intercrop significantly ($P < 0.001$) affected the tradable tuber yields of cassava in Lemfu. The tradable root yields were significantly ($P = 0.002$ and $P < 0.001$) decreased by 21 % and 28 % in intercropping with groundnut over that of intercropping with soybean and cowpea, respectively.

In Zenga site, the groundnut plants were infected by the rosette disease and this infection might reduce the dry matter production of groundnut (www.plantwise.org). This might also reduce the ability of groundnut to improve soil N through BNF (Okito *et al.*, 2004). Consequently, this might lead to the reduction of soil organic matter input to the soil from the decomposition of groundnut biomass which improves physical, chemical and biological properties of the soil and attendant increased crop yields (Gerh *et al.*, 2006). Therefore, this might probably reduce benefits from the groundnut to the cassava plants relative to intercropping with soybean or cowpea. Conversely, significant differences ($P < 0.001$) on the tradable tuber yields were found between the pure cassava and cassava intercropping with different legumes in Lemfu. The intercropping with soybean and cowpea increased the tradable tuber yields by 31 % and 45 %, respectively over the pure cassava. No significant difference on the non-tradable tuber yields was found between the pure cassava and cassava intercropping with different legumes in both sites.

Figure 4.21 shows the effect of intercropping with different legumes on the tuberyields of cassava in the two study sites.

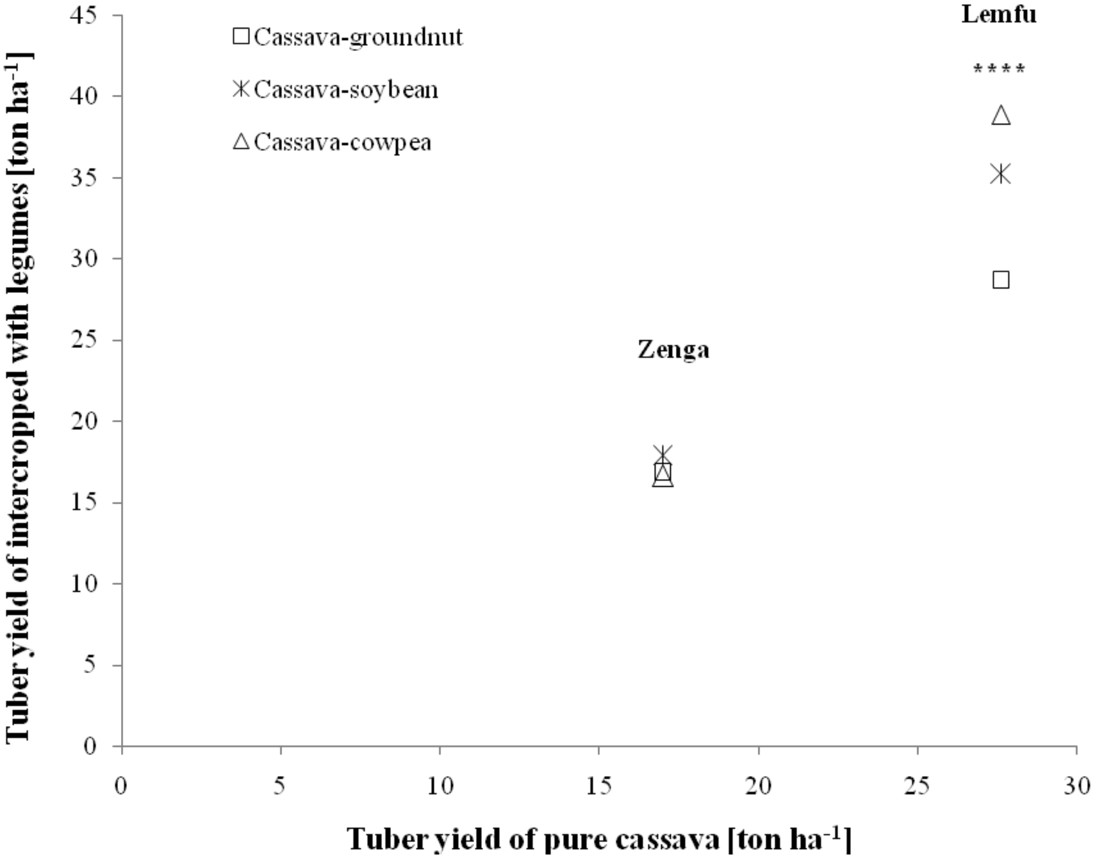


Figure 4.21: Cassava tuber yields as affected by the different intercropped legumes in cassava-legume intercropping systems in Zegna and Lemfu sites. *** = $P < 0.001$.

In Zenga, the tuberyields of cassava were not significantly affected by cassava intercropping with different legumes as compared to the pure cassava. Maximum tuberyields (17.89 ton ha^{-1}) were recorded in the cassava- soybean intercrop (Figure 4.21). This finding was in agreement with several authors (Polthanee and Kotchasatit (1999) in a cassava-mungbean intercrop; Zinsou *et al.* (2005) in a cassava-sorghum intercrop; Sikirou and Wydra (2004) in a cassava-cowpea intercrop; Ennin and Dapaah (2008) in cassava-legume intercrops; Njoku and Muoneke (2008) in a cassava-cowpea intercrop) who observed no significant effect on cassava tuberyields by intercropping. This could also be due to the fact that the intercropped legume matured before competition developed between the two crop species and cassava had time to recover from the competitive effects of the legume (Fukai *et al*., 1990). Thus, cassava tuberinitiation and bulking were not subjected to any intercrop competition, having harvested the legumes earlier before the tuberization process commenced in cassava. In contrast, the intercrop with legume treatments had significant effect on the tuberyields of cassava relative to the pure cassava in Lemfu site. Similarly, several authors {Polthanee *et al.* (2001) in a cassava-legume intercrop; Dung (2002) in a cassava-groundnut intercrop; Dung *et al.* (2005) in a cassava-flemingia intercrop; Osundare (2007) in a cassava-legume intercrop; Mbah *et al.* (2011) in a cassava-okra intercrop} reported the positive effect of intercropping on the cassava root yields as compared to the pure stand.

In Lemfu site, the cassava intercropping with soybean or cowpea significantly ($P < 0.001$) increased the cassava tuberyields over the pure cassava (Figure 4.21). Oguzor (2007), Mbah *et al.* (2010) and Umeh *et al.* (2012) obtained similar results when cassava was intercropped with soybean. Udeata (2005) and Kurtz (2004) also suggested that the presence of legumes in the cassava intercropping system was not detrimental, rather may have been beneficial to the cassava crop. The beneficial effects of legumes result from enriching soil by improving the soil N status, as legumes have the ability to fix N through BNF (Kim, 2005; Aigh, 2007). Thus, the increased cassava root yields can be attributed to improving the N economy of the soil by the legumes. This also could be due to the adding organic matter to the soil through the leaves and stems of legume, which were advantageous to the intercropping system. In addition, this higher productivity of the intercrop system might have resulted from complementary and efficient use of plant growth resources by the component crops (Li *et al.*, 2003; Li *et al.*, 2006). Ghanbari *et al.* (2010) found that intercropping with legumes can increase the land equivalent ratio (LER), light interception and shading in intercropping system as compared to the pure cropping system. They also observed the reduction of water evaporation and improvement of soil moisture conservation by legume intercropping, leading to a yield advantage of intercropping over the pure crop stands. This might be due to the fact that intercropping systems have decreased disease severity (Zinsou *et al.*, 2005) or controlled weed pressure (Amanullah *et al.*, 2007; Olasantan *et al.*, 2007). Conversely, Udealor (2002), Mbah and Ogidi (2012), and Hidoto and Loha (2013) found the reduction of cassava tuberyields by intercropping with soybean as compared to the pure cassava.

In Lemfu, cassava tuberyields were significantly ($P < 0.001$) increased by 41 % in the cassava-cowpea intercropping system relative to the pure cassava. Anilkumar *et al.* (1991) observed similar results of increased cassava root yields by intercropping with cowpea. This finding was not in line with previous findings of several authors (Polthanee *et al.*, 2001; Sikirou and Wydra, 2004; Hidoto and Loha, 2013) who reported that cassava intercropping with cowpea decreased the tuberyield as compared to the pure cassava. Muhr *et al.* (1995) also found that the occurrence of below-ground competition during cassava growth resulted to decrease cassava tuberyields in cassava-legume intercrops.

4.5.1.3 Economic analysis as affected by the different legume types

The total benefits and net benefits were significantly ($P = 0.035$) differed between the intercrop with groundnut and soybean or cowpea in both Zenga and Lemfu sites (Table 4.10).

Table 4.10: Economic analysis, including total benefits (TC), total costs (TC), net benefits (NB), benefit-cost ratio (BCR) and marginal rate of return (MRR) relative to the pure cassava system, as affected by the different legumes in cassava-legume intercropping systems in Zenga and Lemfu sites

	TB	TC	NB	BCR	MRR
	$\$\ \mathrm{ha}^{-1}$			$\$\ \$^{-1}$	
Zenga					
Cassava-groundnut	3354	1465	1888	2.29	D
Cassava-soybean	3673	1279	2394	2.87	1.27
Cassava-cowpea	2062	898	1164	2.30	3.22
Pure cassava	510*		510	0.41	-
SED (all treatments)	306***		306***	0.32***	
Lemfu					
Cassava-groundnut	3992	1350	2642	2.96	0.17
Cassava-soybean	5388	1322	4065	4.07	2.98
Cassava-cowpea	5480	1161	4320	4.72	5.11
Pure cassava	3368	815	2553	4.13	-
SED (all treatments)	415***		415***	0.42***	
SED (site)	780	762			

SED = standard error of differences, *** = $P < 0.001$ and D = dominated treatment (i.e., treatments with lower net benefits with higher total costs, relative to the pure cassava treatment). CG, CS and CC refer to the cassava-groundnut intercrop, the cassava-soybean intercrop and the cassava-cowpea intercrop, respectively.

The lowest total and net benefits were recorded when groundnut was grown as the intercrop in both sites (Table 4.10). This might be partly because of the higher total cost but mostly because of lower groundnut grain yields and cassava tuber yields in the cassava-groundnut interctop relative to the cassava intercropping with soybean or cowpea. Neither of total benefits nor net benefits differed between the cassava intercropping with soybean and cowpea in both sites. Maximum total and net benefits were recorded when cowpea was intercropped with cassava (Table 4.10). This might be due to the fact that cowpea seed was considerably less expensive and the seed rate was lower than groundnut or soybean. This could also be due to the less labour requirement to harvest and thresh cowpea as compared to groundnut or soybean.

The benefit-cost ratios (BCR) were only favourable in both the cassava intercropping with soybean and cowpea in Zenga. In Lemfu, the BCR was significantly lower ($P = 0.028$) in the cassava-groundnut intercrop compared to the cassava intercrop with soybean or cowpea (Table 4.10). Cassava intercropping with soybean or cowpea was more profitable over the pure cassava in both sites. The marginal rate of return (MRR) analysis was only favourable in the cassava intercropping with soybean or cowpea (MRR more than \$ 1.18 $\$^{-1}$). This could be due to higher tuber yields of cassava due to intercropping with soybean or cowpea. Polthanee *et al.* (2001) reported that economic benefits were increased by intercropping with legumes due to the improvement of land use efficiency over the pure cassava. The author also found that the cassava-cowpea intercropping system increased economic benefits over the pure cassava. Maximum MRR was recorded in the cassava-cowpea intercrop (\$ 3.22 to 4.13 $\$^{-1}$) in both sites. This might be due to better cassava tuberyields in the cassava-cowpea intercropping system in both sites recorded.

4.5.2 Effect of cowpea intra-row spacing on crop yields and economic returns in the cassava-cowpea intercropping system

4.5.2.1 Soil physico-chemcial properties in Zenga and Lemfu sites

Some selected physico-chemical properties in Zenga and Lemfu in the cassava-cowpea intercropping system are shown in Table 4.11.

Table 4.11: Soil physico-chemical properties in Zenga and Lemfu sites in the cassava-cowpea intercropping system

Soil parameters	Units	Zenga	Lemfu	Probability
Total soil organic carbon	%	1.26	0.5	***
Total N	%	0.10	0.04	***
Available P	ppm	3.24	1.26	*
pH (H_2O)		5.30	5.32	ns
CEC	$cmol_c\ kg^{-1}$	5.00	1.33	***
Exchangeable K	$cmol_c\ kg^{-1}$	0.12	0.02	***
Exchangeable Ca	$cmol_c\ kg^{-1}$	1.98	0.58	***
Exchangeable Mg	$cmol_c\ kg^{-1}$	0.58	0.21	**
Clay	%	24	18	*
Sand	%	51	78	***
Silt	%	25	4	***
Soil texture		Sandy clay loam	Sandy loam	

*, ** and *** = significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; ns = not significant.

Total soil N, available soil P, exchangeable K^+, Ca^{2+}, Mg^{2+}, silt % and clay % were significantly ($P = 0.001$, $P = 0.045$, $P = 0.001$, $P = 0.01$, $P = 0.004$, $P = 0.005$ and $P = 0.008$) higher in Zenga than in Lemfu, respectively (Table 4.11). These results indicate that soils from Zenga had higher soil fertility status than that of Lemfu. A significant ($P = 0.004$) higher sand % of Lemfu also indicates that soil from Lemfu had low water holding capacity and low ability to hold nutrients as well as more susceptible to leaching of applied nutrients before the plant uptake.

4.5.2.2 Cowpea grain yield as affected by cowpea intra-row spacing

The effect of cowpea intra-row spacing on the yields of cowpea in Zenga and Lemfu sites is shown in Figure 4.22.

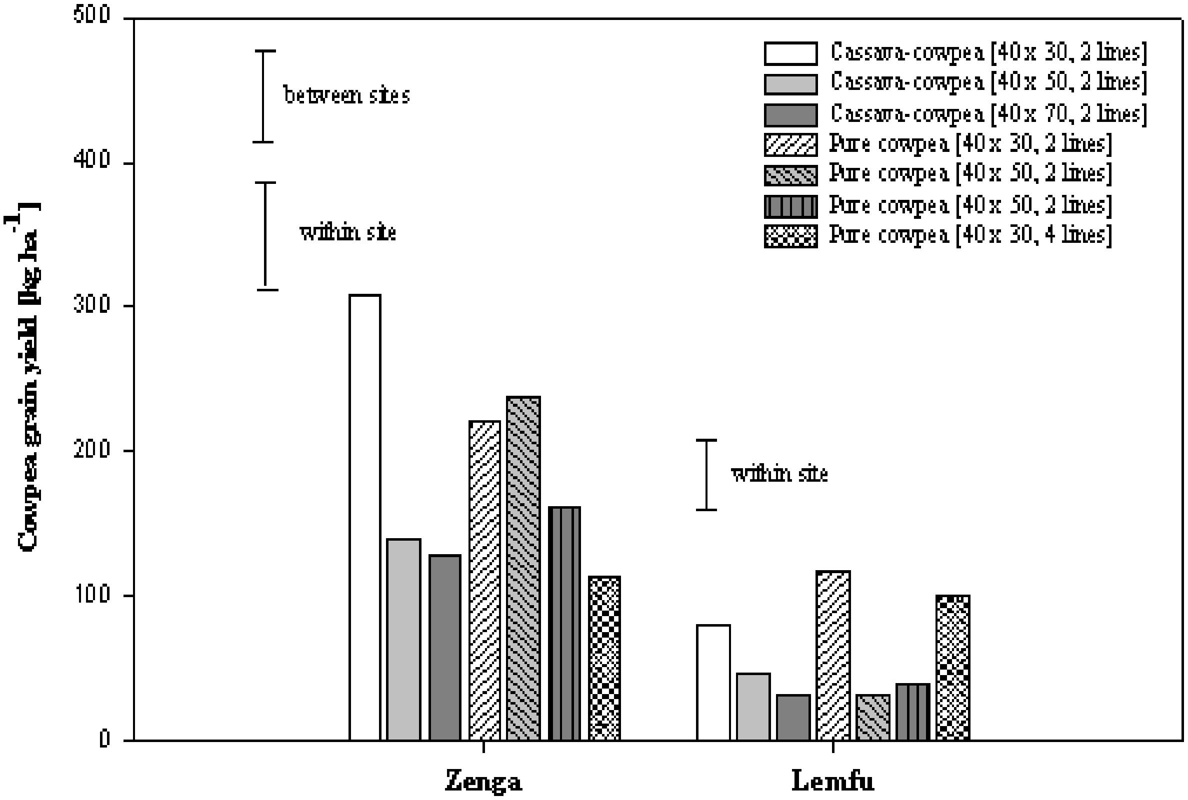


Figure 4.22: Cowpea grain yields as affected by cowpea intra-row spacing in the cassava-cowpea intercropping system in Zenga and Lemfu sites. *Error bars represent standard error of difference (SED) for comparison of all treatments.*

In cassava-cowpea intercropping system, the intra-row spacing of cowpea had no significant effect on grain yields of cowpea in both sites. Maximum average grain yields were recorded at the intra-row spacing of 30 cm (309 and 79 kg ha^{-1}) followed by the intra-row spacing of 50 cm (139 and 47 kg ha^{-1}) and 70 cm (128 and 32 kg ha^{-1}) in Zenga and Lemfu, respectively (Figure 4.22). This could be explained by the fact that the intra-row spacing of cowpea might not have reached the interspecific competition between the plants for resources such as space, light, nutrients and moisture. Similarly, Mariga (1990) in the cowpea-maize intercrop and Njoku and Muoneke (2008) in the cassava-cowpea intercrop reported that grain yields were not affected by the intra-row spacing of cowpea.

In contrast, the previous studies of Udealor (2002) and Mbah and Ogidi (2012) conveyed significant higher grain yields by the higher plant population density of soybean due to better utilization of environmental factors with less interference from the neighboring cassava plants with initial slow growing period in the cassava-soybean intercrop.

In this intercropping system, the grain yields of cowpea at the intra-row spacing of 30 cm were only significantly ($P = 0.048$) higher than those at 70 cm spacing in Zenga. The increase in grain yields might be due to the small ground area around the individual plant which provides early canopy cover, thus capturing light more efficiently and utilizing soil moisture and nutrients more effectively for grain filling (Umar *et al*., 2012). This finding is similar to that of Adipala *et al.* (1998) in the cowpea-sorghum intercrop and Udom *et al.* (2006) in the cowpea-sesame intercrop where the closer intra-row spacing improved the grain yields in the cowpea intercropping system.

In the pure cowpea system, there were no significant differences on cowpea grain yields between the different intra-row spacing (Figure 4.22). This finding is similar to the previous studies of Miko and Manga (2008) in sorghum, Wailare (2010) in pearl millet and Malami and Samáila (2012) in cowpea; where the grain yields were not affected by the spacing regime. Highest grain yield was recorded at the intra-row spacing of 30 cm (294 kg ha^{-1}) followed by the intra-row spacing of 50 cm (286 ha^{-1}) and 70 cm (162 kg ha^{-1}) in Zenga (Figure 4.22). In Lemfu, maximum average grain yield was recorded at the intra-row spacing of 30 cm (156 kg ha^{-1}) followed by the intra-row spacing of 70 cm (37 kg ha^{-1}) and 50 cm (40 kg ha^{-1}) (Figure 4.22).

No significant difference on the grain yields was found between the intra-row spacing of 30 cm with 2 lines and 4 lines in both sites (Figure 4.22). This indicates that the intra-row spacing of cowpea was not subjected to the grain yields of cowpea in the pure stand. The present finding was in contrast to the studies by Caliskan *et al.* (2004) in sesame, Sener *et al.* (2004) in maize, Agbaje *et al.* (2012) in kenaf, Hassan and Arif (2012) in mustard, Shahsavari (2012) in red castor and Umar *et al.* (2012) in sesame; who reported that the intra-row spacing significantly affected the grain yields of component crops. Higher average grain yields were recorded at the intra-row spacing of 30 cm with 2 lines in both sites (Figure 4.22).

In both sites, cowpea grain yields were not significantly decreased by intercropping with cassava at all intra-row spacing as compared to the pure cowpea. Similarly, Leihner (2002) stated that the grain yield of legumes did not vary greatly in response to planting densities within a relative wide range In contrast, Fatokun *et al.* (2000) in cowpea, Acikgoz *et al.* (2009) and Shamsi and Kobraee (2011) in soybean observed that the grain yields were significantly influenced by the plant population density.

Intercropping with cassava had no influence on the grain yields of cowpea in all intra-row spacing relative to the pure cowpea in both sites. It can be assumed that intercropping with cassava may not have reached the interspecific competition between the intercrop components for growth resources and the depressive effect of cassava. This might be explained by the suitable compatibility of cowpea and cassava as intercrops due to the wide maturity period gap between cowpea (3 months) and cassava (12 months) and the slow initial growth of cassava. In addition, this may be attributed to the different growth habits of the two crop species where cowpea is low growing and cassava has erect growth. A similar result was also reported by Njoku and Muoneke (2008) in a cassava-cowpea intercrop. In contrast, Mason *et al.* (1986) found that cowpea intercropping with cassava produced lower grain yields than that of the pure cowpea.

Cowpea grain yields were significantly ($P < 0.001$) different between the two study sites. Zenga site produced about 314 % higher cowpea grain yields as compared to Lemfu site. This might be due to the better soil chemical properties of Zenga than those of Lemfu (Table 4.11).

Although inorganic fertilizer was applied to cowpea plants, the grain yields of cowpea recorded were very low in both study sites. For instance, the grain yields ranged between 152 to 309 kg ha^{-1} in Zenga, while in Lemfu they ranged between 32 to 134 kg ha^{-1} (Figure 4.22). The yields of cowpea were lower than the range of yields (350 to 700 kg ha^{-1}) attained by the farmers in Africa which is reported by Ogbuinya (1997). These low yields could be due to high weed pressure, pests and diseases and poor soil structure.

4.5.2.3 Cowpea biomass yield as affected by cowpea intra-row spacing

The influence of cowpea intra-row spacing on cowpea biomas yield in both Zenga and Lemfu sites is shown in Figure 4.23.

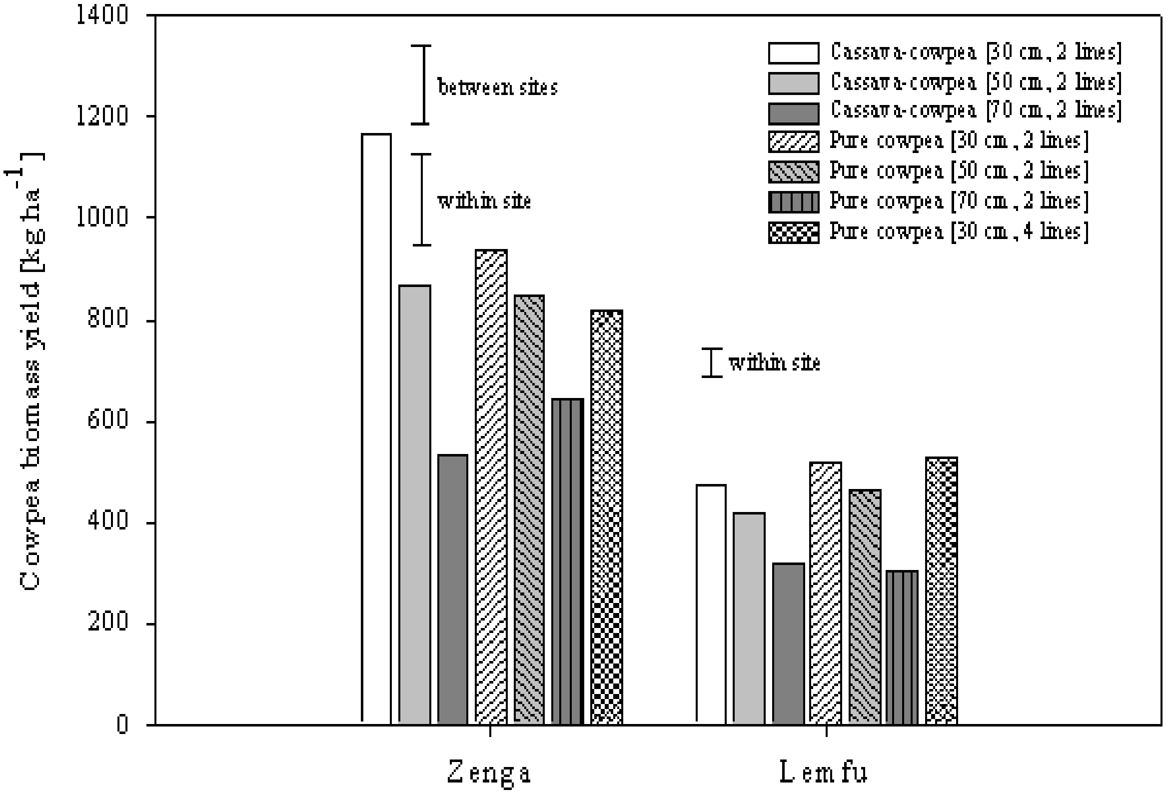


Figure 4.23: Groundnut biomass yield as affected by variety and inorganic fertilizer application in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments. L and IG mean the local variety and improved variety, respectively.*

In cassava-cowpea intercropping system, the intra-row spacing of cowpea had no significant effect on cowpea biomass yields in both sites. In contrast, Adipala *et al.* (1998) reported that the intra-row spacing of cowpea had significantly affected the biomass production of cowpea in the cowpea-sorghum intercropping system. Maximum biomass yields were recorded at the intra-row spacing of 30 cm (1169 and 472 kg ha^{-1}) followed by the intra-row spacing of 50 cm (870 and 417 kg ha^{-1}) and 70 cm (535 and 319 kg ha^{-1}) in Zenga and Lemfu, respectively.

In this intercropping system, biomass yields recorded a significant (P = 0.004) increase of 119 % and 48 % at the intra-row spacing of 30 cm over that of intra-row spacing of 70 cm in Zenga and Lemfu, respectively. This might be probably due to better utilization of light by the closer spacing of plants, resulting into higher biomass production for grain filling at the closer intra-row spacing of 30 cm. This finding was in line with the previous study of Adipala *et al.* (1998) where the closer intra-row spacing improved the biomass production in the cowpea-sorghum intercrop.

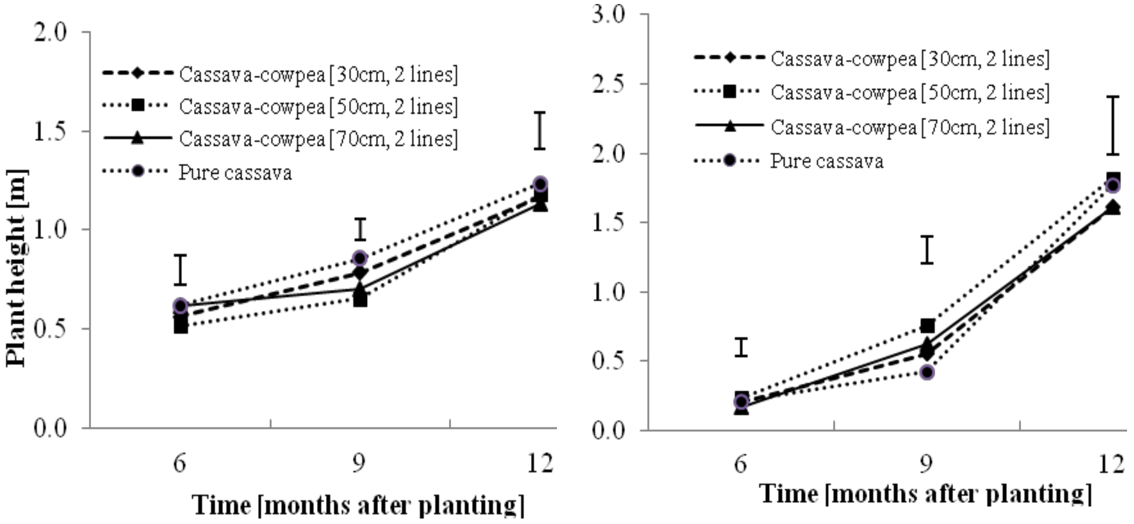
In the pure cowpea, there were no significant differences on biomass yields between the intra-row spacing treatments in the two study sites except in Lemfu where the intra-row spacing of 30 cm produced significantly ($P = 0.039$) higher biomass yield than that of 70 cm intra-rowspacing. Similarly, Miko and Manga (2008), Wailare (2010) and Malami and Samáila (2012) reported that the biomass yields of pearl millet, sorghum and cowpea were not significantly affected by the intra-row spacing. Conversely, the biomass yields were also significantly influenced by the intra-row spacing in summer maize (Liu *et al.*, 2010), in red castor (Shahsavari, 2012) and wheat (Naseri *et al.*, 2012). Maximum biomass yields were recorded at the intra-row spacing of 30 cm (939 and 516 kg ha^{-1}) followed by the intra-row spacing of 50 cm (846 and 465 kg ha^{-1}) and 70 cm (641 and 306 kg ha^{-1}) in Zenga and Lemfu, respectively.

The effect of plant population density of cowpea had no significant effect on the biomass yields as there were no significance differences on the biomass yields between the intra-row spacing of 30 cm with 2 lines and 4 lines in both sites. In contrast, Liu *et al.* (2010) and Naseri *et al.* (2012) found the effect of the plant population density in summer maize and wheat, respectively.

In both sites, the biomass yields were not significantly affected when cowpea was sown by varying intra-row spacing as compared to the pure cowpea. This seems to be a good compatibility of the two crops for cowpea biomass production under a given environmental condition. This could be due to the fact that the canopy of cassava plants had started closing up after cowpea harvest. Similar results were also found by Njoku and Muoneke (2008) in the cassava intercropping with cowpea. In contrast, Oseni and Aliyu (2010) reported that biomass yields were higher in the pure cowpea than in cowpea intercroped with sorghum. Zenga produced significantly ($P < 0.014$) about 95 % higher cowpea biomass yields than Lemfu. This might be due to the better soil chemical properties (soil fertility) of Zenga than those of Lemfu (Table 4.11).

4.5.2.4 Cassava plant height as affected by cowpea intra-row spacing

The results of the effect of cowpea intra-row spacing on the plant height of cassava observed at different times after planting in the two study sites are shown in Figure 4.24 (a) and (b).



(a) Zenga

(b) Lemfu

Figure 4.24: Cassava plant heights at different times after planting, as affected by the cowpea intra-row spacing. *Error bars represent standard error of difference (SED) for comparison of all treatments with time after planting.*

The intra-row spacing of cowpea had no significant influence on the plant height of cassava in the two study sites. This might be probably because the cowpea intra-row spacing used in this study might not have reached crowding and the interspecific competition for light. Similar results had been reported by Aduramigba and Tijani-Eniola (2001) in the groundnut-cassava intercrop and Njoku and Muoneke (2008) in the cowpea-cassava intercrop. This findings were however not in line those of Badi *et al.* (2012) who reported that that the plant height was significantly affected by the intra-row spacing since the intra-row spacing is one of the factors contributing plant density in a plot which resulted in competition for space, light, moisture and nutrients..

The cassava intercropping with cowpea at all intra-row spacing also had no significant influence on the plant height at any time relative to the pure cassava. This might be due to the fact that the cowpea might not have reached the interference for light to the neighboring cassava plants. This finding was in line with studies by Aduramigba and Tijani-Eniola (2001) in the cassava-groundnut and Njoku and Muoneke (2008) in the cassava-cowpea intercrop, who reported no effect of intercropping on cassava plant height over the pure cassava. In contrast, Amanullah *et al.* (2007) stated that when cassava intercropped with cowpea the reduction of plant height was found due to the smothering effect of the luxuriant vegetative growth of cowpea before the fifth month, after which this effect was lessened. Prabhakar and Nair (1992) also observed the effect of intercropping on the plant height of cassava when cassava intercropped with groundnut.

4.5.2.5 Cassava tuber yield as affected by cowpea intra-row spacing

The effect of cowpea intra-row spacing on the tuber yields of cassava in Zenga and Lemfu sites was shown in Figure 4.25. No significant difference on the tuber yields between the two sites was found.

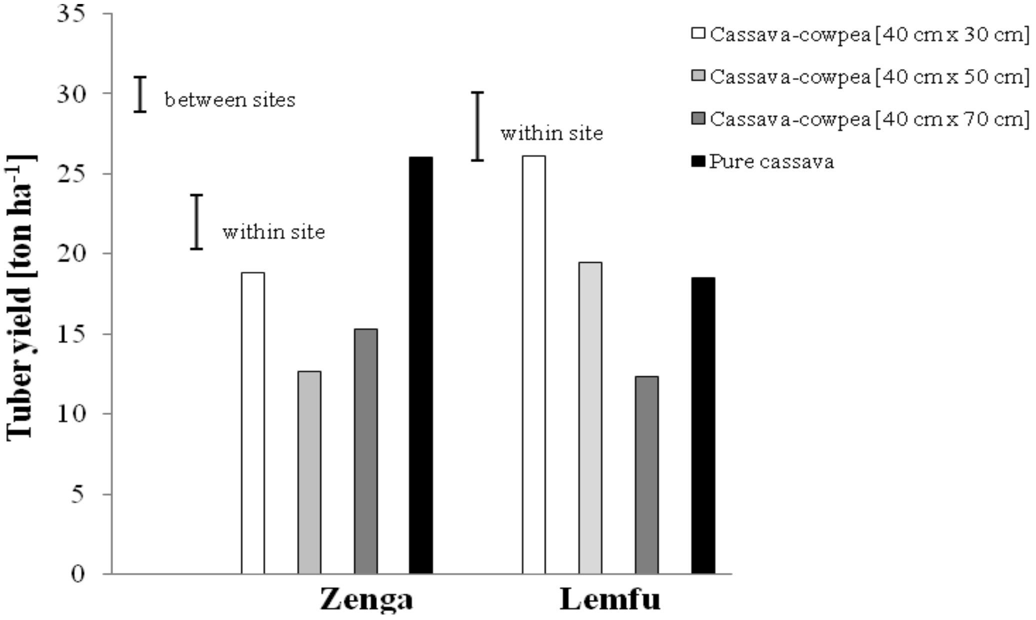


Figure 4.25: Cassava tuber yields as affected by cowpea intra-row spacing. *Error bars represent standard errors of difference for comparisons of all treatments.*

The intra-row spacing of cowpea had no significant influence on the cassava tuber yields in both sites. Conversely, Ijoyah *et al.* (2012) found that the yields of egusi melon were significantly affected by varying intra-row spacing of maize in the egusi-maize intercropping system. Jagtap *et al.* (1998), Eke-Okoro *et al.* (1999), Njoku *et al.* (2010) also reported that cassava tuber yields were significantly increased by decreasing the intra-row spacing of cowpea as a result of incremental contribution of nitrogen by high population of cowpea in cassava-cowpea intercropping system. Maximum tuberyield of cassava was recorded at the intra-row spacing of 30 cm (19 ton ha^{-1}) followed by the intra-row spacing of 70 cm (15 ton ha^{-1}) and 50 cm (13 ton ha^{-1}) in Zenga. In Lemfu, maximum tuber yield was recorded at the intra-row spacing of 30 cm (23 ton ha^{-1}) followed by the intra-row spacing of 50 cm (17 ton ha^{-1}) and 70 cm (22 ton ha^{-1}).

There were also no significant differences on the tuberyields between the pure cassava and the cassava-cowpea intercropping system in both sites, with the exception of the intra-row spacing of 50 cm in Zenga which only significantly (P = 0.007) decreased by 51 % relative to the pure cassava. This indicates that cowpea crops may be compatible in cassava intercropping system. This implies that cassava tuber initiation and bulking were not subjected to any interspecific competition of component crops, having harvested cowpea earlier before an increase rate of tuberization. This finding was in agreement with previous studies in the cassava-cowpea intercropping system by Savithri and Alexander (1995) and Njoku and Muoneke (2008). In contrast, Sikirou and Wydra (2004) found the reduction of cassava tuberby intercropping with cowpea. Polthanee *et al.* (2001), and Hidoto and Loha (2013) reported that the intercropping with cowpea decreased the tuberyields of cassava by up to 37 % depending on the growth habits and vegetative development of the crops in the cassava-cowpea intercropping trials in South America (CIAT, 1993; Polthanee *et al.*, 2001). No significant difference on the tuber yields between the two sites was found.

4.5.2.6 Cassava stem yield as affected by cowpea intra-row spacing

The results of cowpea intra-row spacing affecting on cassava stem yields in Zenga and Lemfu was shown in Figure 4.26.

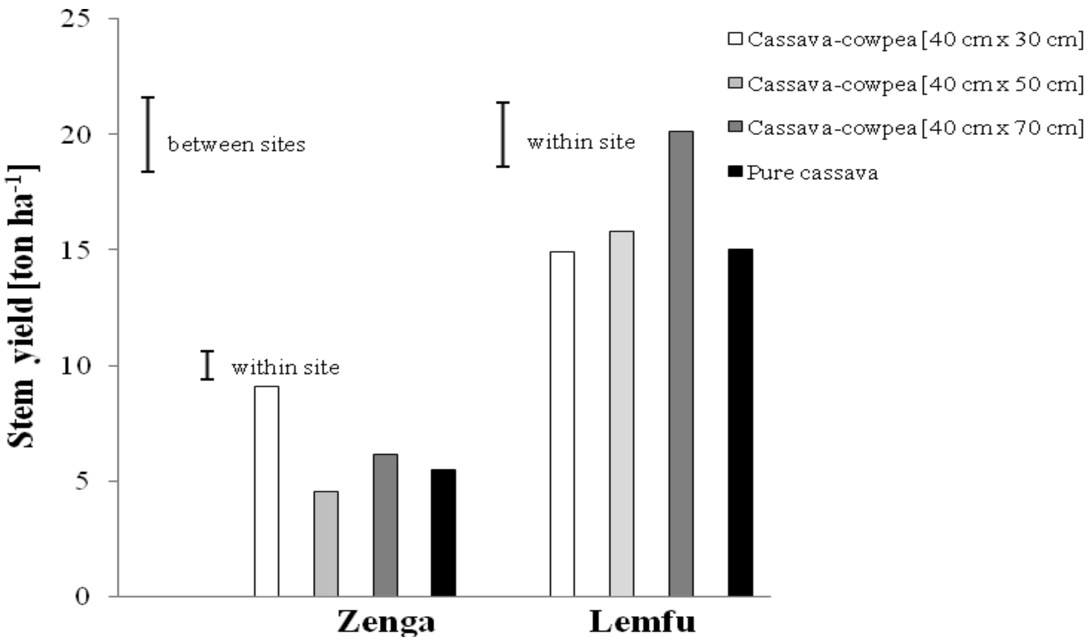


Figure 4.26: Cassava stem yields as affected by the intra-row spacing of cowpea in the cassava-cowpea intercropping system in Zenga and Lemfu sites. *Error bars represent standard errors of difference for comparisons of all treatments.*

The intra-row spacing of cowpea had no significant influence on the cassava tuberyields in both sites (Figure 4.26). Conversely, Ijoyah *et al.* (2012) found that the yields of egusi melon were significantly affected by varying intra-row spacing of maize in the egusi-maize intercropping system. Jagtap *et al.* (1998), Eke-Okoro *et al.* (1999), Njoku *et al.* (2010) reported that cassava tuberyields were significantly increased by decreasing the intra-row spacing of cowpea as a result of incremental contribution of nitrogen by high population of cowpea in cassava-cowpea intercropping system. Maximum tuberyield of cassava was recorded at the intra-row spacing of 30 cm (19 ton ha^{-1}) followed by the intra-row spacing of 70 cm (15 ton ha^{-1}) and 50 cm (13 ton ha^{-1}) in Zenga. In Lemfu, maximum tuberyield was recorded at the intra-row spacing of 30 cm (23 ton ha^{-1}) followed by the intra-row spacing of 50 cm (17 ton ha^{-1}) and 70 cm (22 ton ha^{-1}).

There were also no significant differences on the tuber yields between the pure cassava and the cassava-cowpea intercropping system in both sites, with the exception of the intra-row spacing of 50 cm in Zenga which only significantly (*P* = 0.007) decreased by 51 % relative to the pure cassava. This indicates that cowpea crops may be compatible in cassava intercropping system. This implies that cassava tuber initiation and bulking were not subjected to any interspecific competition of component crops, having harvested cowpea earlier before an increase rate of cassava tuberization. This finding was in agreement with previous studies in the cassava-cowpea intercropping system by Savithri and Alexander (1995) and Njoku and Muoneke (2008). In contrast, Sikirou and Wydra (2004) found the reduction of cassava tuber by intercropping with cowpea. Polthanee *et al.* (2001), and Hidoto and Loha (2013) also reported that the intercropping with cowpea decreased the tuberyields of cassava by up to 37% depending on the growth habits and vegetative development of the crops in the cassava-cowpea intercropping trials in South America (CIAT, 1993; Polthanee *et al.*, 2001).

4.5.2.7 Land use efficiency as affected by cowpea intra-row spacing

In this study, the total LER of cowpea and cassava in the intercrop at different cowpea intra-row spacing were all above 1.0 ranging from 1.35 to 2.17 (Zenga) and 1.85 to 2.35 (Table 4.12).

Table 4.12: Land equivalent ratio (LER) of cassava-cowpea intercropping system as affected by the intra-row spacing of cowpea in Zenga and Lemfu sites

	Partial LER		Total LER
Treatment	Cowpea	Cassava	Cowpea + cassava
Zenga			
40 cm x 30 cm	1.39	0.8	2.17
40 cm x 50 cm	0.85	0.5	1.35
40 cm x 70 cm	0.85	0.57	1.42
overall	1.03	0.62	1.65
SED (all treatments)	0.51	0.14	0.48
Lemfu			
40 cm x 30 cm	0.87	1.07	1.93
40 cm x 50 cm	1.55	0.8	2.35
40 cm x 70 cm	0.84	1.01	1.85
overall	1.09	0.96	2.04
SED (all treatments)	0.41	0.18	0.54
SED (sites)	0.28	0.12	0.22

In cassava-cowpea intercropping system, the intra-row spacing of cowpea had no significant influence on the tuber yields of cassava in both study sites, except in Zenga where cassava tuber yields were significantly ($P = 0.035$) increased by 100 % at the intra-row spacing of 30 cm as compared to that of 50 cm. This might be due to the fact that cassava is a tall crop of long duration with slow initial growth cover and cowpea matures normally when cassava is just attaining maximum canopy development. This finding was in contrast to the findings by Borin and Frankow-Lindberg (2005), who reported the reduction of stem yields by intercropping with legumes as compared to the pure cassava stand. The cassava intercropping with cowpea at varying intra-row spacing of cowpea had no significant effect on the tuber yields as compared to the pure cassava. This indicates that the presence of cowpea in the cassava-cowpea intercrop was not detrimental to cassava stem yields.

There were significant ($P < 0.0001$) differences on the tuber yields between the two study sites. Lemfu produced 172 % higher tuber yields of cassava than Zenga although the soil chemical properties (soil fertility) were significantly higher in Zenga site relative to Lemfu site (Table 4.11). This could also be caused by variation in rainfall which was comparable in both sites (Figure 4.1).

4.5.2.8 Economic analysis as affected by cowpea intra-row spacing

In cassava-cowpea intercropping system, the intra-row spacing of 30 cm had the highest net benefits ($ 1395 and 1306 ha^{-1}) followed by that of the intra-row spacing of 70 cm ($ 783 and 1117ha^{-1}) and 50 cm ($ 625 and 720 ha^{-1}) in Zenga and Lemfu, respectively (Table 4.13).

Table 4.13: Economic analysis, including total benefits (TB), total costs (TC), net benefits (NB) and benefit-cost ratio (BCR), as affected by the intra-row spacing of cowpea in cassava-legume intercropping systems in Zenga and Lemfu sites

Treatment	TB	TC	NB	BCR
		$ ha^{-1}		$ $$^{-1}$
		Zenga		
Cassava-Cowpea (30 cm, 2 lines)	2563	1168	1395	2.19
Cassava-Cowpea (50 cm, 2 lines)	1763	1138	625	1.55
Cassava-Cowpea (70 cm, 2 lines)	1901	1117	783	1.70
Pure cassava	2592	808	1784	3.21
Cowpea (30 cm, 2 lines)	573	609	-36	0.94
Cowpea (50 cm, 2 lines)	558	579	-21	0.96
Cowpea (70 cm, 2 lines)	317	558	-241	0.57
Cowpea (30 cm, 4 lines)	297	753	-456	0.39
SED (treatment)	297***		291***	0.34***
		Lemfu		
Cassava-Cowpea (30 cm, 2 lines)	2514	1208	1306	2.08
Cassava-Cowpea (50 cm, 2 lines)	1889	1169	720	1.62
Cassava-Cowpea (70 cm, 2 lines)	2257	1140	1117	1.98
Pure cassava	2343	774	1569	3.03
Cowpea (30 cm, 2 lines)	304	615	-311	0.49
Cowpea (50 cm, 2 lines)	73	527	-454	0.14
Cowpea (70 cm, 2 lines)	78	499	-421	0.16
Cowpea (30 cm, 4 lines)	263	733	-470	0.36
SED (treatment)	258***		267***	0.20***
SED (site)	299		267	0.31

SED = standard error of difference, **** = $P < 0.001$.

The intra-row spacing of 30 cm significantly ($P = 0.02$) increased the total benefits and the net benefits as compared to the intra-row spacing of 50 cm in Zenga site (Table 4.13). This might be due to the positive effect on the cassava tuberyields at the intra-row spacing of 30 cm over that of 50 cm. However, neither the total benefits nor the net benefits differed between the intra-row spacing of 50 cm and 70 cm in both sites. The benefit-cost ratio (BCR) was only favourable (BCR greater than $ 2 $$^{-1}$) in the cowpea intra-row spacing of 30 cm in both sites (Table 4.13). This might be due to the higher average cowpea grain yields and cassava tuberyields at the intra-row spacing of 30 cm. In the pure cowpea, none of the cowpea intra-row spacing significantly increased the total benefits, the net benefits and BCR in both sites, indicating that there was no economic benefit from varying the intra-row spacing of cowpea in the two study sites. In Zenga, the pure cassava was more profitable than cassava-cowpea intercropping system at the intra-row spacing of 50 cm or 70 cm. However, no significant differences on the net benefits were observed between the pure cassava and the intercropping with cowpea at the intra-row spacing of 30 cm.

In Lemfu, there were no significant differences on the net benefits between the pure cassava and the cassava-cowpea intercropping at the intra-row spacing of 30 cm or 70 cm (Table 4.13). However, the net benefits significantly differed between the pure cassava and the cassava-cowpea intercropping at the intra-row spacing of 50 cm. The BCR of the pure cassava was significantly higher ($P = 0.018$) than that of the cassava-cowpea intercropping at all intra-row spacing in both sites. This might be due to the fact that the additional net benefits from cowpea did not cover the additional cost of cowpea in the cassava intercrop. There were no significant differences on the net benefits and

BCR between the intra-row spacing of 30 cm with 2 lines and 4 lines, indicating that there was no economic benefit in increasing cowpea population in the pure cowpea system in both sites. BCR vaules were unfavourable (< 2) in the treatments of the pure cowpea systems in both sites. This could be attributed to the infection of cowpea aphids that reduce the production of cowpea in Africa (Egho (2011).

4.5.3 Effect of cassava planting time on the crop yields and economic returns in the cassava-groundnut intercropping system

Some selected soil physic-chemical properties in Zenga are shown in Table 4.14.

Table 4.14: Selected physico-chemical soil properties in Zenga site before planting in the cassava-groundnut intercropping system

Soil parameters	Units	Zenga
pH (H_2O)	%	6.11
Total N	%	0.13
Available P	mg kg^{-1}	3.53
Total soil organic carbon	cmol$_c$ kg^{-1}	3.12
CEC	cmol$_c$ kg^{-1}	7.33
Exchangeable K	cmol$_c$ kg^{-1}	0.23
Exchangeable Ca	cmol$_c$ kg^{-1}	4.23
Exchangeable Mg	cmol$_c$ kg^{-1}	1.16
Clay	%	22.14
Sand	%	51.77
Silt	%	25.02

4.5.3.1 Groundnut grain yields as affected by the relative planting time of cassava in Zenga site

The relative planting time of cassava had no significant influence on the grain yields of groundnut in the cassava-groundnut intercrop in both short rain and long rain (Figure 4.27).

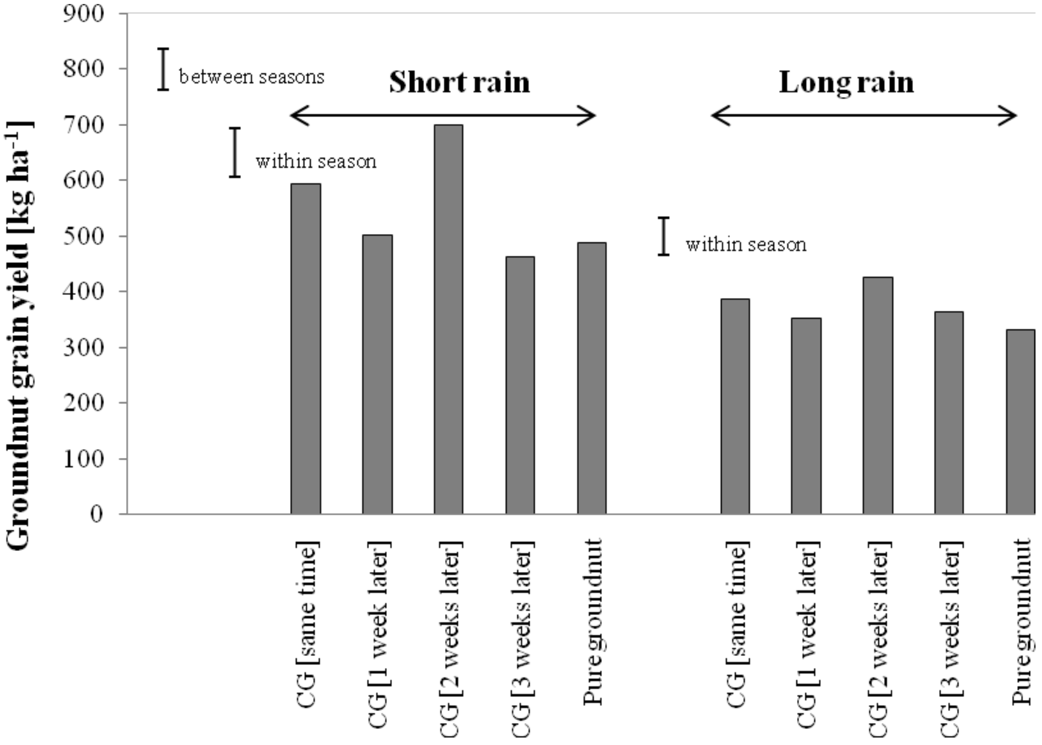


Figure 4.27: Groundnut grain yields as affected by the relative planting time of cassava in short rain and long rain in Zenga site. *Error bars represent standard error of difference (SED) for comparisons of all treatments. CG refers to the cassava-groundnut intercrop.*

Maximum grain yields (699 kg ha^{-1} and 426 kg ha^{-1}) were recorded in the treatment of cassava planted 2 weeks after the groundnuts in both short rain and long rain (Figure 4.27). The grain yields were only significantly ($P = 0.01$) different between the treatments of cassava planted 2 weeks and 3 weeks after the groundnuts in short rain (Figure 4.27). The grain yield of groundnut was not significantly influenced by intercropping with cassava in both seasons except in short rain where a significant ($P = 0.015$) difference on grain yields between the cassava-groundnut and the pure cassava planted 2 weeks after the groundnuts was found. There was a significant ($P = 0.0007$) difference on the grain yields between the two seasons.

Though there was no effect of cassava planting time on groundnut grain yield in the cassava-groundnut intercrop, other studies (Agyekum, 2004; Addo-Quaye *et al.*, 2001a; 2001b) have reported the decreased grain yields as a result of relative planting time of the crop who reported the decreased grain yields by the relative planting time of the crop which has been contributed to the interspecific competition between the two crops for resources (Assefa and Ledin, 2001) and shading by the early established crop (Misbalhumanir *et al.*, 1989).

When cassava was planted 2 weeks after the groundnut in short rain, the grain yield was higher over the cassava planted 3 weeks after the groundnuts. This could be attributed by higher rainfall in the period of third week than fourth week of April, 2011 (Figure 4.27). The result implies that the intercropping with groundnut had no influence on groundnut grain yield relative to the pure groundnut. Since cassava has a slow early growth (Lebot, 2009), resulting in slow canopy formation (Putthacharoen, 1998) and groundnut matures after attaining maximum canopy development of cassava, there is a competition gap between the periods when each of the component crops is making critical demands for growth resources such as light, water and nutrients (Trenbath, 1974). This could also be contributed by different growth habits between the two crops where groundnut is low growing and cassava has erect type. Conversely, Polthanee *et al.* (2001) found a significant effect of cassava on groundnut grain yield when cassava was planted at the same time as the groundnuts.

The short rain produced more grain yield, about 28 to 54 % higher than long rain. This could probably be due to lower rainfall distribution in October, 2011 resulting in relatively lower germination percentage of groundnut (about 21 %) relative to April, 2011 (Figure 4.3). Grain yields of groundnut was lower than the range of yields attained under farmers' field conditions in Africa which were reported by Freeman *et al.* (1999) to be estimated only 700 kg ha^{-1} in groundnut. These low yields could be attributed to high weed pressure, pests and diseases and poor structure of the soil in the study sites, at the Bas-Congo, DR. Congo (CIALCA, 2009a).

4.5.3.2 Groundnut biomass yield as affected by the relative planting time of cassava

No significant effect of cassava planting time on the biomass yields of groundnut in the cassava-groundnut intercrop was found in both seasons (Figure 4.28).

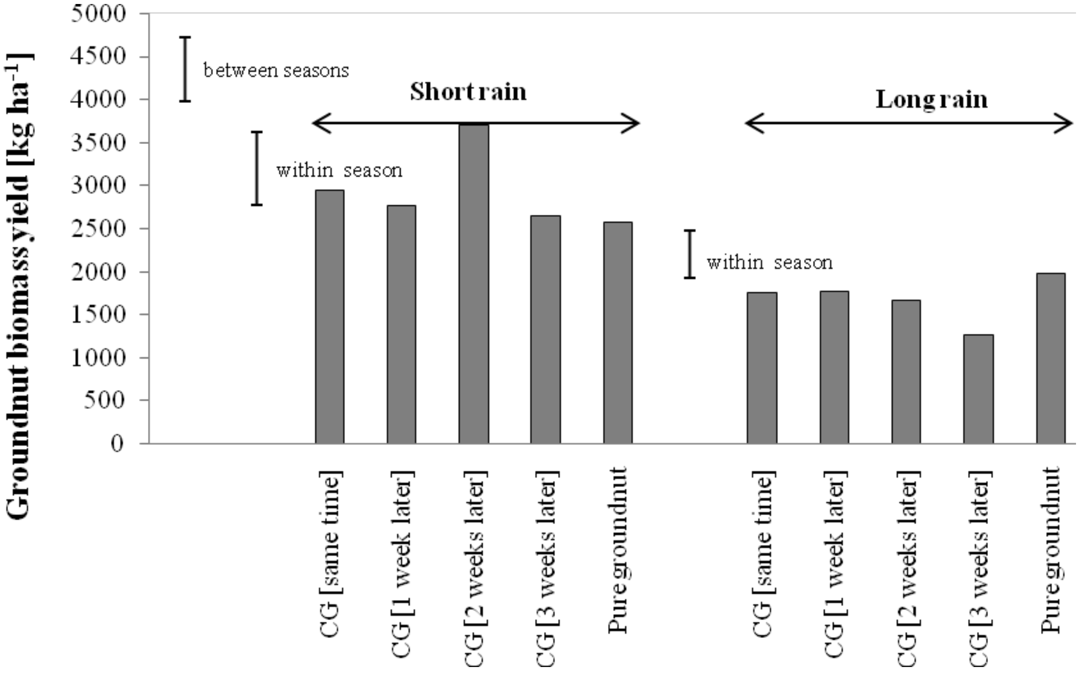


Figure 4.28: Groundnut biomass yields as affected by the relative planting time of cassava in short rain and long rain in Zenga site. *Error bars represent standard error of difference (SED) for comparisons of all treatments. CG refers to the cassava-groundnut intercrop.*

Maximum biomass yields (3700 kg ha^{-1} and 1775 kg ha^{-1}) were recorded in the cassava planted 2 weeks after the groundnuts in short rain and in the cassava planted 1 week after the groundnuts in long rain, respectively. The intercropping with groundnut at all cassava planting times had no significant influence on groundnut biomass yields relative to the pure groundnut in both seasons. This might be due to the fact that the relative planting time of cassava used in this study might not have reached the interspecific competition for resources such as space, light, moisture and nutrient. The result indicates that intercropping with cassava had no influence on groundnut biomass yield in the cassava-groundnut intercrop. This could be attributed to the slow early development of cassava (Udealor and Asiegbu, 2005; Njoku and Muoneke, 2008) which might not reach the interspecific competition for resources (space, light, moisture and nutrients) with the groundnut crop. This might also be due to the suitable compatibility of the two crops as intercrops due to the wide maturity gap. This is in line with previous finding of Njoku and Muoneke (2008) in the cassava-cowpea intercrop. Conversely, Dung *et al.* (2005) found a significant effect of cassava on the biomass yields of Flemingia in the cassava-Flemingia intercrop.

4.5.3.3 Cassava tuber yield as affected by the relative planting time of cassava

The relative planting time of cassava had a significant (*P* = 0.045) influenced on the tuberyields of cassava in both seasons (Figure 4.29).

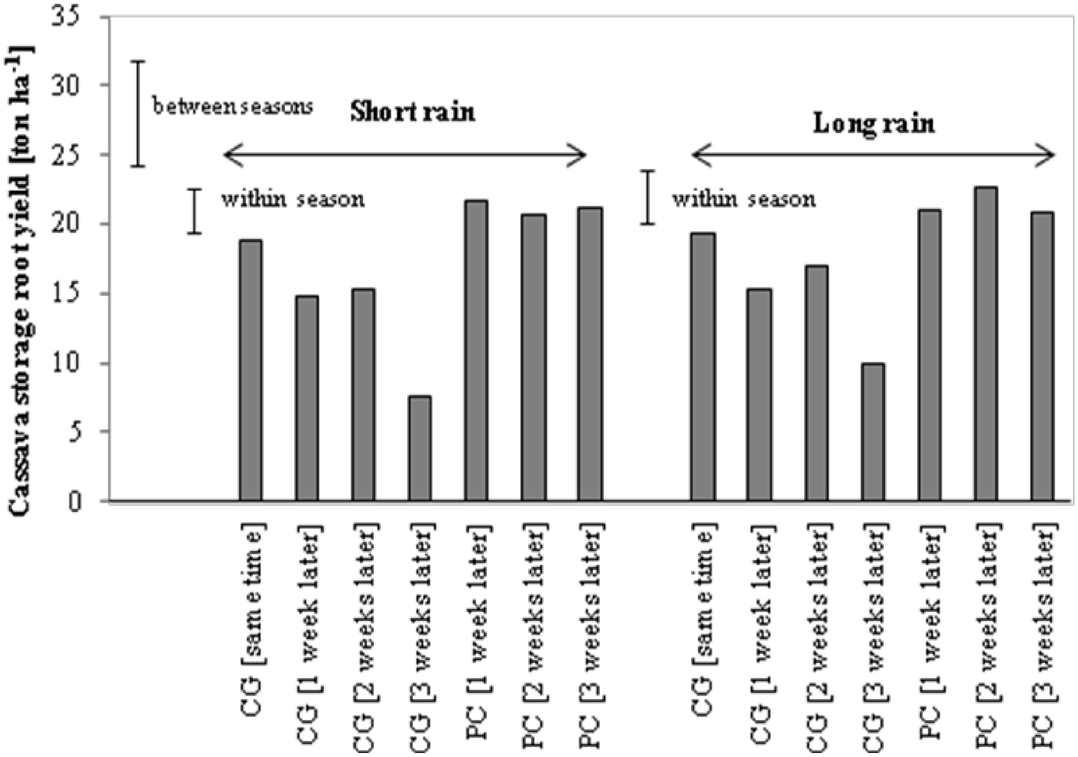


Figure 4.29: Cassava tuber yields as affected by the relative planting time of cassava in short rain and long rain in Zenga site. *Error bars represent standard error of difference (SED) for comparisons of all treatments. CG and PC mean the cassava-groundnut intercrop and the pure cassava cropping system, respectively.*

When cassava was planted 3 weeks after the groundnut, the tuberyields were significantly (*P* = 0.037 and *P* = 0.042) decreased by 60 % and 63 % in short rain and long rain, respectively relative to cassava planted at the same time as groundnut. For the pure cassava cropping system, there was no significant effect of cassava planting time on cassava storage yields in both short rain and long rain. The effect of intercropping with groundnut on the tuberyields was not observed in both seasons. The tuberyield was only significantly (*P* = 0.019 and *P* = 0.001) decreased by 64 % and 73 % in the cassava intercrop 3 weeks after the groundnut as compared to the relative treatment of pure cassava in short rain and long rain, respectively.

The relative planting time of cassava had influence on the tuberyields of cassava in the cassava-groundnut intercrop. Cassava planted 3 weeks after the groundnut significantly decreased cassava tuberyields as compared to cassava planted at the same time as groundnut in the cassava-groundnut intercrop. This might be due to the interspecific competition for growth resources (space, water and nutrients) between the two crops and shading by groundnut plants to cassava when cassava was planted 3 weeks after the groundnut. Leihner (2002) also found that cassava yields can be considerably decreased if the intercrop is planted earlier than cassava, creating strong interspecific competition for growth resources at a time when cassava is still a weak competitor.

The results indicate that cassava can be planted at the same time or not later than 2 weeks after the groundnut without affecting the tuberyields in the cassava-groundnut intercrop. Intercropping with groundnut had no influence on the tuberyields in the cassava-groundnut intercrop. Trenbath (1974) stated that the yields of the main crop and its intercrop were not affected by their association where there was a competition gap between the periods when each of the component crops has critical demands for growth resources. This could be due to the fact that groundnut, a short-duration crop (90 days) matured just after the maximum canopy development of cassava and harvested earlier before an increase rate of tuberbulking process in the cassava crop.

The results of this study suggest that the presence of groundnut in the cassava-groundnut intercrop had no negative effect on the root yields of cassava when cassava was planted at the same time or not later than 2 weeks after the groundnut. Planting cassava in long rain gave higher cassava root yields by 71 % than planting in short rain. This might be due to the higher rainfall distribution of long rain than that of short rain (Figure 4.3) or weed pressure.

4.5.3.4 Cassava stem yield as affected by the relative planting time of cassava

In the cassava-groundnut intercrop, the relative planting time of cassava did not affect the stem yields of cassava in both short rain and long rain (Figure 4.30).

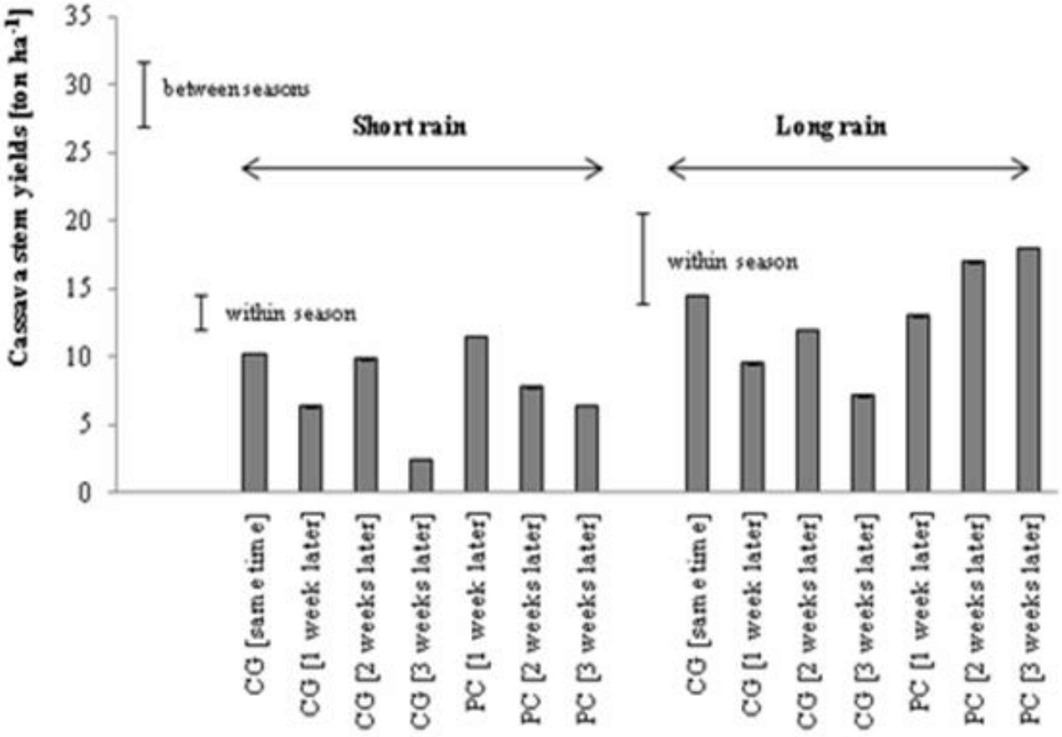


Figure 4.30: Cassava stem yields as affected by the relative planting time of cassava in short rain and long rain in Zenga site. *Error bars represent standard error of difference (SED) for comparisons of all treatments. CG and PC mean the cassava-groundnut intercrop and the pure cassava cropping system, respectively.*

The lowest stem yields (2.5 and 7 ton ha^{-1}) were recorded in the cassava planted 3 weeks after the groundnuts in short rain and long rain, respectively. In the pure cassava cropping system, the planting time of cassava had no significant effect on the stem yields in both short rain and long rain. No significant difference on the stem yields was found between the treatments of pure cassava and the relative treatments of cassava intercropping with groundnut in both short rain and long rain.

The result indicates that intercropping with groundnut had no influence on the stem yield of cassava. This might be due to the different growing habits of the two crops while cassava has erect growth and groundnut is low growing. This result is not in line with the previous study of Borin and Frankow-Lindberg (2005) who reported the reduction of stem with petiole yields of cassava by intercropping with legumes as compared to the pure cassava.

4.5.3.5 Economic analysis as affected by the relative planting time of cassava

In the cassava-groundnut intercrop, cassava planted at 3 weeks later than groundnut was less profitable as it resulted in a significant ($P = 0.045$) decrease in the net benefits of 1648 \$ ha^{-1} with unfavourable BCR (less than \$ 2 $\$^{-1}$) as compared to the treatment of cassava planted at the same time in short rain (Table 4.15). This reduced benefit might be due to the negative effect on both cassava root yield and groundnut grain yield.

Table 4.15: Economic analysis, including total benefits (TC), total costs (TC), net benefits (NB) and benefit-cost ratio (BCR), as affected by the relative planting time of cassava in short rain and long rain in Zenga site

Treatment	TB	TC $ ha^{-1}	NB	BCR $ $$^{-1}$
		Short rain		
CG [same time]	3631	1371	2260	2.7
CG [1 week later]	3242	1371	1871	2.4
CG [2 weeks later]	3766	1371	2395	2.8
CG [3 weeks later]	1983	1371	612	1.5
PG [same time]	983	704	279	1.4
PC [1 week later]	2989	802	2188	3.7
PC [2 weeks later]	2258	802	1456	2.8
PC [3 weeks later]	2719	802	1917	3.4
SED (treatment)	435***		435***	0.4***
		Long rain		
CG [same time]	2744	1251	1493	2.2
CG [1 week later]	2071	1251	820	1.6
CG [2 weeks later]	2488	1251	1237	2.0
CG [3 weeks later]	1728	1251	478	1.4
PG [same time]	600	704	-104	0.9
PC [1 week later]	3051	800	2251	3.8
PC [2 weeks later]	3159	800	2359	3.9
PC [3 weeks later]	2417	800	1616	3.0
SED (treatment)	529**		529**	0.6**
SED (season)	177*		177	0.2

SED = standard error of difference. *, ** and *** and **** = $P < 0.01$, $P < 0.01$, and $P < 0.001$ respectively. CG, PG and PC mean the cassava-groundnut intercrop, the pure groundnut and the pure cassava, respectively.

In long rain, no significant differences on total and net benefits were observed between the treatments. The BCR ($ 2.2 $$^{-1}$) was favourable when cassava was planted at the same time with groundnut. The lowest BCR ($ 1.3 $$^{-1}$) were recorded in the treatment when cassava was planted 3 weeks after the groundnuts. The BCR was not favourable for the pure groundnut cropping system in both seasons. This might be due to the low grain yields of groundnut recorded. In the pure cassava cropping system, cassava planting time had no significant effect on both total and net benefits in both seasons. The BCR was favourable in all treatments in both seasons. The cassava-groundnut intercropping was significantly ($P = 0.039$) less profitable relative to the pure cassava. This could be due to lower revenue obtained from the groundnut crop and higher cost of production. This finidning was in contrast with previous findings of Polthanee *et al.* (2001) in the cassava-groundnut intercrop, Langat *et al.* (2006) in the sorghum-groundnut intercrop and Egbe and Idoko (2012) in the pigeonpea-maize intercrop who reported that the intercropping systems were more profitable than the pure stands.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the study area, there was a great influence of cassava varieties on their root yields. Improved varieties produced higher root yields than local varieties in all sites. However significant effects of soil type on the cassava root yields were not detected and soil withhigher fertility scores produced higher tuberyields of cassava in all sites. According to famers' perceptions, weed pressure, low soil fertility, pests and diseases, insufficient land and labour, high price fluctuation, lack of capital/credit, insufficient land and low price markets were the important factors governing cassava production and commercialization.

The use of improved variety significantly increased cassava yields and obtained more profitable outcome with inorganic fertilizer application over the local variety in the cassava pure cropping system. The use of inorganic fertilizer is essential to increase the productivity and can be highly profitable despite the high price of fertilizer in both sites.

For the groundnut monocrop, the use of improved variety not only increased groundnut yields but also increased net profit compared to the local variety in both sites. Under the current market conditions, the application of inorganic fertilizers improved groundnut yields and the profitability of groundnut production systems in the two study sites.

In the cassava-groundnut intercropping system, the application of inorganic fertilizer or the combined application of inorganic and organic (Chromolaena) inputs increased the yields of groundnut. Sole inorganic fertilizer application, sole organic input application and the combined application of inorganic and organic inputs also increased the tuberyields in both sites. Therefore, the combined application of inorganic and organic inputs is essential to increase the profitability of cassava intercropping system.

In the cassava-legume intercropping system, the grain yields were not significantly different between the different legumes in the two study sites. The results showed that growing cassava as monocrop or intercropped with cowpea or soybean have benefit in both sites. It was obvious that the choice of intercropped legume is very important to attain the maximum profit in the cassava-legume intercropping system.

In both study sites, significant effect of intra-row spacing of cowpea on both grain and biomass yields of cowpea and cassava yields were not found in the cassava-cowpea intercropping system. However, the spacing had impact on grower's income as the closer spacing (30 cm) gave higher income than the wider spacing (50 or 70 cm).

The results of this study showed cassava should be intercropped with groundnut within 2 weeks after sowing of groundnut. Late growing of cassava is associated with a lower cassava tuberyield, resulting in a lower profit in the cassava-groundnut intercrop. However, the relative planting time of cassava had no significant influence on the yields of groundnut in the cassava-groundnut intercrop.

5.2 Recommendations

Based on the findings of this study the following recommendations can be made;

i. To increase the productivity of cassava and groundnut, farmers should grow cassava by using the improved variety and should apply inorganic fertilizer site specifically. The recommended application rates of N, P and K fertilizer for cassava are 40 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1} in Zenga. For

Lemfu, the appropriate rates are 80 kg N ha^{-1}, 40 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}. The most appropriate N, P and K fertilizer application rates for groundnut are 10 kg N ha^{-1}, 23 kg P_2O_5 ha^{-1} and 12 kg K_2O ha^{-1} for the two study sites.

ii. To improve crop yields and profitability, farmers should apply inorganic fertilizer, organic inputs and the combined application of inorganic and organic inputs in the cassava-groundnut intercropping system.

iii. Farmers in this study area could be advised to plant soybean or cowpea in the cassava intercropping system for better crop productivity and profitability.

iv. To enhance yields and income, the closer cowpea intra-row spacing (30 cm) was recommended for the cassava-cowpea intercropping system.

v. In order to increase crop yields and profitability, farmers should plant cassava at the same time or not later than 2 weeks after the groundnuts in the cassava-groundnut intercrop.

5.3 Area for further research

Further research is needed in the following areas:

i. Need to investigate more precise fertilizer types and application rates for specific sites with the aim of improving nutrient use efficiency and minimizing the risk of nutrient loss prior to plant uptake

ii. Need to determine the amount of inorganic and organic inputs needed in the cassava-legume intercropping system under different agro-ecological conditions

iii. Need to determine the effect of improved agronomic practices on crop productivity with a large-scale experimentation by using different cassava and legume varieties across different sites

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APPENDICES

Appendix 1: Characterization of cassava production system at Bas-Congo, DR. Congo

Section A: Information general

1. Date of interview: ______________________

2. Name of team leader: ______________________

3. Name of other team members: ______________________

4. ID of the operation: (zone agent / action site / number of operations)

   (same number that was used during the baseline) _______ / ________ / __________

Bas-Congo = BC
Kanga-Kipeti = 1
Lemfu = 2
Mbanza Nzundu = 3
Zenga = 4

5. GPS coordinates of the house of the household head (in decimal degree C. - to copy the baseline): latitude (N / S) ____________; longitude (W / E) ____________

6. Comments on the quality of the house:

Walls (1 = clay, 2 = wood, 3 = bricks, 4 = other: specify)

____

The roof (1 = grass, 2 = plates, 3 = tiles, 4 = other: specify)

____

Section B: Characterization of cassava varieties

Variety	Source of cuttings	Local or improved ?	Duration of use of the variety	Tuber production (yield)	Earliness	Resistant to drought	Resistant to virus	Resistant to virus transimitted by diseases	Resistant to low soil fertility	Colour of bark of tuber	Colour of tuber	Size of tubers	Smooth taste of tubers	Root require fermenation?	Tasete after frermentation
1.															
2.															
3.															
4.															
5.															
6.															

(1): = 1 for <1 year, 2 = between 2-5 years 3 = 5-10 years = 4 for> 10 years (2): 1 = very poor 2 = poor, 3 = average 4 = good, 5 = very good, (3): 0 = early, 1 = medium, 2 = long; (4): 1 = very poor resistance (with much loss of production), 2 = low resistance (with loss of production), 3 = moderately resistant, 4 = good resistance (but the farmer knows or still looking for better varieties), 5 = very good resistance (the variety is quite good and there is no problem in terms of production, (5): 1 = very little, 2 = little, 3 = average, 4 = off 5 = very wide; (6): 1 = v.mild, 2 = mild, 3 = average, 4 = sour / acid, 5 = very bitter / acid (7): 0 = no, 1 = yes.

SECTION D: Labour used for cassava cultivation

How do you demand of labor for the following activities (for all fields in the entire household)?

Activities	During what month (s)?	Male household		Female household		Childeren in the household		Hired labour		Non-hired laborers (eg association members, neighbors)	
		No. of person	*No. of working day*	*No. of person*	*No. of working day*	*No. of person*	*No. of working day*	*No. of person*	*No. of working day*	*No. of person*	*No. of working day*
Land clearing											
Planting bed preparatio											
Application of fertilizer/organic input											
Cutting preparation											
Planting											
1st weeding											
2nd weeding											
3ième weeding											
4ième weeding											
5ième weeding											
6ième weeding											
Pesticide or insecticide spraying											
Harvesting											

SECTION E: Cassava production

What are the main factors influecing the cassava production?

Factor 1 ____
Factor 2 ____
Factor 3 ____

1 = lack of land, rent land 2 = high, 3 = lack of capital / credit, 4 = lack of plowing, 5 = low soil fertility, drought = 6; 7 = pest / disease, 9 = lack of improved varieties / arranged; 10 = lack of cuttings; 11 = lack of inorganic fertilizers; 12 = lack of organic inputs, lack of market = 13, 14 = distance market; 15 = bad road to the market; 16 = red to reach the market; 17 = high taxes; = 18 at low price market fluctuations 19 = high / price uncertainty; 20 = other: specify.

SECTION F: Cassava commercialization

What are the main factor affecting the commercialization of cassava?
Factor 1:____
Factor 2: ____
Factor 3: ____

(1 = lack of land, rent land 2 = lack of labour, 3 = stoniness, 4 = Erosion, 5 = low soil fertility, 6 = weed pressure; 7 = pest / disease pressure, 8 = lack of good cuttings)

Appendix 2: Interpreting soil analysis data

Evaluation of pH in soils

Rating	pH (H_2O)
Extremely acidic	4.0 - 4.4
Very strongly acidic	4.5 - 5.0
Strongly acidic	5.1 - 5.5
Moderately acidic	5.6 - 6.0
Slightly acidic	6.0 - 6.5

Source: Landon (1991)

Evaluation of N and C in soil

Rating	Total N	Organic C
	%	
High	> 0.25	> 3.0
Moderate	0.12 – 0.25	1.5 – 3.0
Low	0.05 – 0.12	0.5 – 1.5
Very low	< 0.05	< 0.5

Source: Tekalign et al. (1991)

Evaluation of extractable P in soil (Olsen Method)

Rating	Extractable P (ppm)
Acutely deficient	< 3.0
Deficient	3.1 – 6.5
Marginal	6.6 – 12
Adequate	13 – 22
Rich	> 22

Source: Landon (1991)

Evaluation of exchangeable cations in soil

Rating	K	Mg	Ca
		$cmol_c\ kg^{-1}$	
Very high	> 0.3	> 0.18	> 2.4
High	0.175 – 0.3	0.08 – 0.18	1.6 – 2.4
Medium	0.1 – 0.175	0.04 – 0.08	1.0 – 1.6
Low	0.05 – 0.1	0.02 – 0.04	0.5 – 1.0
Very low	< 0.05	< 0.02	< 0.5

Source: Tekalign *et al.* (1991)